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HYDROPOWER DEVELOPMENT WITH A FOCUS ON ASIA AND WESTERN EUROPE

Overview in the framework of VLEEM 2

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Preface

This study was performed in the framework of the so-called VLEEM-2 project. VLEEM is the acronym for Very Long Term Energy-Environment Model. This project is executed by a team consisting of Enerdata (Project leader, France), Max Planck Institut für PlasmaPhysik (IPP Garching, Germany), Forschungszentrum Jülich (Germany), Verbundplan (Austria), Department of Science, Technology and Society (STS) of Utrecht University (NL) and ECN Policy Studies (NL) under a contract from the EU. The activities of ECN Policy Studies are co-financed by the Dutch Ministry of Economic Affairs. The authors wish to acknowledge the valuable help they got from colleagues within and outside the research institute.

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Abstract

This study has several purposes:

- It gives a short technological introduction to hydropower generation.
- It provides an extensive overview over hydropower projects throughout the world.
- It contains a discussion of the future role of hydropower in the world electricity supply system. Especially the dichotomy between small and large hydro projects is tackled.
- Finally an estimation is made of how much potential in hydropower reserve exists, a potential, which will be crucial for the further market penetration of ‘intermittent’ renewable electricity sources and their need for having a buffer between the random electricity generation and the electricity demand.

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SUMMARY

The current mix of world energy supply is mainly based on oil, coal, natural gas, and - to a lesser extent - on hydropower and nuclear energy. Until 2020 natural gas will even grow in importance. Beyond 2020, however, due to depletion of cheap and near-demand gas reserves, due to political reasons (hesitations with regard to conventional nuclear power), and due to environmental reasons (global warming), new technologies and increased use of renewable energy must be put in place. Massive investment in energy infrastructure will be needed (OECD, 2002).

In OECD countries most of the growth of renewable energy is expected to come from wind and biomass. However, in developing countries hydropower is expected to be the fastest-growing renewable energy source (OECD, 2002).

River power plants and high-pressure systems with reservoirs and dams convert the kinetic energy with turbines and generators into electrical energy. Hydropower systems are also used for flood control and irrigation. Storage systems with pumps allow storage of energy for different time horizons (daily, weekly, or seasonally).

At present, about 19% of the global electricity generation comes from hydropower. This 2,600 TWh of global hydropower generation per year corresponds to 32 % of the economically feasible hydro potential and 18.2 % of the technically feasible potential. That means, that - theoretically - the current world electricity demand could be covered by hydropower.

Untouched hydropower potential is identified in developing countries of South and Central Asia, Latin America, and Africa, but also in Canada, Turkey and Russia. In Western Europe and the US, the additional hydropower potential is limited, because of advanced development but also due to environmental and political reasons. However, in these countries (notably in the US) modernisation of hydropower stations could add considerable amounts of electricity - a figure of 12-35% may be found in literature - compared to the current generation of hydropower.

There are many and sometimes huge projects under construction or planned (Table S.1).

Table S.1 *Hydropower capacity under construction or planned in selected world regions*

Region or country	Commissioning date	Hydro under construction or planned [GW]
Canada	2003-2012	6.6
Mexico	2007-2012	5.7
Central America	2003-2016	4.4
South America	2003-2010 (and beyond)	34.9
China	2002-2020	77.7
India	2003-2014	>11.6
Nepal	2003-2010 and beyond	20.5
Pakistan	2003-2010 and beyond	>7.1
Myanmar	2003-2010 and beyond	4.5
Vietnam	2003-2016	5.7
Africa	2003-2010 and beyond	9.0
Turkey	2003-2009 and beyond	>3.6
Power generation China, 2003	Installed electricity generation capacity per capita 0.25 kW. Generation/capita 1,064 kWh (world average: 2,200 kWh). Total power generation 1,500 TWh from 355 GW. Additional installed capacity 20 GW/a until 2005.	
Power generation China, 2005	72.4% thermal, 24.5% hydro, 2.4% nuclear, 0.7% new energy.	

Source: Internet source 1.

In Eastern Europe the focus is on modernisation of hydropower plants.

In the US and in most of the countries of Western Europe new large-scale hydropower plants are generally not accepted for environmental reasons. The focus is on upgrading of hydropower plants or on relatively small hydropower projects.

Potentials of hydropower

In the literature several types of hydropower potentials may be found:

- The (gross) theoretical potential, based on computations of the potential of water flows, without taking into account technical, economical, and environmental constraints.
- The technically feasible potential or the net exploitable potential. This is the amount of hydropower that could be developed from a technical point of view. Economical and environmental constraints are not considered.
- The economically feasible potential. This is the amount of hydropower that could be developed based on economical constraints. Environmental constraints are not considered.

Construction and generation costs

A key feature of investments in hydroelectric power generation projects is that they require long-term loans with extensive grace periods because they are capital-intensive, have a long construction phase with significant risks and have a long useful life. The average construction costs of hydropower plants are between \$ 1,100/kW (China, Latin America) and \$ 1,400-1,800/kW (Africa, India, Turkey), with exceptions both of higher and lower construction costs.

The generation costs especially for older hydropower plants are very low. On average the generation costs are less than a third of that of coal, oil, gas or nuclear, when considering all real costs for the latter.

Limits for hydropower development: environmental problems

The past has shown that hydroelectric power plants especially in large-scale projects can bring a lot of problems: (Internet source 2)

- Hindering the fish by blocking fish moving up the river to the spawning grounds.
- Decreasing of wildlife in river grounds and former rain forests by flooding.
- Dislocation of people for dam projects, e.g. in case of Three Gorges Dam (China) 1.13 million people.
- Oxygen reduction in the water by rotting of flooded vegetation killing fish and plants.
- Emission of methane after rotting. Methane is a strong greenhouse gas that has 21 times more effect than CO_2.
- Dissolving of natural metals from stones and soils (e.g. mercury) after flooding.
- Water quality (oxygen reduction) and sedimentation problems (filling) by reducing the flow speed.
- Problems for fish population as a result of flushing for clearing sedimentation.
- Stranding fish in shallow water areas by power plant operation.
- Potential dam breaking (war, earthquakes).

Solutions for these problems are:

- The environmental questions of hydropower systems must be compared with the effects of the alternatives (acid rain, global warming, etc.).
- Leaving untouched smaller and wild rivers.
- Integration in nature planning.
- Fish-friendly solutions.

Dimensions of hydropower plants

There are several classifications related to the dimension of hydropower plants. An actually useful classification is the following: (Internet source 3)

Micro hydro:	<100 kW
Mini hydro:	100 - 500 kW
Small hydro:	500 kW - 50 MW
Large hydro:	>50 MW.

The EU regards 'small' hydropower as less than 10 MW. Hydropower plants larger than that are denoted as 'large-scale'.

On a global scale, the relation between small hydropower (including mini/micro) and large hydropower was 1:20 (115 and 2,260 TWh, respectively) in 1995. For the year 2010, this relation is expected to be 1:18 (220 and 3,990 TWh, respectively) (Internet source 4)

In countries with a presently high share of small-scale hydropower plants, this share is expected to stagnate or even decline. Only in areas dominated by big hydropower projects today, the future will bring an increased market penetration of small hydropower (Table S.2).

Table S.2 *Ratio between small and large-scale hydropower generation*

	Ratio between small and large-scale hydropower generation	
	1995	2010
Europe	1:10	1:11.5
Asia	1:7	1:10
Latin America	1:132	1:100

Source: Internet source 4

In the EU, an additional 45 TWh/a (11 GW) of small-scale hydropower and 400 TWh/a (127 GW) of large-scale sites could be exploited in the next 10 years (Hydropower, 2000). With regard to pumped storage, only projects with an additional generating capacity of 2.5 GW (1.5 TWh/a) are identified in the EU (Internet source 4; Hydropower, 2000).

1. INTRODUCTION

Hydropower, along with biomass, is an important renewable energy source. The current mix of world energy supply is mainly based on oil, coal, natural gas, and - to a lesser extent - on hydropower and nuclear energy. Until 2020 natural gas will even grow in importance. Beyond 2020, however, due to depletion of cheap and near-demand gas reserves, due to political reasons (hesitations with regard to conventional nuclear power), and due to environmental reasons (global warming), new technologies and increased use of renewable energy must be put in place. Massive investment in energy infrastructure will be needed (OECD, 2002).

In OECD countries most of the growth of renewable energy is expected to come from wind and biomass. However, in developing countries hydropower is expected to be the fastest-growing renewable energy source (OECD, 2002).

Hydropower is based on the kinetic energy of rivers using turbines. Hydroelectric projects can include dams, reservoirs, stream diversion structures, powerhouses containing turbines, and transmission lines. Reservoirs behind dams often provide other benefits, e.g. recreation, flood control and navigation, irrigation, and municipal water supply (US GAO, 2001).

According to the World Commission on Dams (WCD)[1], the world's more than 45,000 large dams have played an important role in harnessing water resources for food production (irrigation), power generation, flood control and domestic water use. On a global scale hydropower has a share of 19% in electricity generation. Also, 30-40% of irrigated land relies on dams, and ca. 800 million people benefit from food produced by dam related irrigation (Internet source 5).

Hydropower is an abundant and reliable source of clean and renewable energy. It offers the benefits of a comparatively inexpensive renewable energy source with low levels of greenhouse gas (GHG) emissions. Therefore, it can play a key role in addressing climate change, particularly in countries with a substantial undeveloped hydropower potential. It should be admitted that climate change could also influence the potential of hydropower in a positive or negative way. Because of the limitations of this study, this effect of climate change is only indirectly touched in Chapter 9 on Western Europe, based on a recent analysis for Europe.

All hydroelectric reservoirs of the world together cover an area the size of France (Internet source 6). This is important, as the rotting of vegetation especially during the first filling of the reservoirs may lead to a substantial formation and emission of methane, a greenhouse gas 21 times more effective than CO_2[1]. In moderate climates, however, the emission of GHGs from hydropower is generally insignificant compared to emissions from a coal-fired power plant. According to research conducted since 1992 - notably by Hydro Quebec - on GHG emissions from hydro reservoirs, a typical hydropower project in a northern environment emits between 10 g and 30 g of CO_2-equivalent per kWh. This is indeed quite low, when compared with 600 g/kWh for gas-fired power and up to 1,000 g/kWh for coal-fired power (comparison based on life cycle, 50 years for hydro and 30 for gas and coal) (Internet source 7). However, the amount of emissions of GHGs representative of hydroelectric dams in tropical areas - e.g. the Amazon River in Brazil - may be substantial, as will be elucidated in Chapter 5, Section 5.2.1 (Internet source 8; Gagnon et al, 2001).

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[1] Estimating the impact of a reservoir on climate change requires a calculation of its net emissions - the emissions measured from the reservoir plus the quantity of gases that would have been absorbed by any sinks that it flooded, minus the gases that would have been released from any greenhouse gas sources that it submerged.

Although there are hydroelectric projects under construction in about 80 countries, most of the remaining hydropower potential in the world may be found in developing countries, particularly in South and Central Asia, Latin America, Turkey, Africa, and Russia. Furthermore, there is a large potential in operational improvement and rehabilitation of hydropower plants. Many hydropower plants were built twenty or more years ago (Electrowatt-Ekono, 2001).

A key feature of investments in hydroelectric power generation projects is that they require long-term loans with extensive grace periods because they are capital-intensive, have a long construction phase with significant risks and have a long useful life.

Potentials of hydropower

In the literature several types of hydropower potentials may be found:

- The (gross) theoretical potential, based on computations of the potential of water flows, without taking into account technical, economical, and environmental constraints.
- The technically feasible potential or the net exploitable potential. This is the amount of hydropower that could be developed from a technical point of view. Economical and environmental constraints are not considered.
- The economically feasible potential. This is the amount of hydropower that could be developed based on economical constraints. Environmental constraints are not considered.

The focus of this study is on the development of hydropower - large-scale and small-scale - in different parts of the world with their economic impacts in terms of initial investment cost. Also, a view is presented on the development potential of hydropower in world regions. Two regions are analysed more in-depth than the others, viz. developing Asia and Western Europe.

Chapter 2 gives a brief overview of the main features of hydropower. After that, the following world regions are addressed:

- North America (Chapter 3).
- Developing Asia (Chapter 4).
- Central and South America (Chapter 5).
- Africa (Chapter 6).
- Middle East (including Turkey, Chapter 7).
- Eastern Europe (Chapter 8).
- Western Europe (Chapter 9). This Chapter differs in content from the preceding chapters and includes a brief overview of the effect of climate change on hydropower potential.

It is acknowledged that this study does not include all regions or countries. Some world regions - e.g. Russia, other FSU countries and a number of Eastern European countries, OECD Pacific - or countries within ‘Developing Asia’ - e.g. Indonesia, Bhutan, and Cambodia - are not covered by this study, due to limits of time, manpower and readily available databases.

Finally,

- A vision is presented on global and local issues (Chapter 10).
- The potential for pumped-storage hydropower and reserves is estimated (Chapter 11).
- And the study is closed with a number of conclusions (Chapter 12).

2. MAIN FEATURES

2.1 Types of hydropower plants

Hydropower plants either are based on reservoirs (Figure 2.1), or are run-of-the-river plants. A run-of-the-river plant draws the energy for electricity production mainly from the available flow of the river. Such a hydropower plant generally includes some short-term storage (hourly, daily, or weekly), allowing for some adaptations to the demand profile. Run-of-the-river hydropower plants are normally operated as base-load power plants. The generation of run-of-the-river plants depends on the precipitation of the watershed area and may have substantial daily, monthly, or seasonal variations. Typically, the average generation (firm capacity) of a run-of-the-river plant is between 55 and 60 percent of the rated power.

In order to reduce the dependence on the stochastic inflow, many hydropower plants feature large reservoirs and corresponding dams. These storage plants have compact turbines, thereby lowering the construction cost. They can be started up and shut down very fast, making them the technology of choice for following the demand, generating peak power, controlling the frequency, and providing fast start-up reserve. These qualities become especially valuable in systems with a high share of intermittent renewable electricity generation, as for example with the relatively high share of wind power in the Danish and (parts of) the German electricity system.

According to the size of the reservoir, energy can be shifted from night to day hours or from seasons with low demand to seasons with high demand. The most flexible version is the pumped-storage technology, which allows to store excess mechanical or electrical energy from overproduction times and to activate it in times of high demand with efficiencies of 70-80%.

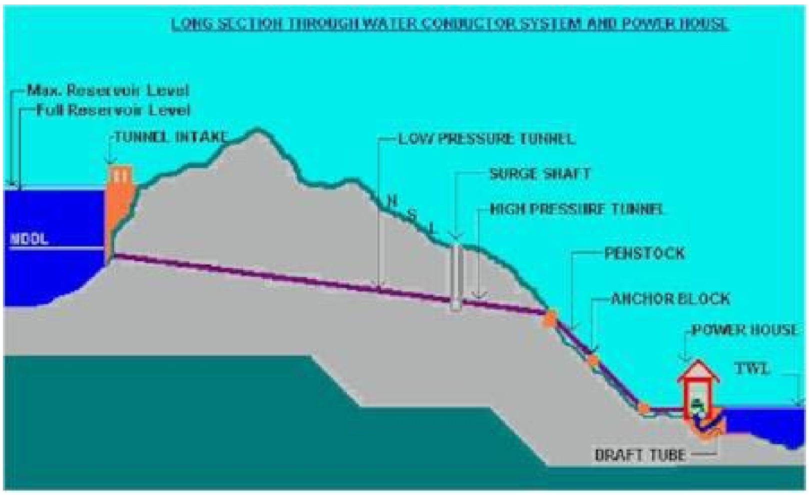

Figure 2.1 *Profile of hydropower plant with dam and reservoir*

A turbine - the prime mover of a hydropower plant - may be (Internet source 9):

- either of the impulse type, to convert energy of water supplied in the form of kinetic energy, such as the Pelton turbine,
- or of the reaction type, to convert energy of water supplied mostly in the form of pressure energy, such as a Francis or a Kaplan turbine.

In pumped-storage hydropower plants, Pelton turbines are used which can operate in a reversible way as a pump. Pelton turbines can span a height of 150-1000 m, denoted as ‘high head’. High-head hydropower stations mainly utilise the natural heads within the rivers and not heads artificially produced by means of high dams. These projects can do with small reservoirs, which are usually located in high mountain valleys with practically no population (Internet source 10).

The next category is ‘medium head’ (20-300 m), for which Francis turbines are used. Generally, a head of 6-30 m is denoted as ‘low head’, and a head of 2-6 m as ‘very low head’. Run-of-the-river plants, based on Kaplan turbines, are characterised by low heads. Hydropower plants based on reservoirs generally are ‘high head’ or ‘medium head’ hydropower plants (Figure 2.2).

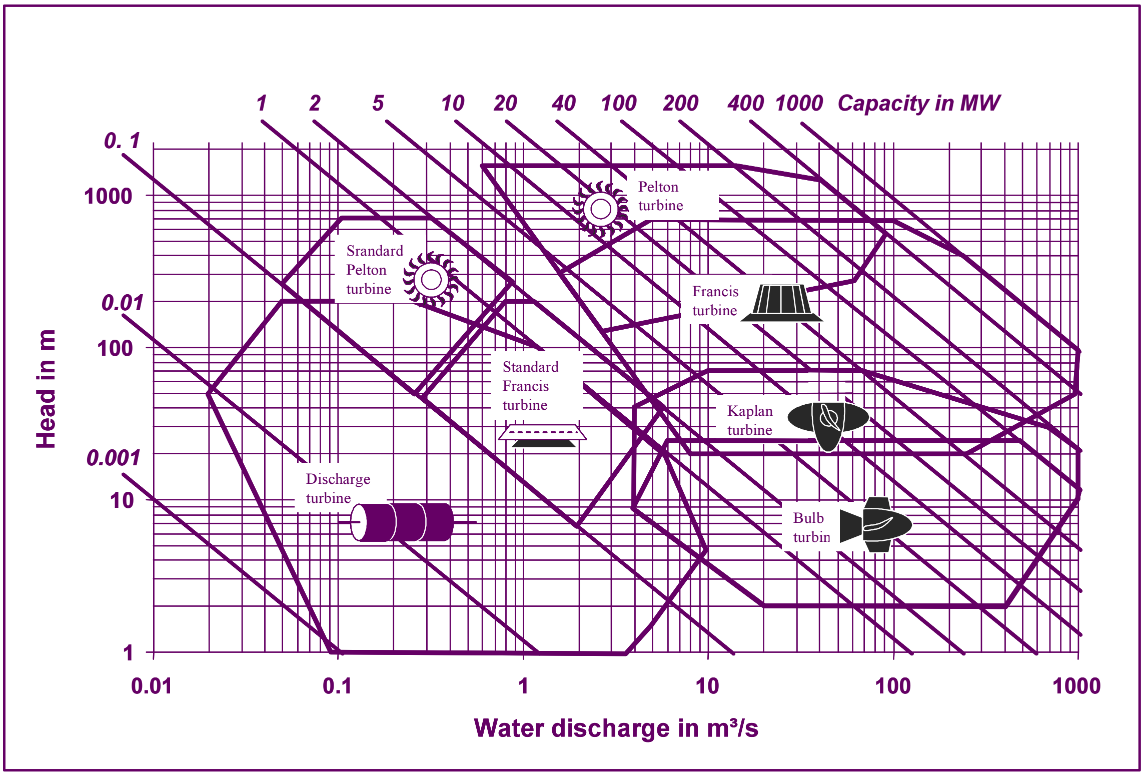

Figure 2.2 *Working areas of different turbine types*
Source: Verbundplan.

2.2 Classification of hydropower plants

Hydropower plants may be categorised to the size into large-scale, mini, or micro hydropower. Micro hydro is up to 500 kW. Mini hydro (Kaplan turbines) ranges from 0.5 to 15 MW (Renewable Energy World, 2001). The EU regards ‘small’ hydropower as less than 10 MW. Hydropower plants larger than that are denoted as ‘large-scale’.

A different classification found in the literature is the following (Internet source 3):

- Micro: <100 kW
- Mini: 100 - 500 kW
- Small: 500 kW - 50 MW
- Large: >50 MW.

Hydropower stations may have capacities in the GWs, with turbines up to 700 MW each. The largest hydropower station under construction is the 18,200 MW Three Gorges Dam in China.

In the following, many data with regard to hydropower are based on publications of the US Energy Information Administration (EIA) (US EIA, 2000, 2001, 2002).

2.3 First look at global hydropower potential

Hydroelectric power may have reached a mature state of development in most Organisation for Economic Cooperation and Development (OECD) countries (see Figure 2.3 for net exploitable hydropower resources and percentage exploited). However, in the developing world - Asia, Central and South America, and Africa in particular - there remains a huge potential for further development. However, concerns about environmental impacts and land requirements for reservoirs have recently constrained multilateral assistance in hydropower development in developing countries. This should be examined in the context of the current discussions on carbon emissions and global warming, giving careful consideration to both developmental needs and environmental and social concerns. Hydropower, large-, mini- and micro-scale, is a time-tested source of electricity generation that is relatively free of greenhouse gas (GHG) emissions. In ecological terms, hydroelectricity has many advantages at a time when considerable efforts are made to reduce GHG emissions (United Nations, 2000).

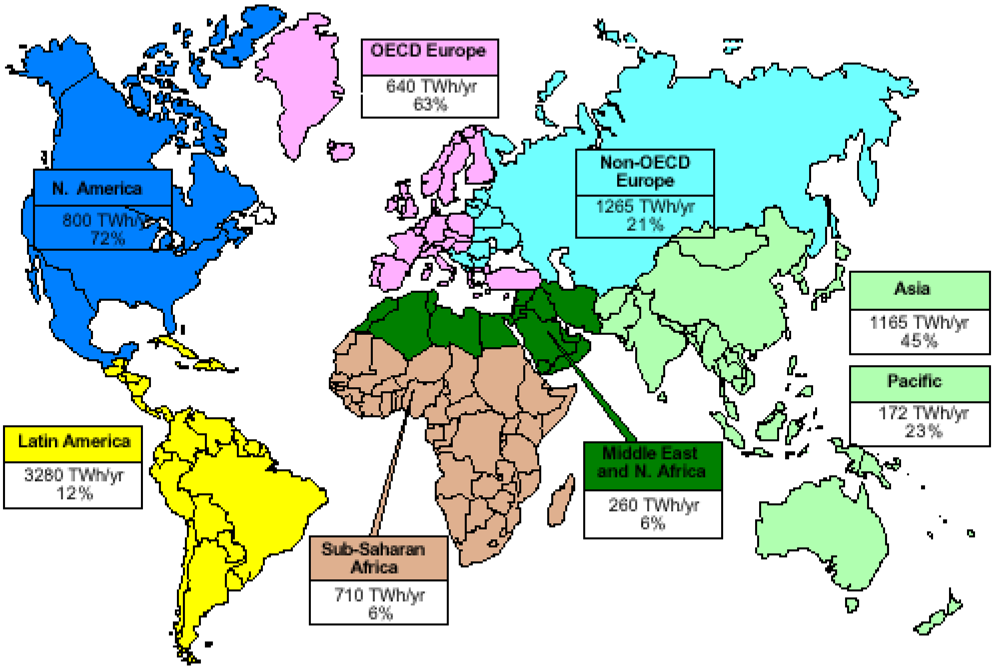

Figure 2.3 *Net exploitable hydropower potential [TWh/a] and percentage exploited*
Source: Department of Economic and Social Affairs of the United Nations Secretariat, based on Energy Statistics Yearbook, 1996 (United Nations publication, Sales No. E/F.99.XVII.3); and Renewable Energy Resources: Opportunities and Constraints, 1990-2020, (London, World Energy Council, September 1993).

3. NORTH AMERICA

3.1 Introduction

In North America, hydropower is the most widely used form of renewable energy. The installed hydropower capacity - exclusive of pumped-storage hydropower - amounts to 155 GW, of which 66 GW in Canada, 80 GW in the United States (US), and 10 GW in Mexico. Hydropower accounts for 60 percent of the electricity generated in Canada, 8 percent in the US, and 19 percent in Mexico. Canada still has several projects under construction or planned. The same holds for Mexico. However, hydropower generation in the US will probably decline in the near future, because most of the best sites have been exploited and because of adverse environmental impacts of hydropower.

In the following, the development of hydropower is highlighted for Canada (Section 3.2), Mexico (Section 3.3), and the United States (Section 3.4).

3.2 Canada

Canada has an enormous exploitable hydro potential, viz. 160 GW. Its economical potential is estimated at 523 TWh/a (Internet source 11), second only to that of Brazil in the Western Hemisphere. Canada and China are the world's biggest users of hydropower. Canada's installed hydro capacity is 65.7 GW (Internet source 12) and 4.5 GW is under construction or planned. So far, less than half of the exploitable potential and 65 percent of the economical potential have been harnessed.

Developers of hydropower projects in Canada use to work closely with native peoples before they start construction on new dams. Hydro Quebec reached an agreement with an organisation of a local tribe on a 3-month study of the 1,200 MW Eastmain-Rupert project. It offered the tribe an opportunity to invest in the project. Other hydropower projects of Hydro Quebec are Toulnustouc River (526 MW), La Romaine (220 MW) and Peribonka River (450 MW).

Manitoba Hydro reached agreements with local tribes for development of two hydropower stations, viz. Wuskwatim (250 MW) and Gull Rapids (560 MW) on the Nelson River. Another hydropower project planned in Manitoba is Nogiti (150 MW). In Ontario, the 90 MW High Falls project is in the planning stage.

The 40 MW Granite Canal project in Newfoundland is due for completion in 2003 and the 2,000 MW Gull Island project - construction cost, including transmission infrastructure, $ 4 billion - in 2008. The Muskrat Falls hydropower project - construction cost $ 1.4 billion - downstream from Gull Island has a potential capacity of 824 MW (US EIA, 1999). During 2001, Government and Newfoundland and Labrador Hydro (NLH) stepped back from commercial negotiations on Muskrat Falls and undertook a review of development options (Internet source 13)

Finally, there are proposals to develop hydroelectric projects in the Northwest Territories of Canada that would total between 12 and 15 GW. These projects would cost an estimated $ 17.5 billion and would be constructed in sparsely populated regions on six separate rivers.

Table 3.1 shows the characteristics of the hydropower projects presented above.

Table 3.1 *Selection of hydropower projects under construction or planned in Canada*

Project	State	Capacity [MW]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Grand-Mere	Quebec	231	N/A	N/A	2003
Toulnustouc River	Quebec	526	400	760	N/A
La Romaine	Quebec	220	335	1,525	2007
Peribonka River	Quebec	450	N/A	N/A	2009
Eastmain Rupert	Quebec	1,200	2,500	2,080	2011
Three small plants	British Columbia	78	68	870	2001-2002
Gull Rapids	Manitoba	560	871	1,560	2012
Nogiti	Manitoba	150	N/A	N/A	N/A
Wuskwatim	Manitoba	250	N/A	N/A	2009
High Falls Power	Ontario	90	50	555	N/A
Granite Canal	Newfoundland	40	N/A	N/A	2003
Gull Island	Newfoundland	2,000	4,000	2,000	~ 2008
Muskrat Falls	Newfoundland	824	1,400	1,700	N/A
Total		6,619		~ 1,750	

Figure 3.1 shows the specific investment cost of hydropower projects under construction or planned from Table 3.1 as a function of cumulative installed capacity.

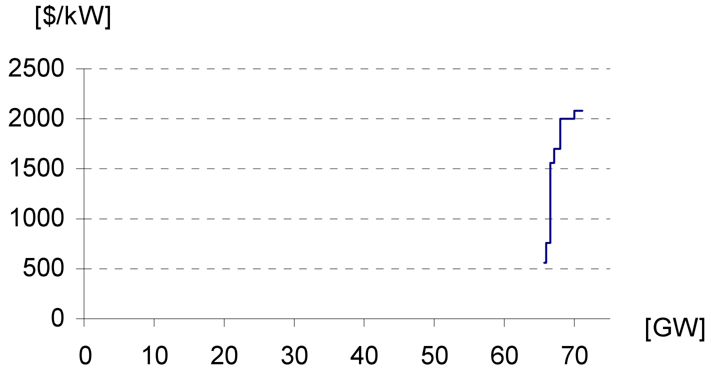

Figure 3.1 *Specific investment cost of hydropower in Canada vis-à-vis cumulative capacity*

3.3 Mexico

Mexico's gross theoretical hydro potential has been assessed as 500 GW (Internet source 14), but this seems to be a mistake. Another estimate of a theoretical potential of 155 TWh/a seems to be more reliable. The net exploitable potential stands at 64 TWh/a and the economically feasible potential - defined in the case of Mexico as covering projects with approved feasibility studies, plus present installed capacity, with an assumed load factor of 35% - at 38.5 TWh/a (Internet source 15).

The installed hydropower capacity is 9.6 GW, and the hydroelectric generation is 33 TWh/a (19% of the total generation of electricity). So far, about 50 percent of the exploitable potential have been harnessed, and this percentage will probably rise to close to 100 within a decade.

A major hydropower project to be developed is the El-Cajon project in the Pacific Coast State of Nayarit. This would be the first large-scale hydropower project to be built in Mexico in more than a decade. Its capacity is projected as 670 to 750 MW and its cost is estimated at $ 650 mln. In September 2002, bids were invited for construction of this hydropower project. Construction would start in January 2003 and completion is scheduled for August 2007. El Cajon will be used to cover peaks in West-Central Mexico (Platts Global Energy, 2002; Internet source 16).

The Papagayo Project is a multipurpose project in the State of Guerrero, providing power generation - 810 MW, annual generation 1.53 TWh - and water supply, as well as flood control, irrigation, pisciculture, tourism, and navigation. The project may supply peak electric power to the main tourism centres located in the Guerrero and Oaxaca States. The capital investments required for all works, systems, and installations are $ 850 mln (Internet source 17).

In Chiapas State, on the border with Guatemala, the 4,200 MW Boca del Cerro Binational Project - dam height 130 m, annual output 17.4 TWh, cost $ 5 billion - on the Usumacinta River is in the planning stage. It has a strong priority based on the seven multi-purpose principal projects to be developed in Mexico (Boca del Cerro, Quetzalli, Huixtan I, Huixtan II, Jattza, Nance and Salto de Agua). These seven projects could provide a total capacity of 9,520 MW, and generate 33 TWh/a (Internet source 18), which is equivalent to 27% of the Mexican electric capacity and 20% of Mexico's electricity generation (Table 3.2).

Table 3.2 *Selection of hydropower projects under construction or planned in Mexico*

Project	State	Capacity [MW]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
El Cajon	Nayarit	670	650	970	2007
Papagayo	Guerrero	810	850	1,050	N/A
Boca del Cerro	Chiapas & Tabasco	4,200	5,000	1,190	N/A
Total		5,680	6,500	~ 1,150	

The use of small hydro plants is being promoted among private investors; a study carried in the states of Veracruz and Puebla identified about 100 sites for mini-hydro installations.

3.4 United States

The hydro resource base of the US is huge: the gross theoretical potential has been assessed as 512 GW, equivalent to 4,485 TWh/a. The economically feasible potential output is put at 376 TWh/a. The installed hydro capacity is 79.5 GW, generating 316 TWh/a in an average year. Therefore, roughly 85 percent of the economically feasible potential has been harnessed.

Hydropower is one of the least expensive sources of electricity in the US. For every kWh of electricity produced by a hydropower plant, only 0.6 ¢ (≈ 0.5 €ct) is needed to finance its operation and maintenance.

The licensing of the construction and operation of new plants is conducted by the Federal Energy Regulatory Commission (FERC), which is responsible for taking into consideration safety and environmental aspects of dam construction. New private-sector projects (when constructed by regulated electric utilities) are subject to economic regulation by state and local bodies, and to state and local regulation with respect to land use, water rights and environmental impacts (Internet source 19).A program manager for FERC projects recently stated: (Internet source 20).

'Hydropower developers have a tough time because they must face a nightmare of federal and state regulations'.

According to the Energy Information Administration (EIA), hydroelectric generation will decline from 316 to 304 TWh/a between 1999 and 2020 due to environmental concerns and other competing needs. Currently, only 40 MW of new hydro capacity is under construction (Bartle, 2002). Most large-scale hydroelectric plants in the US were built and are operated by various Federal Government bodies. The projects are usually intended to serve multiple purposes, including irrigation and public water supply, flood control, and recreation as well as power generation. Depending on the dominant purpose, dam construction and operation may have been undertaken by the Bureau of Reclamation, Department of the Interior - for irrigation projects - or the US Army Corps of Engineers - for flood control projects.

However, according to the US Department of Energy (DoE), the modernisation of the hydropower stations has largely been ignored, and could add 20,000 to 30,000 MW of renewable generating capacity at existing dams (Internet source 21).According to the Union of Concerned Scientists, an estimated 4,600 MW of capacity could be added at existing small dams, with another 6,000 MW in improvements at large dams (Internet source 22).

Recently, the 3.5 MW Edwards dam on the Kennebec River (Maine) was removed. The same holds for the 9.6 MW Condit, 12 MW Glines Canyon, and 12 MW Elwha dams in Washington State. Two hydropower dams in the Sandy River Basin of the state of Oregon will be removed, creating a 20-km^2 wildlife and public recreation area (Internet source 23).The US Army Corps of Engineers will improve fish passages at four dams on the lower Snake River (Washington State) rather than removing the dams entirely, to boost the survival of dwindling salmon populations (Internet source 24).

4. DEVELOPING ASIA

4.1 Introduction

Developing Asia is one of the regions in the world that has ambitious plans to continue the development of large-scale hydropower projects. China, India, Laos, Malaysia, Nepal and Vietnam, among other countries in developing Asia, have extensive plans to expand their hydropower resources, and all have plans to use large-scale hydropower to achieve their goals. All countries also develop small hydropower plants, generally as a part of renewables programmes.

The next Sections highlight the development of hydropower in China (4.2), India (4.3), Nepal (4.4), Pakistan (4.6), Lao PDR (4.7), Malaysia (4.7), Myanmar (4.8), the Philippines (4.9), Thailand (4.10), and Vietnam (4.11).

4.2 China

4.2.1 Introduction

With a vast territory and a host of rivers, China has the largest hydropower resources of the world. Its theoretical potential is 676 GW, with a generation capability of 5,920 TWh/a. The majority of the resources is concentrated in Southwest, Central, and Northwest China (Internet source 25). China's exploitable potential stands at 378 GW or 1,923 TWh/a, and its economically feasible potential at 290 GW or 1,260 TWh/a (Los Alamos National Lab., 1996a, 1996b).

Hydropower has a share of 17% in power *generation* in China. According to the State Power Corporation of China, the country's largest power producer, the installed hydropower capacity would increase from 82.7 GW by the end of 2001 (Internet source 26) to 100 GW by 2005, after that to 125 GW by 2010, and finally to 150 GW by 2015.

The projected installed capacity in 2015, viz. 150 GW, is equal to 40 percent of the exploitable hydropower resources. The share of hydropower in China's generation *capacity* will steadily rise to 27% by 2005, which is 3.5% more than today (Internet source 27, 28). China is still building hydropower projects with a combined capacity of 25,600 MW (Internet source 29).

Large hydropower projects in China are presented by Province (Section 4.2.2) and summarised in Section 4.2.3. The development of small hydropower is briefly addressed in Section 4.2.4.

4.2.2 Hydropower projects by Province

Guizhou

In 2000, Tianshengqiao I & II - total capacity 2,520 MW, annual generation 13.4 TWh, capital cost $ 2.4 billion (over Yn 20 billion[2]) - astride the borders of *Guangxi* and *Guizhou* Provinces were completed. They are designed to transmit electricity from west to east China. Several other large hydropower plants are planned on the Honghe River (Internet source 30, 31, 32). Also, the 3,000 MW Goubitan Hydropower plant (construction cost Yn 12.2 billion ≈ $ 1.47 billion) on the Wujiang River and the 1,000 MW Siling Hydropower plant are planned in *Guizhou.*

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[2] 1 US$ = 8.2766 Yuan (August 2002).

Fujian

In December 2001, the 600 MW Mianhuatan Hydropower Station - annual output 1.52 TWh - on the Tingjiang River in East China's *Fujian* Province went into operation. The plant will greatly help enhance local flood-control efforts, and accelerate the development of local river transportation and tourism as well as aquaculture. The hydropower plant costs approximately $ 604 mln (Yn 5 billion) (Internet source 33, 34).

Henan

The Xiaolangdi Project - 1,836 MW, dam height 154 m - is the biggest hydroelectric project ever built on the Yellow River, bearing multiple purposes mainly for flood control and sediment alleviation, while concurrently for water supply, irrigation and power generation. The Yellow River, China's second longest river, flows through a densely populated and a major agricultural area. Xiaolangdi includes a complex system of 15 large tunnels with an underground powerhouse and a 154-m high dam. It is one of 27 dams planned for the Yellow River. Reportedly, some 200,000 people had to be resettled. Xiaolangdi is expected to generate 5.1 TWh on an annual base, and its construction cost is $ 4.2 billion (Internet source 35).

Qinghai

In August 2000, construction started on the 1,500 MW Gongboxia Hydropower Station - dam height 139 m, annual generation 5.14 TWh - on the upper reaches of Yellow River in *Qinghai* Province. It is the third large-scale hydropower station on the Yellow River. The total investment is $ 845 mln (Yn 7 billion).

Construction of the 3,600 MW Laxiwa Hydropower Station started in 2002. The first generators will become operational by 2008. Laxiwa will cost an estimated $ 2.27 billion (Yn 18.8 billion) to build (Internet source 36, 37, 38).

Hubei

In 1997, construction started on the 252 MW Gaobazhou Hydropower Station - dam height 57 m, annual generation 0.9 TWh, construction cost $ 370 mln (Yn 3.076 billion) - on the Qingjiang River (a major tributary of the Yangtze River) in Central China's *Hubei* Province. It was completed in 2001. Some 16,000 people have been resettled (Internet source 39).

The giant 18,200 MW Three Gorges Dam with a dam height of 181 m on the Yangtze River (the country's longest river) in *Hubei* Province is the world's largest hydropower project under construction. Construction started in 1993. Three Gorges Project Development Corp announced that four generating units are to start production in 2003. Each generating unit has a capacity of 700 MW. Three Gorges Dam will be fully operational in 2009 (Platts Global Energy, 2002).

Three Gorges Dam is constructed in two phases. Phase I began in October 1997 and will be completed with the installation of 14 700 MW turbines and generators in 2006. In phase II - to be operational in 2009 - another 12 700 MW turbines will be installed. From 2009, Three Gorges Dam will generate 84.7 TWh/a. With a total budget of $24.51 billion (Yn 203.9 billion) the final cost of Three Gorges Dam is said to be around $21.73 billion (Yn 180 billion) by 2009, a significant reduction on the initial forecast (US EIA, 1999; Internet source 40).

Environmentalist and political opposition to Three Gorges Dam has been intense, driven mainly by the fear for catastrophic long-term ecological effects (Internet source 41). Disruption of heavy silt flows in the river would cause rapid silt build-up in the reservoir, creating an imbalance upstream, and depriving agricultural land and fish downstream of essential nutrients. Since these problems would hit both the power plant's turbines and numerous farmers and fishermen, considering ecology is common sense (Internet source 42, 43).

An estimated 1.13 million residents are affected by the creation of the dam's reservoir. By the end of November 2001, China had spent about $ 3.5 billion (Yn 28.7 billion) on resettlement of 418,000 people. The project committee reported that by the end of September 2002, more than 640,000 residents had been resettled (Internet source 44). According to the World Bank, China has one of the better resettlement programs in the world (Li, 2002; Zhu, 1998).

Since 2002, the project was reorganised into the Three Gorges Project Development Corporation. It is seeking capital through an equity offering - initial public offering (IPO) - open to foreign investors, when the first four generators begin generating power in 2003 (Internet source 45). The IPO is expected to raise $ 480-600 million (Yn 4-5 billion) (Internet source 46).

Quingjiang

The 1,600 MW Shuibuya hydroelectric project - dam height 233 m, annual output 3.92 TWh - on the Qingjiang River (upstream of the Gaobazhou hydropower plant in *Hubei*) was recently approved. Preparatory work for the project has been carried out. The first generator will start producing power in 2006 and the entire project is due for completion by 2009. The construction cost of Shuibuya is estimated at $ 1.45 billion (Yn 12 billion) (Internet source 47).

Guanxi

In July 2001, Guangxi Longtan Hydropower Development Co. started construction of the Longtan Hydroelectric Project on the Hongshui River in *Guangxi* Province. Longtan is the second largest hydropower station - 5,400 MW, dam height 216 m, annual output 15.67 TWh, total cost $ 2.98 billion (Yn 24.7 billion) - under construction in China. The first generator is due to be operational in 2007, and the entire power plant in 2009 (Internet source 48, 49).

The 540 MW Baise/Hongjiadu project is a large water conservation facility (dam height 179 m) under construction on the Wujiang River, capable with multiple functions, including power generation, irrigation, navigation, and water supply. It will generate 1.52 TWh annually, and its construction cost is $ 578 mln (Yn 4.8 billion) (Internet source 50, 51, 52).

Construction of the 405 MW Pingban hydropower plant on the Honshui River has been approved. The first phase will be operational in 2004, while the whole plant is due for completion at the end of 2005. The hydropower plant will generate 1.6 TWh annually, and its construction cost is put at $ 249.3 million (Yn 2.07 billion) (Internet source 53).

Jinping No 1 - 3,600 MW, annual output 18.2 TWh, construction cost $ 3.625 billion (Yn30 billion) - is to be built on the Yalongjiang River (upper reaches of the Yangtze River). In total four large hydropower stations - aggregate capacity 9,050 MW - are planned on this river. Jinping No 1 is assumed to play a pivotal role in developing hydropower resources and invigorating the economy of western China (Internet source 54, 55).

Yunnan

Two medium-scale projects developed in *Yunnan* are the Nalan Hydropower Station Project and the Wenshan-Malutang Project. Construction of the Wenshan-Malutang Project started in January 2002. The construction cost of Nalan (135 MW) and Wenshan Malutang (100 MW) is $ 103.9 mln (Yn 860 mln) and $ 50.1 mln (Yn 415 mln), respectively (Internet source 56).

China is developing a scheme of eight dams in the Southwestern *Yunnan* Province. The hydropower stations are to be built on the middle and lower reaches of the Lancang River[3]. The eight hydropower plants will have an aggregate installed capacity of 15,550 MW, and will generate 74.1 TWh annually:

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[3] The Lancang River is China's fifth longest river, and the lower reaches of it are known as the Mekong River in Southeast Asian countries.

- In 1997, construction started on the 1,350 MW Dachaoshan hydroelectric project - dam height 111 m, annual generation 5.93 TWh, capital cost $ 1.06 billion (Yn 8.87 billion) - on the Lancang River. It is the second of the aforementioned eight-dam scheme. Dachaoshan is developed as a part of the west-to-east power transmission scheme, and is scheduled for completion in 2003. The number of people relocated was 5,200 (Internet source 57).
- The 4,200 MW Xiaowan hydroelectric project - dam height 292 m, annual output 18.89 TWh, construction cost $ 6 billion (Yn 50 billion) - on the Lancang River is one of the largest of its kind in China. Hydropower stations on the Lancang River, like Xiaowan, regulate the flow of water on the lower reaches of the river, thereby making it more navigable. They also play a role in irrigation. Power from the Xiaowan hydroelectric plant will be transferred to the coastal Province of *Guangdong*, in Southwest China. The number of people to be relocated is put at 28,750 (Internet source 58) Xiaowan is built jointly by the China National Power Industrial Corporation and the *Yunnan* government. Construction started in January 2002, and the project is to be completed by 2012 (Internet source 59, 60, 61).
- The other five dams to be built on the Lancang River are undergoing feasibility studies and one of these - Jinghong, about 300 km north of the Thai border - will probably be completed around 2012. The 1,500 MW Jinghong hydroelectric project is thus prioritised within the framework of the eight-dam scheme. The governments of China and Thailand have signed an investment agreement to jointly develop this project. The dam will be 118 m high, and its construction cost is estimated at $ 1.21 billion (Yn 10 billion) (Internet source 62, 63, 64).
- Another giant hydroelectric project is Nuozdahu - 5,500 MW, and second only to Three Gorges Dam - on the Lancang River. Thailand could be interested to participate in building of Nuozdahu. Construction would start in 2006 and end around 2015. Upon completion, it could transmit 3,000 MW to energy-short *Guangdong* and 1,500 MW to Thailand, while providing 1,000 MW for *Yunnan* itself. The number of people to be relocated is put at 14,800. The construction cost is $ 3.62 billion (Yn 30 billion) (Internet source 65, 66).
- The Huangdeng Gradient hydroelectric project on Lancang River is the 16th of the hydroelectric stations to be built on the Lancang River. The hydropower plant has a designed capacity of 1,600 MW, and will generate 13,35 TWh annually. Its construction cost is approximately $ 815 mln (Yn 6.75 billion) (Internet source 67).

Capital from electricity generation by Three Gorges Dam (*Hubei*) will be used to build two more giant hydropower stations - Xiluodu and Xiangjiaba - on the Jinshajiang River (at the upper course of the Yangtze River) in *Yunnan*. This plan indicates the start of the development of hydropower resources on the upper reaches of the Yangtze River, which has the richest hydropower resources in the world. Total four hydropower plants are to be set up in the lower reaches of the Jinshajiang River over the next 20 years. Upon completion, these plants would have an aggregate capacity of 36,700 MW, twice the installed capacity of Three Gorges Dam.

The aforementioned hydropower plants - Xiluodu and Xiangjiaba - occupy less farmland and local dwelling lands than other large hydroelectric stations (Internet source 68). The hydropower plants will have a combined capacity of more than 18,000 MW, comparable to Three Gorges Dam.

In case of the 12,600 MW Xiluodu multipurpose project - dam height 273 m, annual generation 57.35 TWh, construction cost $ 14 billion - the focus is laid on electricity generation while taking into account flood control, sand blocking and improvement of navigation. Construction could start in 2005, and be finished by 2016 (Internet source 69, 70, 71, 72).

The Xiangjiaba Hydropower Plant has passed the technological appraisals along with Xiluodu. Xiangjiaba is also multifunctional. It has a designed capacity of 6,000 MW and a generation capability of 30.0 TWh/a (Internet source 73, 74).

Sichuan

In *Sichuan* Province, the 36 MW Jiandaoya Hydroelectric Project - output 157 GWh/a - on the Tongjing River has been put in service. The investment cost was $ 50 mln (Internet source 75)

The 760 MW Zipingpu hydroelectric dam (dam height 156 m) on the Minjiang River (a major tributary of the Yangtze River) is under construction. When completed in December 2006, it will supply potable water and extend the area under irrigation from 672,670 to one million hectares. Its construction cost is $ 750 mln (Yn 6.24 billion) (Internet source 76).

The 3,300 MW Pubugou hydroelectric project - output 14.58 TWh/a, construction cost $ 2.66 billion (Yn 22.1 billion) - on the Dadu River (a tributary of the Yangtze River) is in the planning stage (Internet source 77). Pubugou could be completed around 2010 (Internet source 78).

4.2.3 Overview

Table 4.1 presents an overview of the hydropower projects (recently completed, under construction or planned) from Section 4.2.2.

Table 4.1 *Selection of hydropower projects completed, under construction, or planned in China*

Project	Province	Capacity [MW]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Tianshengqiao I&II	Guizhou	2,520	2,400	950	2000
Goubitan	Guizhou	3,000	1,470	490	N/A
Siling	Guizhou	1,000	N/A	N/A	N/A
Mianhuatang	Fujian	600	604	1,010	2001
Xiaolangdi	Henan	1,836	4,200	2,290	2002
Gongboxia	Qinghai	1,500	845	560	N/A
Laxiwa	Qinghai	3,600	2,270	630	2008+
Gaobazhou	Hubei	252	370	1,470	2001
Three Gorges Dam	Hubei	18,200	21,730	1,190	2009
Shuibuya	Qingjiang	1,600	1,450	910	2009
Longtan	Guangxi	5,400	2,980	550	2009
Baise/Hongjiadu	Guangxi	540	578	1,070	N/A
Pingban	Guangxi	405	249.3	620	2005
Jinping No 1	Guangxi	3,600	3,625	1010	N/A
Nalan	Yunnan	135	103.9	770	N/A
Wenshan Malutang	Yunnan	100	50.1	500	N/A
Dachaoshan	Yunnan	1,350	1,060	790	2003
Xiaowan	Yunnan	4,200	6,000	1,430	2012
Jinghong	Yunnan	1,500	1,210	810	2012
Nuozdahu	Yunnan	5,500	3,620	660	2015
Huangdeng Gradient	Yunnan	1,600	815	510	N/A
Xiluodu	Yunnan	12,600	14,000	1,110	2016
Xiangjiaba	Yunnan	6,000	N/A	N/A	2016+
Jiandaoya	Sichuan	36	50	1,390	N/A
Zipingpu	Sichuan	760	750	990	2006
Pubugou	Sichuan	3,300	2,660	810	2010
Total		~ 81,100		~ 1,000	

Figure 4.1 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 4.1 as a function of cumulative installed capacity.

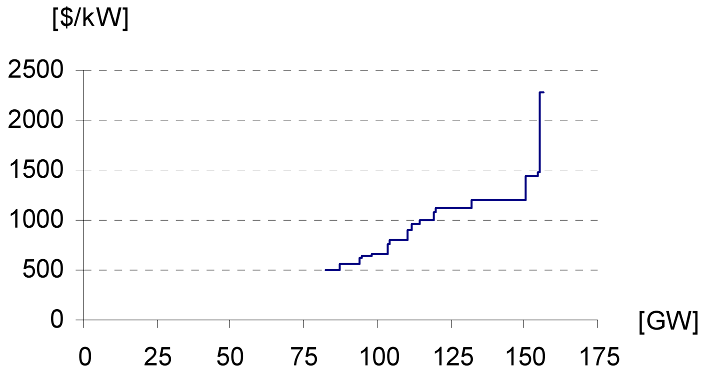

Figure 4.1 *Specific investment cost of hydropower in China vis-à-vis cumulative capacity*

4.2.4 Small hydropower

In China, around 75 million rural people still have no access to power (Internet source 79). By the end of 2001, China had over 43,000 Small Hydro Power stations (SHPs) - defined as 15 MW or less - with a total installed capacity of 26,260 MW, capable of supplying 87.1 TWh annually. Around 300 million people receive electricity from SHPs (Jiandong, 2003).

There is strong focus on expansion of small-scale hydro in rural areas. Small hydro was projected to provide power in 600 rural counties by 2001 and 1,400 by 2010. China already invested $ 1.6 billion to add 1,000 MW of rural electric capacity each year since 1993.

The Global Environmental Facility (GEF) and the World Bank have begun a 10-year project to increase China's non-conventional renewable energy use by 14.3 GW by 2010.

The Ministry of Science and Technology (MOST), the State Development and Planning Commission (SDPC), and the State Economic and Trade Commission (SETC) have jointly set up a 'Program on New and Renewable Energy Development in China (1996-2010)'. One of the targets of this program is 117 GWh of electricity from small hydro by 2010 (Internet source 80).

4.3 India

4.3.1 Introduction

India's hydropower potential ranks fifth in the world. Its gross theoretical hydropower potential is put at 2,638 TWh/a (Internet source 81). According to the Central Electricity Authority (CEA), India has a net exploitable potential of 149 GW, and an economically viable hydropower potential of 84 GW or 440 TWh/a (at 60% load factor) (Internet source 82).

Hydropower accounts for one-quarter of India's power generated and 27 percent of the installed generating capacity. The latter is planned to increase to 40 percent. The installed hydropower capacity stood at 25.2 GW in May 2001, and 15.4 GW is reported to be under construction. So far, only 17 percent of the net exploitable potential and 30 percent of the economically viable potential have been harnessed.

More than 695 dams are constructed for purposes of irrigation, electricity generation, etc. In 2002, a Preliminary Ranking Study (Internet source 83) ranked 399 hydropower schemes with an aggregate capacity of 107 GW. The schemes were prioritised in the six River Systems in the order of their attractiveness for implementation. The study should serve as a guide for potential developers to choose hydro schemes for investigations and implementation. National Hydroelectric Power Corporation (NHPC), the largest hydropower operator in India, has drawn up a plan to add over 49 GW of hydro capacity in the next 20 years (Internet source 84).

Large hydropower projects in India are presented by State (Section 4.3.2) and summarised in Section 4.3.3. The development of small hydropower is briefly addressed in Section 4.3.4.

4.3.2 Hydropower development by State

Maharashtra

In May 1999, construction started on the 14 MW Bhandardara multipurpose scheme - irrigation and power generation - in *Maharashtra* State. This hydroelectric project - output 47 GWh/a, construction cost $ 13.3 mln - was developed with help from the US, and was completed in July 2001 (Internet source 85, 86).

Himachal Pradesh

In 1993, construction started on the 1,530 MW Nathpa-Jhakri hydroelectric project on the Satluj River in *Himachal Pradesh* State. The project comprises a 60.5-m high dam, and an underground desilting complex. It is meant to supply power to *Himachal Pradesh* and the Northern Regional Grid States in India. The construction cost is put at $ 1,583 billion (INR 76.66 billion[4]), and it is scheduled to come on-stream in 2003 (Internet source 87).

The 86 MW Malana hydroelectric project is built on a tributary of the Parbati River. Negative impacts of the project include loss of forest, loss of land, soil erosion at the construction site, pollution by construction spoils, health risks, cultural hazards, water-borne diseases, and vector-borne diseases. Besides power generation, the positive impacts include potential for employment, recreation and tourism, and additional habitat for aquatic wildlife (Internet source 88).

The 800 MW Parbati Stage II hydroelectric project is a run-of-the-river project, comprising a 91-m high dam, on the Parbati River. It is indicated that 'the project area is sparsely populated and there is little habitation at the diversion site and the power house'. Only 8 ha of forestland will be submerged. Parbati Stage III is a 501 MW run-of-the-river project, comprising a 75-m high dam. Only 5 ha of cultivated land will be submerged.

The 300 MW Chamera Stage II turnkey hydroelectric project - dam height 39 m, annual output 1.5 TWh, construction cost $ 310 mln (INR 15 billion) - on the Ravi River is due for completion in 2004 (Internet source 89, 90, 91).

National Thermal Power Corporation (NTPC) will build, own, and operate the 163-m high Kol Dam (800 MW). Construction was resumed after a delay of several years since the state was unable to secure the required funds (Internet source 92).

Mizoram

In 2000, the CEA approved the 80 MW Bairabi Hydro Plant in the northeastern State of *Mizoram*, including a 204-foot (62 m) high dam across the Bairabi River. It will improve navigation from the dam to downstream communities through a 180-km waterway. The construction cost of the hydropower plant is put at $ 111 mln, and it will be commissioned in 2007.

Manipur

Construction work on Loktak Downstream - 90 MW, annual generation 420 GWh - in *Manipur* State is due to start in 2003. Loktak Downstream is due for completion in 2008, and its construction cost is estimated at $ 119 mln (Internet source 93, 94).

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[4] 1 US$ = 48.424 INR (January 31st, 2003).

In January 2003, the Government of *Manipur* signed a Memorandum of Understanding (MoU) with the implementing agency of Tipaimukh Multi-Purpose Project, Northeastern Electric Power Corporation (NEEPCO)[5]. Following the agreement, the CEA has given its techno-economic clearance for commencement of construction activities on the 1,500 MW Tipaimukh Dam - dam height 162 m, construction cost $ 817 mln - on the Barak River at the *Manipur-Mizoram* border. The dam is set to completely submerge eight villages. Part of the project cost is needed for rehabilitation of inhabitants. Construction work is due to start in 2003 (Internet source 95, 96).

Madhya Pradesh

In 2000, India's Supreme Court approved completion of the 1,450 MW Sardar Sarovar dam on the Narmada River in *Madhya Pradesh* State. The maximum permitted dam height of 295 feet (90 m) was raised to 328 feet (100 m) in August 2001. Sardar Sarovar will not only provide power to *Madhya Pradesh*, but also offer irrigation to 1.8 million hectares of land and associated food production benefits to *Gujarat*, *Rajasthan*, and other arid areas along the banks of the Narmada River. Furthermore, it will supply drinking water to 25 to over 40 million people. Its construction cost is $ 5.37 billion (INR 260 billion) (Internet source 97, 98, 99).

Jammu & Kashmir

A major hydropower project being executed by the NHPC is the Dulhasti project (390 MW) in the northern Indian State of *Jammu & Kashmir*. The Dulhasti project was to be completed in 2002. The 450 MW Baglihar hydropower plant - construction cost $ 335 mln (INR 16.23 billion) - is built on the Chenab River (Internet source 100).

Jammu & Kashmir have signed an agreement with National Hydroelectric Power Corporation (NHPC) to build seven hydropower plants, with an aggregate capacity of 2,778 MW and a total investment of $ 3.6 billion. Five of these plants - Pakal Dul, Uri-II, Sewa-II, Nimooo Bazgo and Chutak - are in the survey and investigation stage.

West Bengal

The NHCP has agreed to participate in the third and fourth stages of Teesta Low Dams (III and IV), a multipurpose water resources project in the State of *West Bengal*, adding 132 MW and 200 MW respectively to the installed capacity.

Sikkim

A detailed action plan has been worked out for the 510 MW Teesta Stage V Hydropower Project in *Sikkim* State, capable of generating 2.57 TWh on an annual base. The construction cost is put at $ 454 mln (INR 21.98 billion) (Internet source 101).

4.3.3 Overview

Table 4.2 gives a selection of hydropower projects in India (recently completed, under construction or planned), based on the projects presented in Section 4.3.2 and Internet sources 102, 103, and 104.

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[5] North Eastern Electric Power Corporation (NEEPCO) is a wholly owned Government of India enterprise.

Table 4.2 *Selection of hydropower projects, completed, under construction, or planned in India*

Project	State	Capacity [MW]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Bhandardara	Maharashtra	14	13.3	950	2001
Nathpa Jhakri	Himachal Pradesh	1,530	1,583	1,030	2003
Malana	Himachal Pradesh	86	N/A	N/A	N/A
Parbati II	Himachal Pradesh	800	N/A	N/A	N/A
Parbati III	Himachal Pradesh	501	N/A	N/A	N/A
Chamera II	Himachal Pradesh	300	310	1,030	2004
Kol Dam	Himachal Pradesh	800	N/A	N/A	N/A
Bairabi	Mizoram	80	111	1,390	2007
Loktak Downstr.	Manipur	90	119	1,320	2008
Tipaimukh	Manipur	1,500	817	540	2014
Sardar Sarovar	Madhya Pradesh	1,450	5,370	3,700	N/A
Dulhasti	Jammu & Kashmir	390	N/A	N/A	2003
Baghilar	Jammu & Kasmir	450	335	750	2005
Pakal Dul	Jammu & Kashmir	1,000	3,600	1,300	- 2008
Busrar	Jammu & Kashmir	1,000			
Kishan Ganga	Jammu & Kashmir	330			
Uri-II	Jammu & Kashmir	280			
Sewa-II	Jammu & Kashmir	120			
Nimooo Bazgo	Jammu & Kashmir	30			
Chutak	Jammu & Kashmir	18			
Teesta Low III&IV	West Bengal	332	N/A	N/A	2005
Teesta Stage-V	Sikkim	510	454	890	2007
Total		~ 11,600		~ 1,450	

Figure 4.2 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 4.2 as a function of cumulative installed capacity.

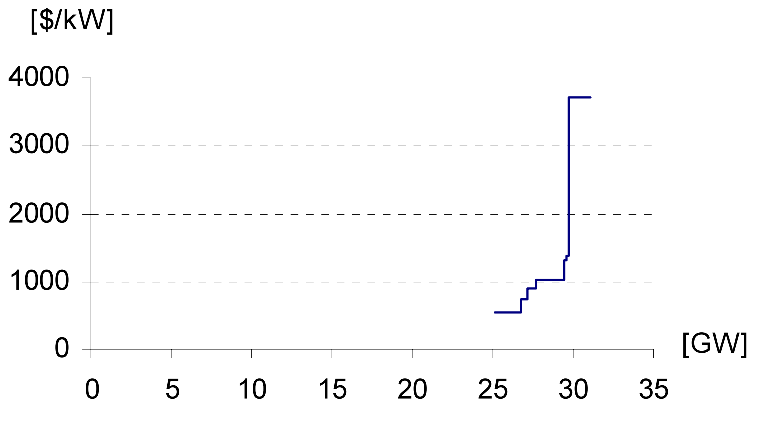

Figure 4.2 *Specific investment cost of hydropower in India vis-à-vis cumulative capacity*

4.3.4 Small hydropower

India has an estimated potential for SHP of about 15,000 MW. 4,096 potential sites with an aggregate capacity of 10,071 MW for projects up to 25 MW capacity have been identified.

Today, 420 SHP projects up to 25 MW station capacity with an aggregate capacity of over 1,423 MW are in operation. These projects are spread throughout the country in hilly regions as well as on canal drops. Over 187 projects in this range with aggregate capacity of 521 MW are under construction (Internet source 105).

4.4 Nepal

4.4.1 Introduction

Nepal has a theoretical hydropower potential of 83 GW, and an economically viable potential of 42 GW or 147 TWh/a (Internet source 106). Hydropower provides 90 percent of Nepal's electricity. At the end of fiscal year 2000-2001, the hydro capacity stood at 373 MW. When projects under construction in 2000 are completed the installed capacity will be approximately 600 MW (Internet source 107).

Nepal's exploitable hydro potential will remain largely untapped due to its difficult geography and poor tax base: only 15 percent of the 23 million inhabitants have access to electricity. According to a consultant with the US Agency for International Development (USAID), the domestic power demand might be 3.0 GW and the total installed hydro capacity 15.0 GW by 2020, leaving a large surplus for export to neighbouring India (Internet source 108).

In 2001, the Government of Nepal introduced a new policy on hydropower - the Hydropower Development Policy - addressing the issues of royalty, downstream benefit, power purchase agreements, and the export of power. Privatisation of hydropower has made significant progress. Nepal gives priority to private-sector participation in a multi-pronged approach to meet the domestic demand and for export purpose (Internet source 109). The first private projects are underway and others, with values running into the billions of dollars, have been proposed (Internet source 110).

Relatively large hydropower projects in Nepal are presented in Section 4.4.2 and summarised in Section 4.4.3. The development of small hydropower is briefly addressed in Section 4.4.4.

4.4.2 Hydropower projects

In 2000, the following hydropower plants were commissioned (Internet source 111):

- Khimti I - 60 MW, annual generation 353 GWh, construction cost $ 139 mln.
- Ilam (Puwakhola) - 6.2 MW, annual generation 41 GWh, construction cost $ 15.7 mln.
- Upper Bhotekoshi - 36 MW, annual generation 250 GWh, construction cost $ 100 mln.
- Modi Khola - 14.8 MW, annual generation 87 GWh, construction cost $ 30 mln.

In March 2002, Kaligandaki A - 144 MW, output 791 GWh/a, construction cost $ 453 mln, partly financed by the Asian Development Bank (ADB) and Japan - on the Kaligandaki River was commissioned (Internet source 112). A listing of environmental and social mitigation measures with associated costs disclosed that total planned mitigation costs amounted to $ 5.3 million, representing only 1.2% of total project cost (Internet source 113). Around the same time, the 3 MW Piluwa-Khola hydropower project - construction cost Rs 280 mln ≈ $ 4.38 mln[6] - was completed (Internet source 114).

In October 2002, the 7.5 MW Indrawati III hydroelectric project - annual generation 37 GWh, construction cost $ 27.8 mln (Rs 1.75 billion) - on the Andrawati River was commissioned. It is a so-called simple run-of-the-river (SRR) scheme (Internet source 115). Two small power

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[6] 1 US$ ≈ 64 Rs.

plants - the 5 MW Daram-Khola power plant (annual generation 33 GWh) and the 14 MW Upper-Modi power plant (annual generation 89.6 GWh) - are due for 2003.

The 20 MW Chilime project - construction cost $ 36.8 mln (Rs 2.32 billion) - is due to come onstream in 2003 (Internet source 116, 117), and the 70 MW Middle-Marsyangdi project - dam height 62 m, annual output 422 GWh, construction cost $ 217 mln (Rs 13.65 billion) - in 2005 (Internet source 118). The 30 MW Chameliya peaking run-of-the-river plant - annual generation 197 GWh, construction cost $ 74.22 mln - is scheduled for completion in 2006.

A number of hydropower plants are firmly planned, among which the 250 MW Upper-Tamakoshi (Rolwaling) hydroelectric project. This project includes a 300-m high dam, the construction of 100-km 220 kV transmission line, and 37-km access road. The total project cost is estimated at $ 277 million (Internet source 119).

In 2002, the Canadian Elysée Frontière seemed committed to develop the 300 MW Upper Karnali Hydropower Project (construction cost $ 492 mln) (Internet source 120, 121).

In 2002, Australia's SMEC International signed a contract for the development of the 750 MW West-Seti hydroelectric project - dam height 195 m, total cost $ 1.2 billion - which will be used mainly for export to India. Some 13,000 people will be impacted by the project. Assessments indicate that around 7,870 people will resettle outside the project area, 1,200 will relocate locally, while 4,000 will remain where they are (Internet source 122, 123, 124).

The Eurorient Investment Group (US) has been allowed to build the 402 MW, $ 1.1 billion, Arun-III run-of-the-river plant on a Build-Own-Operate-Transfer (BOOT) basis. This involves an arrangement by which a private developer builds an infrastructure facility using limited or non-recourse financing in return for the right to operate the facility and charge users a fee in order to generate a commercially acceptable rate of return (15% or more) on investment. The private developer owns and operates the project for a specified amount of time, usually 25 to 30 years, after which ownership is transferred to the government without compensation (Internet source 125).

Environmental groups have criticised Arun III as potentially dangerous to Nepal's forests. Also, the World Bank withdrew its support because of the height of the financial burden for Nepal (Internet source 126).

India and Nepal are preparing, under the Mahakali Treaty signed between the governments in 1996, construction of the giant 6,480 MW, $ 2.98 billion, Pancheshwore Multipurpose Project on the Mahakali River (Indo-Nepal border) (Internet source 127).

Another giant hydroelectric project in the planning stage is the Karnali-Chisapani Multipurpose Project, with a potential installed capacity of 10,800 MW. This would be not only the largest infrastructure project in Nepal, but also one of the world's largest hydropower stations. The construction cost of Karnali-Chisapani is put at $ 4.812 billion.

4.4.3 Overview

Table 4.3 gives a selection of hydropower projects in Nepal (recently completed, under construction or planned), based on Section 4.4.2.

Table 4.3 *Selection of hydropower projects completed, under construction, or planned in Nepal*

Project	Capacity [MW]	Generation [GWh/a]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Khimti I	60	353	139	2,320	2000
Ilam (Puwakhola)	6.2	41	15.7	2,500	2000
Upper Bhotekoshi	36	250	98	2,720	2000
Modi Khola	14.8	87	30	2,000	2000
Kaligandaki A	144	791	453	3,150	2002
Piluwa Khola	3	20	4.38	1,460	2002
Indrawati III	7.5	37	27.8	3,700	2002
Daram Khola	5	33	N/A	N/A	2003
Upper Modi	14	89.6	N/A	N/A	2003
Chilime	20	101	36.8	1,840	2003
Middle Marsyangdi	70	422	217	3,100	2005
Chameliya	30	197	74.22	2,470	2006
Budhi Ganga	22	N/A	46	2,090	N/A
Rautahat	24	N/A	39	1,630	N/A
Likhu Khola	34	N/A	61	1,790	N/A
Kabeli	35	N/A	68	1,940	N/A
Tamur Mewa	100	N/A	192	1,920	N/A
Upper Tamakoshi	250	N/A	277	1,110	N/A
Upper Karnali	300	1,794	492	1,640	N/A
West Seti	750	3,300	1,200	1,600	N/A
Dudh Koshi	300	N/A	675	2,250	N/A
Lower Arun	308	2,275	481.1	1,560	N/A
Upper Arun	335	2,050	500.8	1,500	N/A
Arun III	402	2,891	1,100	2,740	N/A
Burhi Gandaki	600	2,495	774	1,290	N/A
Kaligandaki 2	660	2,660	772	1,170	N/A
Pancheshwore	6,480	10,671	2,980	460	N/A
Karnali-Chisapani	10,800	20,942	4,812	450	N/A
Total	~ 21,800			~ 1,725[1]	

[1] Exclusive of the giant Pancheshwore and Karnali-Chisapani Multipurpose Projects.

Figure 4.3 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 4.3 as a function of cumulative installed capacity.

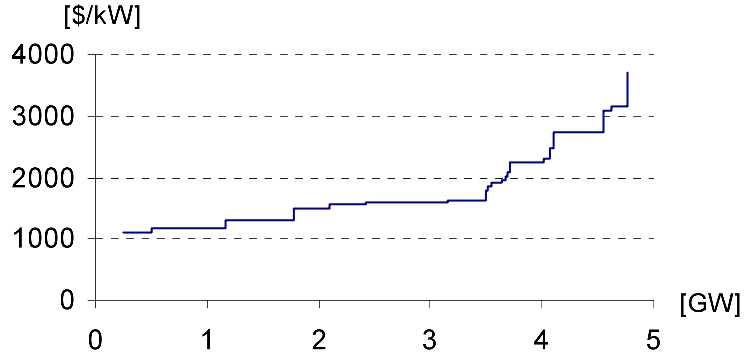

Figure 4.3 *Specific investment cost of hydropower in Nepal vis-à-vis cumulative capacity*

4.4.4 Small hydropower

The Nepal Electricity Authority (NEA) has introduced the Small Hydropower Master Plan Project. Several small and medium-sized hydropower plants are in various stages of construction. Such projects have been screened and ranked by consultants from the World Bank. Six of them - total capacity approximately 800 MW - have been prioritised for development.

4.5 Pakistan

The mountainous northern half of Pakistan has a potential of 24 GW or 130 TWh/a of hydroelectric resources for development. However, difficulty of access and the high cost of transmission to the populous south make development of this potential a distant prospect. In 1999, the installed hydropower capacity was 4.8 GW, and 1.6 GW was under construction. Hydropower accounts for 37 percent of Pakistan's electricity generation (Internet source 128).

Several hydroelectric dams are under construction, among which Ghazi Barotha and Malakand III. The 1,450 MW Ghazi Barotha hydro project will be completed after a construction delay due to a payment dispute with construction firms involved in the project - resolved in February 2002 - and withdrawal of expatriate staff due to security concerns. According to the Water And Power Development Authority (WAPDA) it would be more than 62% complete in 2000. The construction cost of Ghazi Barotha is estimated at $ 2.199 billion.

WAPDA accounts for the lion's share - it will tap internal resources to invest $ 1.145 billion, or 52 percent of the total ($ 2.199 billion). Multilateral lending to the Pakistan government is the second most important funding source. The World Bank provides a twenty-year loan of $ 350 million, and ADB a twenty-five year loan of $ 300 million. National development funds covered most of the remainder, with Japan's Overseas Economic Co-operation Fund (OECF) offering $ 275 million and Germany's Kreditanstalt für Wiederaufbau (KfW) $ 129 million (Internet source 129).

Ghazi Barotha is built at the confluence of the Indus and Haro Rivers in the Northwest Frontier Province. Although Ghazi Barotha is a large-scale scheme, it is not expected to result in wide displacement of local population. It is a recent example of a major hydropower project, carefully planned and prepared to take full account of the environmental, resettlement, and social aspects. It was the first major hydro project where an independent Environment Review Panel was established and became involved from the first day of the feasibility studies, in line with the provisions of Operational Directives of the World Bank (Internet source 130).

The 81 MW Malakand III A multipurpose plant under construction in the Northwest Frontier Province - construction cost $ 112 mln - will irrigate 3,200 ha of land, and is due for commissioning in 2005 (Internet source 131, 132). The 35 MW Daral Kwhar plant - annual output 148 GWh, construction cost $ 38 mln - is due for commissioning in 2006 (Internet source 133, 134).

Several more hydropower projects of WAPDA are under review: the 3,600 MW Kalabagh Dam (construction cost $ 5.7 billion) and 3,360 MW Diamer (Basha) Dam. The Kalabagh Dam will provide water for the irrigation of 1.6 million ha mainly in Punjab (Internet source 135). The Federal Minister for Water and Power promised that controversial irrigation projects like Kalabagh Dam would be launched only after a national consensus, and a guaranteed share for Pakistani authorities in the net profit of the projects (Internet source 136).

Table 4.4 gives an overview of hydropower projects in Pakistan (recently completed, under construction or planned).

Table 4.4 *Selected hydropower projects completed, under construction, or planned in Pakistan*

Project	Capacity [MW]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Ghazi Barotha	1,450	2,199	1,520	2002
Malakand III	81	112	1,380	2005
Daral Khwar	35	38	1,080	2006
Kalabagh Dam	3,600	5,700	1,580	N/A
Diamer (Basha) Dam	3,360	N/A	N/A	N/A
Total	~ 8,500		~ 1,550	

WAPDA has been requested to develop small hydropower in Pakistan. It has identified 591 such sites that can generate 1000-1500 MW of electricity, besides providing irrigation water. The government of Pakistan hopes to support the development of renewables such as mini-hydro with its new Small Renewable Energy Power (SREP) program. Small power producers will be given a license for a 21-year period to sell their power through the national power grid.

4.6 Lao PDR (Laos)

Lao PDR has a gross theoretical hydro potential of 26,500 MW. The exploitable potential stands at 18,000 MW, 10,000 MW of which is denoted as ‘feasible’. In 2000, 627 MW of hydropower had been installed (97% of the installed generating capacity) (Internet source 137).

The Foreign Investment Management Committee (FIMC) of the Government of Laos maintains a list of ‘promising hydropower projects’ for the benefit of interested foreign investors wishing to invest in hydropower projects (Table 4.5) (Internet source 138).

Table 4.5 *Promising hydropower projects on Mekong tributaries in Lao PDR*

Basins	No. of Projects	Capacity [MW]	Generation [GWh/a]
1. Nam Tha	1	230	1,130
2. Nam Beng	1	45	230
3. Nam Ou	2	1,345	6,790
4. Nam Suang	1	195	960
5. Nam Khan	2	260	1,310
6. Nam Ngum	7	1,730	8,540
7. Nam Lik	2	230	1,155
8. Nam Mang	3	110	455
9. Nam Ngiap	2	935	5,390
10. Nam Sane	1	90	440
11. Nam Theun	6	2,435	15,890
12. Nam Hin Boun	1	16	80
13. Se Bang Fai	1	60	310
14. Se Bang Hiang	3	400	2,000
15. Se Kong & Se Done	16	2,180	12,950
Total	49	10,260	57,630

With the help of the Mekong River Commission, the Lao Government has identified up to 60 possible large-scale hydropower projects and expects to develop 7,000 MW hydropower capacity by 2020. Out of the 7,000 MW, Laos is expecting to export to Thailand 1,700 MW by 2008. It hopes to export to Vietnam 1,500 to 2,000 MW by 2010. Hydropower generating capacity is expected to reach more than 3000 MW by the year 2006 and Lao PDR is actively seeking private investments to reach this target.

Financing for power development in Lao PDR may take different forms depending on whether the project is in the small to medium or large categories:

1. Small and Medium Projects
   For small and medium sized projects, the Government would endeavour to obtain official financing for the projects, which would then be executed by Electricité du Laos (EdL). Loans would be sought from multilateral, bilateral and export credit sources on concessionaire terms.
2. Export Projects
   In the case of major power developments, the size of the venture and the huge financing requirements demand an altogether different approach. The participation of the private sector is needed to mobilise the necessary financial and organisational resources required by such projects.

Development of large projects is by private sector execution and operation on a Build-Own-Operate-Transfer (BOOT) basis (Internet source 139).

The hydropower projects in the capital works plan of EdL for which feasibility studies have been completed are both economically and financially profitable because of the large proportion of export sales attributable to them (Internet source 140).

The 210 MW Theun-Hinboun Hydropower Project - annual output approximately 1.5 TWh, construction cost $ 260 mln - on the Theun-Kading River (a tributary of the Mekong River) was completed in 1998. Power from Theun Hinboun is mainly sold to Thailand for foreign exchange earning (Internet source 141, 142).

Houay Ho - 150 MW, dam height 79.5 m, output 570 GWh/a, project cost including interest during construction $ 220 mln - is the first privately financed joint venture hydropower project in Lao PDR. Houay Ho was constructed from 1994 to 1998, and power sales to Thailand began in 1999 (Internet source 143, 144).

The 60 MW Nam-Leuk hydro plant - dam height 45 m, output 230 GWh/a, capital cost $ 130 mln - on the Nam Mang River entered service in 2002 (Internet source 145, 146, 147).

The 1,088 MW Nam-Theun 2 project - dam height 48 m, output 5.94 TWh/a, estimated cost $ 1.2 billion - is the largest hydro project of Laos. Developed as a BOOT scheme by EdF (Electricité de France), the Electricity Generating Company of Thailand, Ital-Thai Development, and the Lao Government, Nam Theun 2 will generate power mainly for Thailand (995 MW).

Although its economic viability has been questioned, the Government sees Nam Theun 2 as a major endeavour to alleviate poverty and lessen the dependence on international aid (Internet source 148, 149). A Power Purchase Agreement was initialled in 2002. Main works will begin in early 2004, and commissioning will be made in progressive steps with full completion in 2008 (Internet source 150, 151).

Table 4.6 presents the aforementioned hydropower projects in Lao PDR (Internet source 152).

Table 4.6 *Selection of hydro projects completed, under construction, or planned in Lao PDR*

Project	Capacity [MW]	Generation [GWh/a]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Theun Hinboun	214	1,356	260	1,210	1998
Houay Ho	152	617	220	1,450	1999
Nam Leuk	60	230	130	2,170	2002
Nam Mang 3	35	141	63	1,800	2005
Xeset 2	76	309	87.9	1,160	2006
Xepon	75	338	139.2	1,860	2006
Nam Ngum 5	100	430	128	1,280	2007
Nam Theun 2	1,086	5,936	1,200	1,100	2008
Huay Lamphanh Gnai	60	354	102	1,700	2010
Xeset 3	20	83	28.6	1,430	2014
Total	1,878	9,794	2,359	~ 1,250	

Figure 4.4 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 4.6 as a function of cumulative installed capacity.

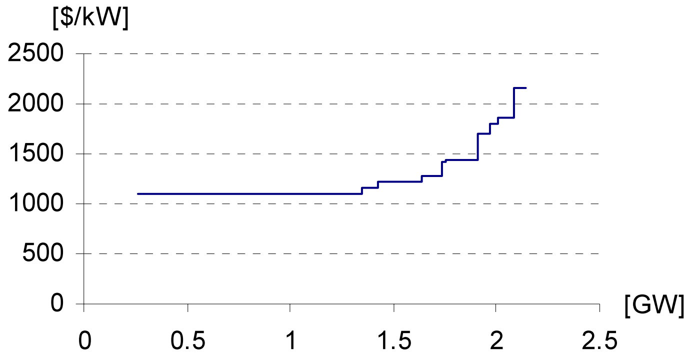

Figure 4.4 *Specific investment cost of hydropower in Lao PDR vis-à-vis cumulative capacity*

4.7 Malaysia

Malaysia has a gross theoretical hydropower potential of 250 GW, and a technically feasible potential of 123 TWh/a. The 2,400 MW Bakun Hydroelectric Project was first approved in 1994. This hydropower project - dam height 670 feet (200 m) - under construction on the Balui River will include the longest and highest capacity submarine cables in the world to transmit power generated from Bakun in Sarawak (Borneo) to Peninsula Malaysia, a distance of 670 kilometres. Three diversion tunnels were completed in 2001. Bakun will flood 69,000 hectares of farmland, and will result in a more balanced generation mix. The share of hydropower will rise to 19.7 percent in 2005 (Internet source 153). The project will cost an estimated $ 2.4 billion (Internet source 154).

4.8 Myanmar

Myanmar (formerly Burma) is topographically endowed with abundant hydropower resources. According to the World Bank, the theoretical potential is 108 GW. As yet Myanmar Electric Power Enterprise has identified an exploitable potential of 39,624 MW or 140 TWh/a on 267 sites. Existing hydropower plants constitute 360 MW (30% of the generating capacity), and hence only 1% of the exploitable potential has been developed (Internet source 155, 156, 157).

Table 4.7 shows the exploitable hydropower potential of Myanmar by State.

Table 4.7 *Exploitable hydropower potential of Myanmar*

State/division	Number of sites	Exploitable hydro potential [MW]
Kachin State	39	2,061
Kayah State	7	3,909
Kayin State	21	17,021
Chin State	22	1,312
Sagaing Division	21	2,399
Tanintharyi Division	14	692
Bago Division	11	387
Magwe Division	8	123
Mandalay Division	17	3,482
Mon State	10	292
Rakhine State	14	247
Shan State	83	7,699
Total	267	39,624

In May 2002, the Japanese government decided to provide $ 5 mln to Myanmar for the rehabilitation of the country's Baluchaung No. 2 hydropower plant (Internet source 158).

Paung Laung - 280 MW, dam height 430 feet (130 m) - is the biggest hydropower project and the biggest infrastructure project carried out in Myanmar. China has signed a $ 160 million contract to design and build the hydropower station, and the Chinese government will provide an export credit for it. Power generation is slated to start in December 2003 (Internet source 159). Another hydropower plant under construction is Nam Kok (42 MW) (Internet source 160).

Two other hydropower projects have been prioritised:
- The Yeywa project on the Myitnge River - 780 MW, dam height 400 feet (120 m).
- A long-planned project on the Bilin River - projected capacity 280 MW.

These projects will need loans totalling more than $ 1 billion (Internet source 161, 162, 163)

In 1995, a master plan study and a pre-feasibility study were finished on three hydropower plants to be built on the Sekong River and its tributaries, viz. the 443 MW Se Kong 4 plant, the 256 MW Xe Kaman 1 plant and the 238 MW Xe Namnoy plant (Internet source 164).

In December 2002, the Government of Myanmar and Thailand's MDX Plc agreed to build the 4,500 MW Tasang hydroelectric dam - dam height 220 m, capital cost $ 5 billion (Internet source 165) - on the Than Lwin River (Salween River) in the southern Shan State. Tasang would ease Myanmar's chronical power shortage and export electricity to Thailand. The first 200 MW turbine will generate power in 2007 (Internet source 166). The Senate foreign affairs panel of Thailand has demanded to cancel Tasang, citing concerns for national security and image.

Recently, Myanmar and India decided to co-operate in energy projects, including hydropower[7], in order to alleviate Myanmar's troubles attracting foreign investment (VOA News, 2003).

Table 4.8 presents the aforementioned hydropower projects in Myanmar.

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[7] On January 21, 2003, Myanmar and India agreed to increase co-operation in energy and boost bilateral trade. The two delegations reviewed energy projects, including hydroelectric power generation.

Table 4.8 *Selection of hydropower projects under construction or planned in Myanmar*

Project	Capacity [MW]	Generation [GWh/a]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Paung Laung	280	N/A	160	570	2003
Nam Kok	42	230	N/A	N/A	N/A
Hutgyi	300	2,148	N/A	N/A	N/A
Bilin	200	N/A	>1,000	>1,020	N/A
Yeywa	780	N/A			N/A
Se Kong 4	443	1,816	N/A	N/A	N/A
Xe Kaman 1	256	1,137	N/A	N/A	N/A
Xe Namnoy	238	1,052	N/A	N/A	N/A
Ta Sang	~ 4,500		5,000	~ 1,100	

4.9 The Philippines

The gross theoretical hydropower potential of the Philippines is 9,150 MW or 47.5 TWh/a, the technically feasible potential 20.3 TWh/a, and the economically feasible potential 18.2 TWh/a (Internet source 167). There is room for additional hydropower in the Philippines. Large hydropower projects totalling 2,175 MW have been identified (Edge, 2002).

As of December 31 2001, the Philippines had an installed hydropower capacity of 2,521 MW (supplying 19% of the electricity). This is projected to increase to 3,500 MW by 2009 as a result of committed hydropower plants, including Bakun AC (70 MW), Casecnan (150 MW), San Roque (345 MW), Tagaloan II (68), Agus III (225 MW), Pulangi IV (85 MW), and Bulanog-Batang (132 MW) (Internet source 168).

The Caliraya, Botocan and Kalayaan (CBK) Project, with a total installed capacity of 726.6 MW, became operational in 2000. Its construction cost was $ 450 mln (Internet source 169).

In October 2001, the 150 MW Casecnan multipurpose project - output 603 GWh/a, total cost $ 650 mln - was commissioned. Casecnan is located in Luzon, the largest island of the Philippines. It was developed under the government's Build-Operate-Transfer (BOT) scheme, and is geared towards stabilising the supply of water for the irrigation requirements of some 102,000 hectares of existing farmlands and 35,000 ha of new farms (Internet source 170, 171).

In 1999, construction started on the 345 MW San Roque Multipurpose Project (irrigation and power generation) - dam height 660 feet (200 m), construction cost $ 1.19 billion - on the Agno River (Luzon). It is the largest private hydroelectric project in Asia. It will irrigate 70,000 ha of rice-land. Completion is scheduled for 2004 (Internet source 172, 173, 174).

Table 4.9 presents the aforementioned hydropower projects in the Philippines.

Table 4.9 *Selected hydro projects completed, under construction or planned in the Philippines*

Project	Capacity [MW]	Generation [GWh/a]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
CBK Project	726.6	N/A	450	620	2000
Bakun AC	70	217	146	2,100	2001
Casecnan	150	603	650	4,330	2001
San Roque	345	N/A	1,190	3,450	2004
Tagoloan II	68	N/A	N/A	N/A	2005
Agus III	225	N/A	N/A	N/A	N/A
Pulangi IV	85	N/A	N/A	N/A	N/A
Bulanog-Batang	132	N/A	N/A	N/A	2010
Total	~ 1,800			~ 1,900	

Untapped small hydro (>100 kW) potential is being studied to assess its feasibility for development. The Philippine government aims to provide electricity access to 9,000 remote villages before 2002, and there are plans to use wind, solar, or mini-hydro in about half of them. Estimates of possible mini-hydro development point to 1,748 MW of new capacity. The government plans to invest $ 330 mln by way of special tax incentives.

4.10 Thailand

Recently, there has been controversy about flooding in Thailand's Ubon Ratchathani Province. Irrigation and hydroelectric dams would have contributed to environmental deterioration in Thailand's northeast (Internet source 175, 176). The Electricity Generating Authority of Thailand (EGAT), however, declared that the Pak Mun Dam on the Mun River was not the cause of flooding (Internet source 177). Thailand is actively engaged in import of electricity from Laos, China and Myanmar.

There are indications that construction would start on a long-delayed hydroelectric project, viz. Kaeng Sua Ten dam - 48 MW, construction cost $ 185 mln. Also, the 48 MW Ta Sae dam - irrigation of approximately 14,000 ha of land, construction cost $ 63.6 mln - is planned.

In late 1992, Thailand signed a non-binding MoU (Memorandum of Understanding) with Laos to purchase output from new installed capacity in Laos totalling 1500 MW from the year 2000. This was extended in June 1996 to 3000 MW by the year 2006 (Internet source 178).

Thailand also signed a MoU on 12 November 1998 for purchase of 1,500 MW of electricity from the Jinghong Hydropower Station in Yunnan Province (China) in 2013, and another 1,500 MW from Yunnan Province in 2014 (Internet source 179). MDX from Thailand and Yunnan Electric are investing in hydropower stations on the Lancang River (Yunnan Province). These hydropower stations are at a distance of some 400 km from the Thai border.

In July 1997, a MoU was signed between Thailand and Myanmar whereby Thailand has agreed to buy up to 1,500 MW from Myanmar by 2010 (Internet source 180).

4.11 Vietnam

Vietnam's gross theoretical potential of hydropower is 34,674 MW or 300 TWh/a, and its economically feasible potential is 18.6-20 GW or 82-100 TWh/a (Internet source 181). The installed hydro capacity is 4.12 GW (Internet source 179), and more than 8 GW is planned. Vietnam is planning to develop 37 new hydropower plants by 2020 with a total budget of $ 19.1 billion (Renewable Energy World, 2002).

The second largest hydropower plant of Vietnam, the 720 MW Yaly Falls dam - construction cost $ 1 billion - on the Se San River was built from 1993 to 2001 (Internet source 182). More than 6,700 people had to be relocated for the dam (Internet source 183). The Se San runs through Cambodia to the Mekong River. The 300 MW Ham Thuan and 175 MW Da Mi hydropower plants on tributaries of the Dong Nai River also went online in 2001 (Internet source 184).

Hydropower plants under construction include Ry Ninh II (8.1 MW), Can Don (72 MW), and Dai Ninh (300 MW) (Internet source 185, 186). Dai Ninh is a multipurpose dam, which will supply water for agriculture in addition to generating electric power (Internet source 187).

The small 12 MW H'Chan hydropower plant - annual generation 56.42 GWh, construction cost $ 12.27 mln - on the Ayun River is due for completion in 2005 (Internet source 188). Construction of the 16 MW H'mun, 34 MW Ea Krong-Ron, and 65 MW Binh-Dien hydro plants has been approved.

In 2000, Electricity of Vietnam (EVN) submitted a feasibility study to the government for the 74 MW Rao Quan hydropower project, which would generate 260 GWh annually and whose reservoir would irrigate 12,281 hectares of rice paddy and 1,600 hectares of cereal crops. The project would also help regulate the flow of the Thach Han River and provide a more reliable water supply for the local population. Rao Quan would cost an estimated $ 140 million.

Out of 24 possible sites along Vietnam's top three rivers, the 260 MW Se San 3 hydroelectric dam - construction cost $ 320 mln - on the Se San River has been selected as an investment priority for development. Construction started in 2002 (Internet source 189, 190). Another hydropower plant under construction is the 120 MW Pleikrong plant - construction cost $ 256 mln (Internet source 191).

The Government approved a feasibility study for the 96 MW Se San 3A Hydroelectric Plant, the fourth to be built on the Se San River. The plant will be built at a cost of $ 124 mln, and will become part of the national power grid by 2007 (Internet source 192). EVN is drafting a plan to build a 260 MW hydro plant on the Ba Ha River, to be built from 2004 and at a cost of about $ 311 mln. After completion of a feasibility study, the project has to be approved (Internet source 188).

Work on construction of the Tuyen-Quang hydroelectric power plant started in December 2002. The 342 MW power plant will be built at a cost of roughly $ 500 mln (Internet source 193).

The National Assembly has approved construction of the 3,600 MW Son La multipurpose project - cost $ 5.435 billion - on the Da River, in order to improve Vietnam's electricity fuel mix, reduce flood damage, and improve irrigation in the Red River Delta (Internet source 194, 195).

Table 4.10 presents the aforementioned hydropower projects in Vietnam. Apart from the individual projects described above, the Table is also based on Internet source 196.

Table 4.10 *Selected hydropower projects completed, under construction, or planned in Vietnam*

Project	Capacity [MW]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Yali Falls	720	1,000	1,390	2001
Ham Thuan	300	} 233	} 490	2001
Da Mi	175			2001
Ry Ninh II	8.1	5.55	685	2003
Can Don	72	86	1,200	2004
Dai Ninh	300	440	1,470	2004
H'Chan	12	12.27	1,020	2005
H'mun	16	N/A	N/A	N/A
Ea Krong-Ron	34	N/A	N/A	N/A
Binh Dien	65	N/A	N/A	N/A
Rao Quan	74	140	1,890	2005
Thuong (Upper) Kontum	210	276	1,310	N/A
Se San 3	260	320	1,230	2007
Pleikrong	120	256	2,130	2007
Se San 3A	96	124	1,290	2007
Ba Ha River Hydro Plant	260	311	1,200	N/A
Tuyen Quang	342	500	1,460	N/A
Dai Thi	250	518	2,070	N/A
Son La	3,600	5,435	1,500	2016
Total	~ 6,900		~ 1,400	

Figure 4.5 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 4.10 as a function of cumulative installed capacity.

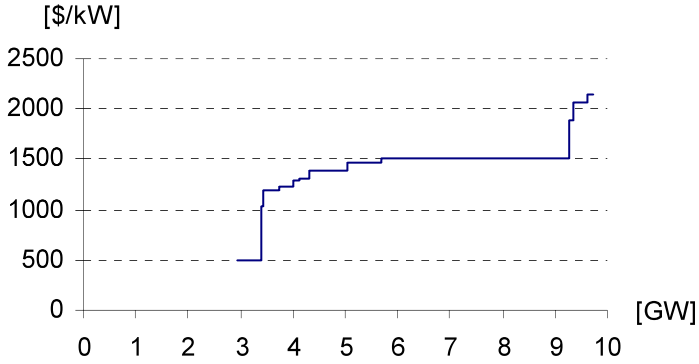

Figure 4.5 *Specific investment cost of hydropower in Vietnam vis-à-vis cumulative capacity*

Finally, mini-hydro systems are installed to supply electricity in the more remote parts of Vietnam.

5. CENTRAL AND SOUTH AMERICA

5.1 Introduction

The total hydropower potential of Latin America is estimated at 594 GW (Internet source 197). Hydropower is relatively important for Central and South America, and many countries rely heavily on hydropower for their electricity supply. Hydropower makes up 80% of Brazil's electricity generation. Paraguay generates virtually all of its electricity from hydropower, Peru and Costa Rica approximately 80%, Venezuela about three quarters, and Chile about 60%.

Hydropower is no longer what it used to be during the golden seventies when the whole region was engaged in a dash for hydro. Most of the best sites have already been developed and new sites face environmental restrictions. It also faces stiffer competition from thermal power than in the past (Internet source 198).

This chapter starts with an overview of hydropower development in South America (Section 5.2), viz. firstly Brazil and secondly other countries of interest of South America. Then, an overview is presented of hydropower development in Central America (Section 5.3).

5.2 South America

5.2.1 Brazil

Endowed with a technical hydropower potential estimated at 255 GW (one of the world's highest), and lacking significant deposits of coal (and, until recently, of oil), Brazil has invested heavily in the planning and building of dams to satisfy the power requirements of a rapidly growing economy (Internet source 199). The technical hydropower potential of Brazil is put at 260 GW, and the exploitable potential at 170 GW or 800 TWh/a. Currently, hydroelectric plants account for 92% of Brazil's 66 GW of generating capacity. The installed hydropower capacity generates about 79% of Brazil's electricity.

Together with Paraguay, Brazil maintains the world's largest operational hydroelectric complex, the Itaipu facility on the Paraná River, with a capacity of 12,600 MW. So far, about 40 percent of Brazil's exploitable hydropower potential have been harnessed (Internet source 200, 201).

The Amazon is the world's second longest river (6,770 km). The river is extremely wide for most of its length, so the potential dam sites are located in its tributaries. These are also very large rivers, such as the Tocantins River (Internet source 202).

In 1998, the 140 MW Guilman-Amorin hydroelectric plant on the Piracicaba River was commissioned. The construction cost was $ 148 mln (Internet source 203).

In 1999, the 1,240 MW Salto Caxias dam - dam height 67 m, annual generation 5.431 TWh, project cost $ 1 billion - on the Iguaçu River was completed. It fulfils 30% of the electricity demand of the State of Paraná (Internet source 204). In 2000, the 1,450 MW Itá hydroelectric power plant on the Uruguai River between the States of Rio Grande do Sul and Santa Catarina was commissioned. Its construction cost was $ 1.4 billion (Internet source 205).

In 2001, the 112 MW Porto Estrela hydropower plant (construction cost $ 50 mln) on the Santo Antonio River began operating. Also in 2001, the 850 MW Lajeado hydroelectric plant (construction cost $ 900 mln) on the Tocantins River became operational.

The 1,140 MW Machadinho hydro plant - construction cost $ 514 mln - on the Uruguai River was completed (Internet source 206). Also in 2002, Itiquira I & II - 156 MW, construction cost $ 146 mln - on the Itiquira River (Internet source 207), and the Cana-Brava run-of-the-river plant - 468 MW, dam height 51 m, construction cost $ 426 mln - on the Tocantins River were commissioned in 2002 (International Power Generation, 2002; Internet source 208).

The 450 MW Itapebi Hydroelectric Plant (construction cost $ 325 mln) on the Jequitinhonha River was to be commissioned in January 2003 (Internet source 209), and the 180 MW Funil hydro plant (construction cost $ 96.5 mln) in March 2003 (Internet source 210, 211).

The 170 MW Pedra do Cavalo hydro plant (construction cost $ 164.6 mln), located on the Paraguacú River in the State of Bahia, is under construction. It will be commissioned in the second half of 2004 (International Power Generation, 2002; Internet source 212).

The 452 MW Peixe Angical hydroelectric plant - construction cost R$ 1 billion ≈ $ 370 mln - is due to become operational in 2005 (Internet source 213, 214). Cemig of Brazil will invest $ 553.5 mln in five hydropower projects - aggregate capacity 1,268 MW - that will become operational in 2005 (Minas Gerais State) (Internet source 215).

The 4,275 MW Tucuruí hydroelectric dam will be upgraded by adding 11 375 MW turbines - investment cost $ 1.508 billion - and thereby increasing the capacity to 8,370 MW in 2005 (installing additional turbines and generators may be rather profitable) (Internet source 216, 217).

The Eletrobrás Ten Year Expansion Plan 1999/2008 calls for the 1,328 MW, $ 1.288 billion, Serra Quebrada power station on the Toncantins River to come on stream in 2006 (Internet source 218).

In 2000, the government announced plans to auction off concession licenses for 11 new large hydro projects, to be constructed in the States Rio Grande do Sul, Minas Gerais, and Rio de Janeiro. Their combined capacity is estimated at 1,396 MW, and they are expected to bring electricity to 8.6 million people. The construction cost is estimated at close to $ 4.1 billion, and they are scheduled for completion by 2004. In 2001, licenses were awarded for 11 additional hydro projects, which are expected to add 2,700 MW of capacity by 2007 (Internet source 219).

In July 2002, Brazil’s national energy regulator, Aneel, tendered concessions to build and operate eight hydroelectric plants in five States - Goias, Minas Gerais, Mato Grosso do Sul, Tocantins, and Maranhao - adding a total of 1,584 MW to Brazil's electricity production capacity. Investment in the projects is expected to total $ 1.5 billion. Three of the plants will be in operation by 2006 while the rest will be operating by 2007 (Internet source 220). At the end of December 2002, Aneel signed contracts for six hydroelectric projects with an aggregate capacity of 437 MW and projected construction cost of $ 536 mln (Internet source 221).

One of the world’s largest hydropower complexes under construction - scheduled to begin producing power in 2008 - is Belo Monte in the State of Pará, with a capacity of 11,182 MW and annual generation of 41.2 TWh. A pair of canals about a quarter-mile wide and seven and a half miles long is to be built to connect two sections of the Xingú River in what is called ‘the largest excavation project since the Panama Canal’. Belo Monte is budgeted at $ 6.6 billion - $ 3.9 billion for construction of the hydropower complex, and $ 2.7 billion to string transmission lines to industrial cities in the south, which will be main consumers (Internet source 222).

The aforementioned hydropower projects in Brazil are summarised in Table 5.1.

Table 5.1 *Selected hydropower projects completed, under construction, or planned in Brazil*

Project	State/River	Capacity [MW]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Guilman Amorin	Piracicaba River	140	148	1,060	1998
Salto Caxias	Iguaçu River	1,240	1,000	800	1999
Itá	Rio Grande do Sul	1,450	1,400	970	2000
Porto Estrela	Santo Antonio River	112	50	450	2001
Lajeado	Tocantins	850	900	1,060	2001
Machadinho	Uruguai River	1,140	514	450	2002
Itiquira	Mato Grasso	156	146	940	2002
Cana Brava	Goiás	468	426	910	2002
Itapebi	Bahia	450	325	720	2003
Funil	Minas Gerais	180	96.5	540	2003
Pedra do Cavalo	Bahia	170	164.6	970	2004
Peixe Angical	Tocantins	452	370	820	2005
Queimado, Aimorés, Irapé, Capim Branco I&II, Pai Joaquim	Minas Gerais	1,268	553.5	440	2005
Tucuruí (upgrading)	Pará	4,095	1,500	320	2005
Serra Quebrada	Tocantins	1,328	1,288	970	2006
6 hydropower plants	Mato Grasso do Sul, Goiás	437	536	1,230	N/A
11 hydropower plants	Minas Gerais, Rio Grande do Sul, Rio de Janeiro	1,396	4,100	2,940	2004
8 hydropower plants	Minas Gerais, Goiás, Mato Grosso do Sul, Tocantins, Maranhao	1,584	1,500	950	2005-2006
11 hydropower plants	N/A	2,700	N/A	N/A	2007
Belo Monte	Pará	11,182	6,600	590	2008
Total		~ 30,800		~ 840[1]	

[1] Exclusive of upgrading of Tucuruí.

The Belo Monte location is considered to be one of the world's most rational hydroelectric opportunities. In order to generate the amount of electricity mentioned above - 41.2 TWh/a - an area of 400 km^2 will be flooded (Internet source 223, 224, 225), half of which is the bed of the river itself. That is equal to over 28 MW/km^2 flooded area for Belo Monte, against 9.3 MW/km^2 in case of Itaipu (Internet source 226), 2.9 MW/km^2 in case of Tucuruí (Internet source 227), and as low as 0.1 MW/km^2 in case of Balbina on the Rio Uatumã (Internet source 228, 229).

Table 5.2 shows characteristics of the aforementioned hydropower projects.

Table 5.2 *Flooded area of reservoirs of four hydroelectric power stations in Brazil*

Project	Year of completion	Capacity [MW]	Generation [TWh/a]	Flooded area [km^2]	Capacity per unit of flooded area [MW/km^2]
Itaipu	1991	12,600	93.4	1,350	9.3
Tucuruí	2005	8,370	N/A	2,850	2.9
Balbina	1990	250	N/A	2,360	0.1
Belo Monte	2008	11,182	41.2	400	28.0

An issue of controversy concerning hydropower plants such as Tucuruí and Balbina is the emission of greenhouse gases. The gradual decomposition of the forest flooded by the reservoir produces methane, although how methane is released into the atmosphere is still a matter of conjecture (Internet source 230, 231). The Balbina dam has a very low ratio of installed capacity to flooded area. Critics of this project regard it as an example of improper planning and construction (Internet source 232). The World Commission on Dams noted in this respect that 'there is no justification for claiming that hydroelectricity does not contribute significantly to global warming' (Internet source 233).

Figure 5.1 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 5.1 as a function of cumulative installed capacity.

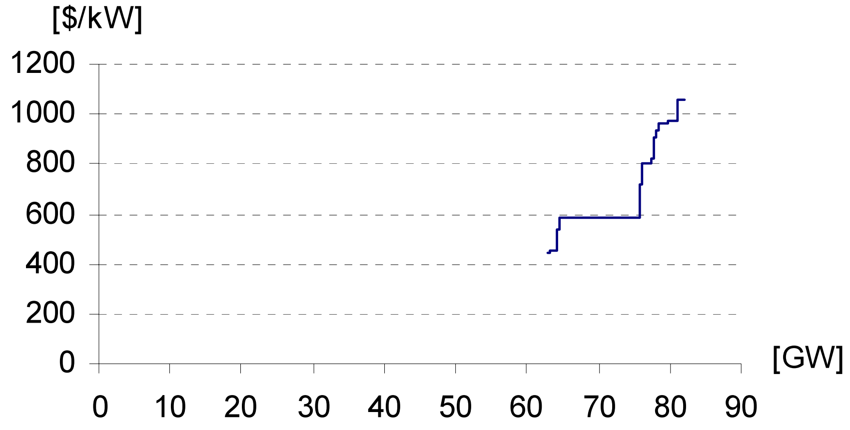

Figure 5.1 *Specific investment cost of hydropower in Brazil vis-à-vis cumulative capacity*

In 1998, Brazil started the National Program for Energy Development of States (PRODEEM), including SHP, in an effort to install 20 GW of renewable capacity. Small-scale hydro (since 1998 defined as plants with a capacity of 1-30 MW) has a technically exploitable potential of 25 TWh/a, nearly 30% of which had been exploited at end-1999. The 1,500 MW of small-scale hydro currently in place will be augmented by an additional 1,000 MW, which is under construction or planned. A good proof of the 'SHP fever' is a study for the northeastern States, except Maranhão, revealing that 54 SHPs on the 15 rivers of interest can be implemented, with an aggregate capacity of 174 MW (Internet source 234).

5.2.2 Argentina

Argentina's gross theoretical hydropower potential is 172 TWh/a and its technically feasible potential is 130 TWh/a, of which about 23 percent have been harnessed. The installed hydro capacity is approximately 9,600 MW (41 percent of the total generating capacity) (Internet source 235, 236).

The hydropower capacity of Argentina is mainly based on a 50% share in two bi-national schemes. One is the 1,890 MW Salto Grande hydroelectric dam - dam height 47 m, annual generation 6.64 TWh (Internet source 237) - shared with Uruguay. The other is the 3,100 MW Yacyretá hydropower plant - currently operating at a reduced head, capacity restricted to 1,800 MW - that was completed in 1998 and shared with Paraguay.

The total amount of hydro capacity under construction at the end of 1999 was 960 MW, with a further 216 MW in the planning stage.

Argentina and Paraguay are planning to build another hydroelectric dam on the Paraná River, the 3,000 MW, $ 3.1 billion, Corpus Cristi dam. In May 2000, Argentina and Paraguay signed a working agreement concerning Corpus Cristi. The agreement calls for constructing the dam through international public bidding, and assures that the project's construction will be environmentally sound. There has been considerable opposition to the project among the local community and among environmentalists. Because of its location between two existing dams, Corpus Cristi would turn the upper section of the Paraná River into a 'staircase' of dams without free-flowing sections (Internet source 238).

5.2.3 Bolivia

Bolivia's technically feasible hydro potential being has been assessed at 39,800 MW or 126 TWh/a, according to Bolivia's Vice Ministry of Energy and Hydrocarbons (Internet source 239). About 50 TWh/a is considered to be economically exploitable. Only a minute proportion of the potential has been harnessed so far - 355 MW (32 percent of the total generating capacity of Bolivia) (Internet source 240).

In May 1999, the 7.4 MW Kanata hydroelectric plant entered service. It generates 22.3 GWh of electricity and produces 8 million m^3 of potable water per year for the City of Cochabamba. The investment cost of the Kanata project was $ 6.1 mln (Internet source 241).

In July 2000, the US Initiative on Joint Implementation (USIJI) approved construction on the Taquesi hydropower project in Bolivia. The project will consist of two run-of-the-river plants with a combined capacity of 83.5 MW and the rehabilitation of an existing 850 MW project on the Taquesi and Unduavi Rivers. The investment cost of the two run-of-the-river plants was $ 68.7 mln. They were commissioned in 2001 (Internet source 242).

5.2.4 Chile

Chile has a technically exploitable hydro potential of about 162 TWh/a, about 12% of which has so far been exploited. Hydroelectricity accounts for some 60% of the electricity consumed in Chile in a typical year. The 1999 drought, a scarcity of water rights near major consumption centres, and environmental opposition to hydropower projects have been factors in the push for diversification (Internet source 243).

The largest hydro scheme currently in hand is the 570 MW Ralco hydroelectric dam - dam height 503 feet (153 m), construction cost $ 568 mln. Ralco is the second of six dams planned for the Biobío River. Originally scheduled for completion in 2002 and now in 2004, Ralco will add 18 percent to the capacity of Chile's central electricity grid (Internet source 244).

5.2.5 Colombia

Colombia's theoretical hydropower potential is estimated to be in the order of 1,000 TWh/a, of which approximately 200 TWh/a is classed as technically feasible. The economically exploitable capability has been evaluated as 140 TWh/a. In 1999, hydro output represented about 25% of the economically feasible potential, and accounted for around 70% of Colombia's electricity generation (Internet source 245).

The 340 MW Urrá I Multipurpose Project is a controversial hydroelectric project on the Sinú River. The principal work on the project began in 1992 and was finished in mid-1998. Urrá I is designed to produce 1.42 TWh/a (Internet source 246, 247). Another large hydro scheme that was recently completed is the 392 MW Porce II hydroelectric plant (Internet source 248).

In 2002, the 375 MW Miel I hydroelectric plant - dam height 617 feet (188 m), construction cost $ 600 mln - started generating power. Although the installed generating capacity of Colombia (around 14,000 MW) considerably exceeds demand in a normal year, there are nevertheless concerns that a drought induced by the El Niño weather phenomenon could adversely influence levels of power supply in the hydro-dependent generation sector (Internet source 249).

5.2.6 Guyana

In 2001, the Government of Guyana and Enman Services of Trinidad and Tobago reached agreement in principle on the construction and operation of a new hydropower station on the Turtruba Rapids along Mazaruni River. The 1,100 MW, $ 2.2 billion, hydropower station will supply electricity for a planned aluminium production plant and export power to neighbouring Brazil. Enman has a two-year period of exclusivity to evaluate the technical, financial, economic, social, and environmental potential of developing the project (Internet source 250).

5.2.7 Paraguay

The gross theoretical hydropower potential of Paraguay is 111 TWh/a, roughly half of which is deemed to be economically exploitable. Paraguay participates in two bi-national hydroelectric schemes, viz. the huge 12,600 MW Itaipu facility on the Paraná River, shared with Brazil, and the 3,100 MW Yacyretá hydropower plant, shared with Argentina (Internet source 251).

The share of 6,300 MW from Itaipu is far in excess of the present and foreseeable needs of Paraguay. In 2001, Paraguay's electricity demand reached 1,145 MW. Consequently, the greater part of the output from Itaipu accruing to Paraguay is sold back to Brazil (Internet source 252).

5.2.8 Peru

Peru has an economically exploitable hydropower potential of 260 TWh/a. Currently, less than 10 percent of this potential has been harnessed (Internet source 253). The installed hydropower capacity amounted to approximately 2,670 MW in 2000, generating approximately 81 percent of Peru’s electricity.

In November 2000, the hydropower complex known as ‘Chinango’ - the 149 MW Chimay and 42 MW Yanango plants - became fully operational. It cost $ 200 mln to complete and marks the single largest private-sector investment for 30 years (Internet source 254).

In 2001, the Peruvian government signed the concession for the construction of the Cheves hydroelectric project on the Huaura River. This 525 MW hydropower plant with an estimated construction cost of $ 560 mln is slated to start operations by 2005 (Internet source 255, 256).

Construction has started on the Huanza Hydroelectric Project, a 90.6 MW run-of-the-river facility on the Pallca River. This project contributes to the goals of the Peruvian Government to accomplish a 90% electrification rate for the country by the year 2010. The construction cost is estimated at $ 100 mln, and completion is scheduled for 2005 (Internet source 257, 258).

Small-scale hydropower also has potential within Peru. The Ministry of Energy and Mines is finishing small-scale hydroelectric power projects in the 1-1.5 MW range and constructing new small hydroelectric power plants in the 500-2,000 kW range (Internet source 259).

5.2.9 Venezuela

In 2001, hydroelectric plants comprised about 65% of Venezuela’s 20,316 MW of installed capacity (Internet source 260). In 2000, Venezuela generated 80.8 TWh, 77% of which was hydropower. Venezuela is home to the world’s second largest operational hydroelectric dam (after Itaipu in Paraguay/Brazil), the 10,055 MW Guri Dam/Raul Leoni hydroelectric facility on the Caroní River (Internet source 261).

Started in 1997, construction on the 2,256 MW Caruachi hydroelectric plant - dam height 55 m, estimated investment cost $ 2.1 billion - is expected to be completed in 2006. Caruachi, on the

Caroní River near the confluence of the Caroní and Oronoco Rivers in the southeastern Bolivar State, is expected to generate power first in 2003 (Internet source 262, 263, 264).

In addition, CVG, the holding company for Venezuela's state-owned hydroelectric generator Edelca, has given the go-ahead for the construction of the 2,160 MW Tocoma hydroelectric project on the Caroní River. The project will require a total investment of some $ 1.8 billion. Tocoma has an estimated completion date of 2010.

5.2.10 Summary of South America exclusive of Brazil

Table 5.3 presents a selection of hydropower projects in the aforementioned South American countries other than Brazil.

Table 5.3 *Selection of hydropower plants in several stages in South America (except Brazil)*

Project	Country	Capacity [MW]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Corpus Christi	Argentina	3,000	3,100	1030	N/A
Kanata	Bolivia	7.4	6.1	830	1999
Taquesi	Bolivia	83.5	68.7	820	2001
Ralco	Chile	570	568	1,000	2004
Urrá I	Colombia	340	N/A	N/A	2000
Porce II	Colombia	392	N/A	N/A	2001
Miel I	Colombia	375	600	1,600	2002
Turtruba Rapids	Guyana	1,100	2,200	2,000	N/A
Chimay	Peru	149	200	1,050	2000
Yanango	Peru	42			2000
Cheves	Peru	525	560	1,070	2005
Huanza	Peru	90.6	100	1,100	2005
Caruachi	Venezuela	2,256	2,100	930	2006
Tocoma	Venezuela	2,160	1,800	780	2010
Total		~ 11,000		~ 1,100	

Figure 5.2 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 5.2 as a function of cumulative installed capacity.

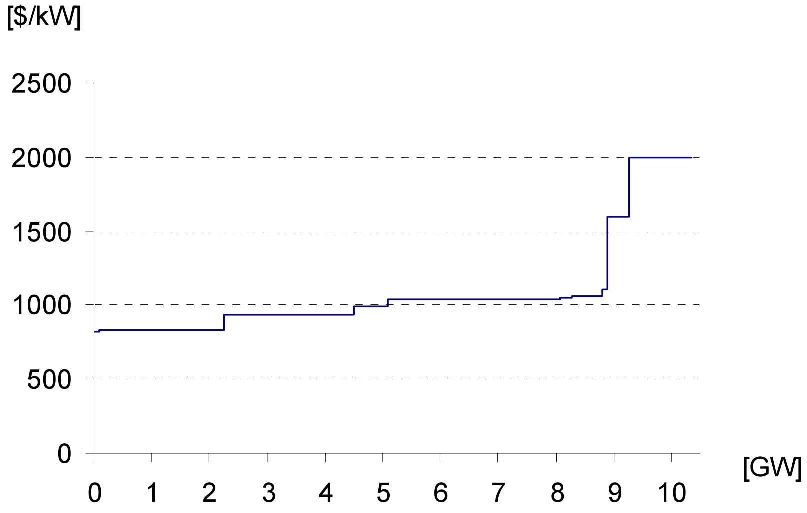

Figure 5.2 *Specific investment cost of hydropower in South America (other than Brazil) vis-à-vis cumulative capacity*

5.3 Central America

5.3.1 Introduction

All Central American countries except Nicaragua have a high share of hydropower in electricity generation (Figure 5.3). Special problems in this area are dry seasons with almost no precipitation from November to May, very high rain falls in August to October and annual fluctuations of available water in the ratio of one in a dry year to two in wet year. This volatility is partly mastered by large storage reservoirs.

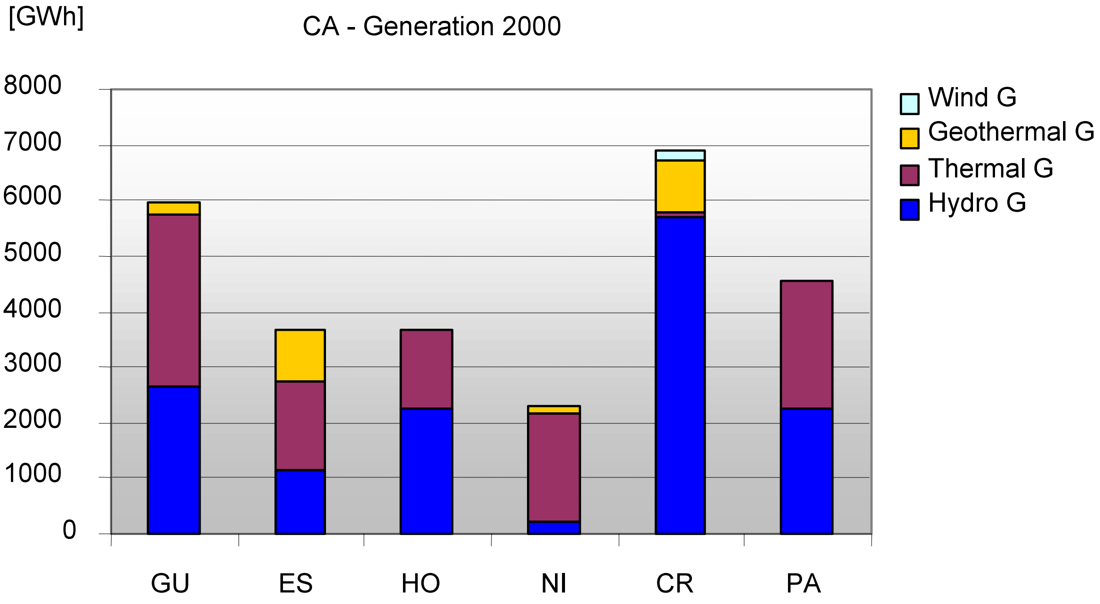

Figure 5.3 *Power generation in Central America by technology type*[8] (UN CEPAL, 2001)

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[8] CR = Costa Rica, ES = El Salvador, GU = Guatemala, HO = Honduras, NI = Nicaragua, PA = Panama.

In the absence of domestic energy resources other than wind and geothermal energy, and with all fossil fuels to be imported from overseas, hydropower provides an economic option for further power expansion. This is reflected by the large number of hydropower projects, which are expected to be implemented in the next ten years (Table 5.4).

5.3.2 Costa Rica

Costa Rica has a large hydropower potential: the gross theoretical hydro potential is estimated at 223 TWh/year, and the economically feasible potential at 4,171 MW, about one-third of which has been harnessed so far (Internet source 265, 266). The installed hydro capacity is 1,391 MW, equivalent to 84 percent of Costa Rica's generating capacity.

Peñas Blancas (33 MW) is under construction (completion in 2003), and Pirris (128 MW) and Guayabo (234 MW) are at the design stage, with completion envisaged for 2008 and 2014, respectively.

5.3.3 Guatemala

The installed hydropower capacity of Guatemala is 417 MW (1998). In 2000, it accounted for 45 percent of the national electricity generation.

In 2000, Hidroeléctrica Papeles Elaborados S.A (HPE) commissioned an 8.2 MW hydropower plant (42 GWh/a) (Internet source 267). The total project investment was $ 12.4 million[9].

The US Hydropower Council and Alaska Power & Telephone, the latter by its subsidiaries Hydrowest International and Hydrowest de Guatemala, have been engaged in development of small hydropower in Costa Rica. In 2002, two small hydropower plants were commissioned: the 12.6 MW Pasbien (annual generation 61 GWh) and the 32 MW Rio Hondo II hydropower plant (annual generation 131 GWh) (Internet source 268, 269).

5.3.4 Summary of Central America

Table 5.4 presents an overview of hydropower projects in Central America.

Table 5.4 *(Candidate) hydropower projects in Central America*

Name of project	Country	Installed capacity [MW]	Investment cost [million $]	Specific investment cost [$/kW]	Reservoir volume [million m^3]	Envisaged year of commissioning
Canjilones	Panama	120	96.6	805	-	2004
Gualaca	Panama	28	51.2	1,829	-	2006
Los Aniles	Panama	35	72.6	2,074	-	2006
Baru	Panama	150	380.7	2,538	137	2007
Chiriqui	Panama	54	101.3	1,876	-	2006
Changuinola75	Panama	158	198.7	1,258	-	2007
Changuinola140	Panama	132	174.5	1,322	-	2009
Changuinola 220	Panama	126	236.6	1,878	473	2010
Santa Maria	Panama	31	43.9	1,416	122	2011
Pando	Panama	29	61.5	2,121	-	2012
Mt Lirio	Panama	49	102.1	2,084	-	2012
Pirris	Costa Rica	128	222.9	1,741	99	2008
Guayabo	Costa Rica	234	326.5	1,395	-	2014

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[9] Power plant and equipment $ 3.7 million, infrastructure and construction $ 6.8 million, studies, administration, legal, and engineering $ 0.8 million.

Table 5.4 *Continued*

Name of project	Country	Installed capacity [MW]	Investment cost [million $]	Specific investment cost [$/kW]	Reservoir volume [million m^3]	Envisaged year of commissioning
Cariblanco	Costa Rica	75	106.2	1,416	-	2007
Losllanos	Costa Rica	84	137.4	1,636	-	2014
Pacuare	Costa Rica	159	295.7	1,860	285	2010
Siquirres 1	Costa Rica	206	685.1	3,326	-	2016
Boruca 200	Costa Rica	832	921.4	1,107	5,430	2012
Bot_Gener_CR	Costa Rica	39	63.4	1,626	-	2004
Bot_Joya_CR	Costa Rica	50	81.7	1,634	-	2005
Toro3	Costa Rica	50	82.1	1,642	-	2008
Larreynaga	Nicaragua	17	45.1	2,653	-	2006
El Carmen	Nicaragua	60	172.3	2,872	1,220	2007
Copalar	Nicaragua	150	268.9	1,793	1,746	2006
Cangrejal	Honduras	50	85.9	1,718	-	2005
Patuca_2	Honduras	270	341.4	1,264	3,899	2007
Patuca_3	Honduras	161	275.2	1,709	4,123	2010
Los Llanitos	Honduras	94	230.0	2,447	693	2006
Aguareina	Honduras	52	199.5	3,837	-	2011
Nacaome	Honduras	30	45.0	1,500	-	2003
Cimarron	El Salvador	243	429.9	1,769	665	2010
Chaparral	El Salvador	60	94.9	1,582	-	2009
Santiaguito	Guatemala	40	50.4	1,260	-	2003
Las Vacas I	Guatemala	20	N/A	N/A	-	2002
Xalala	Guatemala	330	536.0	1,624	663	2011
Santa Tereza	Guatemala	20	N/A	N/A	-	2004
Las Vacas II	Guatemala	20	N/A	N/A	-	2003
San Judas	Guatemala	30	48.8	1,627	-	2004
Total		4,416		~ 1,650		

Figure 5.4 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 5.4 as a function of cumulative installed capacity.

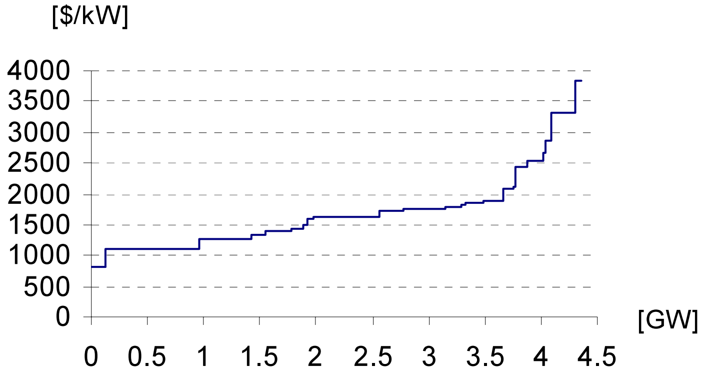

Figure 5.4 *Specific investment cost of hydropower in Central America vis-à-vis cumulative capacity*

6. AFRICA

6.1 Introduction

In Africa, hydropower and other renewable energy sources have not been widely established, except in a few countries. Egypt and Congo (Kinshasa) have the largest volumes of hydro capacity. Ivory Coast, Kenya, and Zimbabwe are almost entirely dependent on hydropower.

The electrification level in Africa is generally lower than in other world regions. Even in Namibia, with Africa's third highest electrification level, only some 20% of the people have access to electricity. In Uganda, this is merely 3 percent.

In Section 6.2 hydropower developments in most of the countries of Africa are briefly described. Section 6.3 presents an overview of selected hydropower projects in Africa.

6.2 Development of hydropower in countries of Africa

6.2.1 Congo DCR

The assessed hydropower potential of the Democratic Republic of Congo (DRC) is by far the largest in Africa and one of the largest in the world. The gross theoretical potential is almost 1,400 TWh/a, about 55% of which are regarded as technically feasible. The installed hydropower capacity is 2,400 MW, and the hydroelectric output is less than 1% of the technically feasible potential (Internet source 270).

There are plans to harness the hydropower potential of the Congo River. This would entail a giant hydroelectric project, called Grand Inga, with a potential capacity of 39,000 MW. Such a hydropower capacity would far exceed the electricity demand of Congo. Therefore, development of the transmission infrastructure goes hand in hand with the development of the generation infrastructure. The capacity of the existing Inga 1 & 2 is 775 MW. When Inga 3 comes on line by 2010 it is expected to have a capacity of 3,500 MW (Internet source 271, 272).

6.2.2 Ethiopia and Eritrea

Ethiopia, including Eritrea, has vast hydropower potential, the second largest of Africa. The country's gross theoretical hydro potential has been calculated as 650 TWh/a, and the technically feasible potential is estimated at more than 250 TWh/a. The economically feasible potential would be 159.3 TWh/a (Internet source 273).

The current hydropower capacity is 450 MW, generating approximately 2.0 TWh/a (90 percent of Ethiopia's electricity). Therefore, a minor fraction of the economically feasible potential has been developed so far (Internet source 274, 275).

In 2001, Tis Abbay II - 73.6 MW, annual generation 359 GWh - was put in service (Internet source 276, 277). Eight new hydropower plants with a capability of generating 10.66 TWh/a are in the construction or planning stage. Three hydropower plants are under construction:

- Gilgel Gibe - 84 MW, annual generation 864 GWh, completion 2003, construction cost $ 300 mln, completed in 2003 (Internet source 278, 279).
- Tekezze - 300 MW, dam height 185 m, 981 annual generation GWh, construction cost $ 224 mln (Internet source 280, 281, 282).

- Gojeb - 150 MW, dam height 130 m, annual generation 364 GWh. The design modifications and upgraded tender documents were completed in 2002 (Internet source 283).

There are a few small, mini and micro hydro plants in operation, and numerous potential sites. About 10 percent of the economically feasible potential are thought to be suitable for small-scale developments.

6.2.3 Ghana

There are 17 potential hydro sites in Ghana, of which only Akosombo (912 MW) and Kpong (160 MW) have been developed so far (Internet source 284). They generate approximately 80 percent of the electricity in Ghana (Internet source 285). The average annual output of the two existing hydro stations (~ 6 TWh) is equivalent to about 50% of Ghana's technically exploitable hydro capability.

The 400 MW Bui dam on the Black Volta River is at a preparatory stage (Internet source 286). It meets a lot of opposition from environmental organisations.

6.2.4 Kenya

The 60 MW Sondu-Miriu hydroelectric project - average annual generation 331 GWh - is the first major hydropower project in Kenya's Nyanza Province alongside Lake Victoria. Construction work started in 1999. The $ 52 mln project is due for completion by the end of 2005 (Internet source 287). However, Japan that is financing construction the project has frozen funds for the second time in two years over poor accountability (International Power Generation, 2002).

6.2.5 Malawi

In September 2000, the first of two units of the 128 MW, $ 130 mln, Kapichira Hydroelectric Plant was connected to the grid. By 2003, a further 64 MW will be added to the grid when Kapichira is completed (Internet source 288).

6.2.6 Mozambique

Mozambique has a hydropower potential of some 12,000 MW. By far the largest hydropower scheme in Mozambique is the 2,075 MW Cahora Bassa hydropower station on the Zambezi. The Cahora Bassa hydropower plant generates 12.75 TWh/a and was commissioned in 1975. The major part of electricity generated is transmitted to the South African grid via two 530 kV DC transmission lines. Other buyers are Mozambique and Zimbabwe. Currently, there are around 3.7 million households in Mozambique - and only 200,000 of these are linked to the electricity grid.

The Mozambican government decided in the late 1990s to embark on a comprehensive and up-to-date feasibility study that could eventually be used as a bankable document for the implementation of a new hydropower station: the 1,200 MW Mepanda Uncua project. The recommendation of developing the new dam at Mepanda Uncua is justified by technical, financial and environmental considerations, in particular the necessity of river re-regulation (Internet source 289). Mepanda Uncua - downstream from the existing Cahora Bassa dam on the Zambezi River - is moving forward, and will cost an estimated $ 2 billion (Internet source 290, 291)

6.2.7 Namibia

In April 2000, Angola and Namibia signed a bilateral co-operation agreement in the field of energy. Angola has a small hydropower capacity of 300 MW. Only about 15% of Angola's population are supposed to have access to electricity supply. The installed hydropower capacity of Namibia is 240 MW. Namibia has Africa's third highest electrification level at 20 %. However, only 4% of Namibia's rural households are connected to the electricity grid (Internet source 292).

The two countries are considering the development of a hydroelectric facility on the Kunene River that will provide power to the Angolan, Namibian and South African grids. The proposed facility would have a generating capacity of 360 MW. Two possible sites for the dam are Baynes and Epupa. A feasibility study has established price tags for the two options, viz. \$ 554 mln for the Baynes site and \$ 543 mln for Epupa. Within a large grouping of international hydropower projects, the Baynes site is positioned very favourable (Internet source 293).

The construction of the dam on the Kunene River will however depend on the consent from the Angolan government that still opposes the project due to environmental concerns (Internet source 294).

6.2.8 Senegal

The 200 MW Manantali hydroelectric dam - construction cost \$ 267 mln - on the Senegal River has been in the pipeline for many years as part of the larger Senegal River valley development program. The project is expected to start generating power in 2003. Senegal will receive approximately 67 MW and the balance will go to Mali and Mauritania (Internet source 295, 296).

Damming of large rivers, whether for hydropower or irrigation projects, has major impacts on downstream floodplains. After the building of the Manantali dam, up to 800,000 people lost access to floodplains that had provided most or part of their means of survival (Internet source 297).

6.2.9 Sudan

In Sudan, two hydropower projects are under construction or planned. The 300 MW Kajbar Dam - co-financed by the governments of China (75%) and Sudan (25%) - has been under construction since late 1998. China has so far spent \$ 200 mln on the project (Internet source 298)

The 1,250 MW Merowe Dam will provide electricity to energy hungry Sudan and cut flooding. The total investment cost is estimated at \$ 1.73 billion, \$ 700 mln of which is related to the turbines and generators, and \$ 375 mln to resettlement (affecting about 50,000 people) and environmental costs. The dam is due for completion by 2009 (Internet source 299, 300).

6.2.10 Tanzania

The 180 MW Lower Kihansi run-of-the-river plant is located in southwestern Tanzania (on Kihansi River, a tributary of Rufiji River). Implementation of the Lower Kihansi hydropower plant started in June 1994 and the power station was officially commissioned in 2000. The total cost of the project was \$ 275 mln (Internet source 301, 302, 303).

6.2.11 Uganda

The installed hydropower capacity of Uganda is around 380 MW. About 97% of Uganda's population do not have access to electricity. The 250 MW Bujagali hydroelectric dam is one of a number of hydroelectric power plants along the upper reaches of the Nile. Construction of the dam was due to start in 2002, and was to be finished by 2005. The contractors of the project will give a binding price - estimated at $ 530 million - for a complete and fully tested power plant at the start of the project (International Power Generation, 2002; Internet source 304).

6.2.12 Zambia

The hydropower potential of Zambia is estimated at 6,000 MW. The current installed hydropower capacity is 1,715 MW (Internet source 305).

The Zambezi River and its tributaries have been exploited for their hydro potential by four countries, viz. Malawi, Mozambique, Zambia and Zimbabwe. There are no existing hydropower plants found in the Angolan, Botswana or Namibian part of the Zambezi Basin. The estimated hydropower potential of the river is 20,000 MW. Close to half of the mapped potential is in Mozambique, about 25 percent in Zambia, and 20 percent in Zimbabwe. A little more than five percent of the potential is divided between Angola, Malawi, and Tanzania (Internet source 306, 307, 308).

On the Zambezi River, 4,684 MW - equivalent to 32.8 TWh/a - has been developed so far:

- Malawi about five percent (~ 234 MW).
- Mozambique about 45 percent (~ 2,075 MW).
- Zambia about 36 percent (~ 1,715 MW).
- Zimbabwe about 14 percent (~ 660 MW).

A total of 42 potential hydro sites in the Zambezi Basin, equivalent to 12,892 MW, occur in Angola, Malawi, Mozambique, Zambia and Zimbabwe:

- Nine in Angola.
- Seven in Malawi.
- 12 in Mozambique. These include Cahora Bassa II, Mepanda Uncua, and Chemba, each of which with a projected installed capacity exceeding 1,600 MW.
- 10 in Zambia. These include Batoka (1,600 MW), Devil's (1,240 MW) and Mupata (1,000 MW) gorges.
- Four in Zimbabwe, also including Batoka, Devil's and Mupata gorges.

Other countries outside the basin may benefit from direct import of electricity from the river's power stations and through the Southern African Power Pool (SAPP) (Internet source 309). SAPP is a regional infrastructure organisation of the Southern African Development Community (SADC). The members of SAPP include the major utilities from 12 SADC countries[10].

In order to forestall a power shortage, two hydroelectric projects are planned:

- The Kafue Gorge Lower Hydroelectric Scheme involves construction of a 600 MW dam and underground power station on the Kafue River, downstream of the existing 900 MW Kafue Gorge Upper power plant. The private sector-led project will cost over $ 600 mln. The Zambian government plans to export the vast majority of the power produced to Zimbabwe, Botswana, and the Democratic Republic of Congo. Construction is currently planned to start in mid 2003 and will take five years.
- The Itezhi-Tezhi Hydroelectric Project and Transmission Line involves the construction of a 120 MW underground power plant at the existing Itezhi-Tezhi Dam, also on the Kafue River. The project will cost $ 100 mln. Construction of High Voltage Transmission Line to

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[10] The SADC includes Angola, Botswana, Congo, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe.

the nearest point of inter-connection to the national grid will require an additional $ 28 mln. The project is due for completion by July 2003 (Internet source 310, 311, 312).

6.2.13 South Africa/Lesotho/Swaziland

South Africa's installed hydropower capacity is approximately 600 MW. South Africa's major power generation company Eskom, imports electricity from the Cahora Bassa Dam in Mozambique. South Africa has plans to build substantial hydroelectric projects. South Africa's Lesotho Highlands Water Project, including six dams on the Senqu River with an estimated investment of $ 8 billion, represents Africa's largest infrastructure project. The project is subject of international criticism: some 30,000 people are to be resettled (Internet source 313, 314).

In April 2002, phase 1 of the Maguga Dam project on the Komati River in Swaziland was inaugurated. In phase 2 hydroelectric generating capacity to the tune of 19 MW will be added. The Maguga Dam is the first of four projected dams intended to harness the Komati River, which flows into Swaziland's northwest sector from South Africa. The dam will provide irrigation water for agricultural schemes, stimulate tourism, and provide power for Swaziland and South Africa. It is also possible to export power through a new 400 kV line as far north as the Democratic Republic of Congo (Internet source 315, 316, 317).

6.3 Summary of hydropower projects in Africa

Table 6.1 presents a selection of hydropower projects in the aforementioned African countries.

Table 6.1 *Selection of hydro projects completed, under construction, or planned in Africa*

Project	Country	Capacity [MW]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Inga 3	Congo	3,500	N/A	N/A	2010
Tis Abbay II	Ethiopia	73.6	N/A	N/A	2001
Gilgel Gibe	Ethiopia	184	300	1,630	2003
Tekezze	Ethiopia	300	224	750	N/A
Gojeb	Ethiopia	150	N/A	N/A	N/A
Bui Dam	Ghana	400	N/A	N/A	N/A
Sondu Miriu	Kenya	60	52	870	2005
Kapichira	Malawi	128	130	1,020	2003
Mepanda Uncua	Mozambique	1,200	2,000	1,670	N/A
Epupa	Namibia/Angola	360	543	1,500	N/A
Manantali	Senegal	200	267	1,340	2003
Merowe Dam	Sudan	1,250	1,730	1,380	2009
Lower Kihansi	Tanzania	180	275	1,530	2000
Bujagali	Uganda	250	530	2,120	2005
Itezhi-Tezhi	Zambia	120	128	1,070	2003
Kafue Gorge	Zambia	600	600	1,000	2008
Maguga Dam	Swaziland	19	N/A	N/A	2005
Total		~ 9,000		~ 1,400	

Figure 6.1 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 6.1 as a function of cumulative installed capacity.

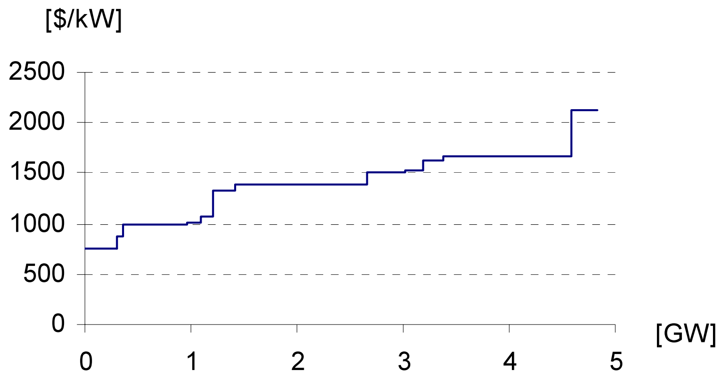

Figure 6.1 *Specific investment cost of hydropower in Africa vis-à-vis cumulative capacity*

7. MIDDLE EAST

7.1 Introduction

Hydropower accounts for 45 percent of Turkey's total installed capacity, and for 7 percent of Iran's installed capacity (2,000 MW out of 30,000 MW). Hydropower will remain an important power generation option in Turkey. The development of hydropower in Turkey is addressed in Section 7.2.

7.2 Turkey

Turkey has a gross theoretical hydropower potential of 433 TWh/a, a technically feasible potential of 216 TWh/a, and an economically feasible potential of 125.3 TWh/a. About 34% of the economically feasible potential have been developed.

The current installed hydropower capacity of 11,643 MW is capable of generating 42,216 GWh in an average year. Hydroelectric power currently accounts for around 40 percent of electricity generated in Turkey. With the completion of the 3,538 MW of capacity under construction in 2001 (capable of generating 11,549 GWh/a), the utilisation of the economically feasible hydropower potential will be raised to 43% (Internet source 318). By 2010, the Government aims to develop 60% of the economically feasible potential, with installed capacity reaching 22 GW. Turkey is expected to develop its full potential by 2025, which would entail a total of 19,175 MW of hydro capacity in addition to the projects currently being built (Internet source 319).

Construction of 102 hydroelectric plants with a generation capability of 40.5 TWh annually is the main part of the investment program of DIS[11] - which owns and operates 85% of the aforementioned hydroelectric capacity of Turkey (Internet source 320).

DSI is realising the ambitious GAP project, one of the largest water resources development projects in the world. The Southeastern Anatolia Project, commonly called GAP (Güneydogu Anadolu Projesi), is a large-scale, multi-sector development project in Southeastern Turkey. Initiated in 1976, GAP is a combination of 13 projects primarily developed for hydroelectric power generation and irrigation. The project involves construction of 22 dams, 14 of which on the Euphrates (Firat) River and 8 on the Tigris (Dicle) River. These dams will facilitate the development and operation of 19 hydroelectric plants with a total capacity of 7,500 MW. At full development, 27.3 TWh will be generated annually. This represents 22% of the economically feasible hydroelectric energy potential of Turkey. Hydroelectric plants in operation in GAP are generating 20 TWh annually. With the hydroelectric plants under construction 7 TWh more will be generated. The overall cost of the project has been set at $ 32 billion (Internet source 321), and the project is due for completion by 2010 (Internet source 322, 323, 324).

GAP will also provide irrigation for 1.693 million hectares of land using an intricate system of canals, siphons, and watercourses to deliver water to Southeastern Turkey. The new irrigation systems will double Turkey's irrigable farmland in a region that has traditionally suffered from light rainfall. New irrigation has already brought about a corresponding boom in agricultural activity. From just one crop per year, in many areas five crops in a two-year cycle have become or will soon be possible (Internet source 325, 326).

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[11] Devlet Su Isleri (DSI), the General Directorate of the State Hydraulic Works, is the primary executive state agency of Turkey for overall water resources planning, managing, execution and operation.

The Atatürk Dam - dam height 604 feet (184 m), annual output 8.1 TWh - is the largest rock-filled dam in Turkey and the sixth largest in the world, situated on the Euphrates in Sanliurfa. The capacity of the hydroelectric dam is 2,400 MW, which is the largest of Turkey and among the 20 largest in the world. Atatürk Dam, which is the foundation of the Southeastern Anatolia Project (GAP), began operation in 1994 and is important not only for energy production but also for irrigation. Water from the reservoirs of Atatürk Dam will be carried to the Harran plain by the Sanliurfa Tunnel System, that is currently built and the largest in the world in terms of length and rate of flow. Atatürk dam will irrigate 882,000 hectares of land (Internet source 327).

The 1,800 MW Karakaya Hydroelectric Power Plant is the second largest hydroelectric power plant in Turkey and among the 30 largest hydroelectric power plants in the world. It is capable of generating 7.4 TWh annually.

The 672 MW Birecik hydroelectric dam - dam height 62.5 m, annual generation 2.5 TWh, construction cost approximately $ 1 billion - on the Euphrates was the first large-scale project in Turkey and at the same time the world's largest hydroelectric power plant built according to the BOT model (Build-Operate-Transfer). Negotiations on Birecik took eight years (Internet source 328). Construction began in April 1996, and the start of operation was in November 2000. Hand-over to the Turkish government is scheduled for 2016. The Birecik dam supplies irrigation for 66,000 hectares of land (Internet source 329, 330). The 515 MW Berke hydroelectric project - annual output 1.669 TWh, construction cost $ 600 mln - on the Ceyhan River was recently commissioned (Internet source 331, 332).

The 184 MW Karkamiş project - dam height 29 m, annual generation 652 GWh/year, construction cost $ 176 mln - is downstream from the Birecik dam on the Euphrates. Work on Karkamiş began in 1996, and the plant was commissioned in December 1999. Karkamiş is one of the smaller dams of the GAP project.

The first phase of the 208 MW Hakkari Dam and Hydroelectric Project - dam height 558 feet (170 m), annual generation 626 GWh - on the Zap River in Southern Anatolia was completed in 2002. The project had an estimated total cost of $ 600 mln (Internet source 333, 334, 335).

The 300 MW Borçka hydroelectric plant - dam height 86 m, annual generation 1.039 TWh/year - is built by a Turkish-Austrian consortium on the Çoruh River. On a distance of 17 km from Borçka, the 115 MW Muratlý hydroelectric plant - dam height 44 m, annual generation 445 GWh - is under construction. Muratlý is the last stage of a hydropower cascade, which comprised a total of 11 hydropower plants on the Çoruh River. Both hydropower plants are built as turnkey projects, and orders for the equipment date from 1999 (Internet source 336).

Another three hydro projects are in the stage of construction or planning (Internet source 337):

- The 121 MW Torul hydroelectric project. Its output is assessed as 322 GWh/a. This project is due for 2005.
- The 462 MW Doğanli Dam & Hydroelectric Power Plant. Its output is estimated at 1.327 TWh/a, and its investment cost at $ 600.6 mln.
- The 245 MW Çukurca Dam & Hydroelectric Power Plant. The purpose of this project is solely electricity generation; annual generation 796 GWh. The investment cost is estimated at $ 290.3 mln.

The 670 MW Deriner hydropower plant - dam height 247 m, annual output 2.118 TWh - is currently under construction and scheduled for completion by 2009.

A major hydropower project under consideration is the 540 MW Yusufeli hydroelectric dam - annual generation 1.705 TWh - on the Çoruh River in Northeast Turkey. It would form part of a wider scheme that includes the associated Artvin dam - to be built later in a second phase - and the aforementioned dams at Borçka and Muratlýi, which form separate projects. The Yusufeli dam would take 7 to 8 years to construct at a cost of $ 844 mln. 30,000 people would be directly or indirectly affected by the Yusufeli dam, and half of them would have to be resettled. UK's AMEC was involved in this project, but after two years (in March 2002) AMEC announced that it would not participate further with the project (Internet source 338, 339, 340).

The proposed Ilisu project - 1,200 MW, dam height 135 m, annual generation 3.833 TWh/a - has been the most controversial project of the GAP scheme (Internet source 341). It would be the largest hydropower project on the Tigris River in the southern part of Turkey (about 60 km upstream from the border with Iraq and Syria). The costs are estimated to be $ 1.52 billion (not including the financing costs) (Internet source 342). According to DSI, approximately 8,100 persons will be directly affected by the Ilisu project (Internet source 343). The Ilisu reservoir will also flood Hasankeyf, a Kurdish town with a population of 5,500, and the only town in Anatolia that has survived since the middle ages without destruction.

Table 7.1 presents the aforementioned hydropower projects in Turkey.

Table 7.1 *Selection of hydro projects completed, under construction or planned in Turkey*

Project	Capacity [MW]	Generation [GWh/a]	Construction cost [million $]	Specific investment cost [$/kW]	Year of completion
Birecik	672	2,500	1000	1,500	2000
Berke	515	1,669	600	1,170	-
Karkamiş	184	652	176	960	1999
Hakkari	208	626	600	2,880	2002
Borçka	300	1,039	N/A	N/A	N/A
Muratlý	115	445	N/A	N/A	N/A
Torul	121.5	322	N/A	N/A	2005
Doğanli	461.6	1,327	600.6	1,300	N/A
Çukurca	244.9	796	290.3	1,190	N/A
Deriner	670	2,118	N/A	N/A	2009
Yusufeli	540	1,705	844	1,560	N/A
Ilisu	1,200	3,833	1,520	1,270	2008
Total	5,232	17,032		~ 1,400	

Figure 7.1 shows the specific investment cost of hydropower projects recently completed, under construction, or planned from Table 7.1 as a function of cumulative installed capacity.

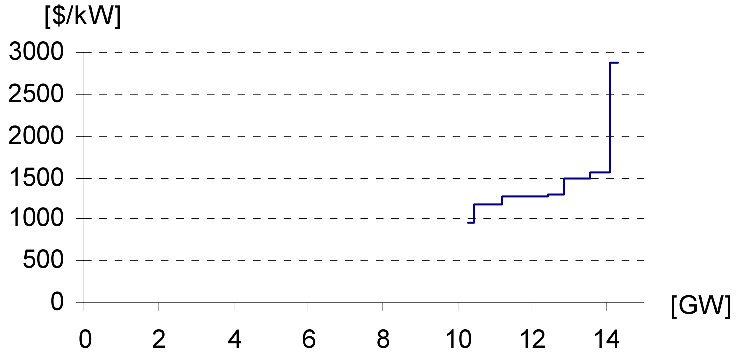

Figure 7.1 *Specific investment cost of hydropower in Turkey vis-à-vis cumulative capacity*

8. EASTERN EUROPE

8.1 Introduction

Eastern European countries are still to a large extent dependent on fossil fuels and nuclear energy for electricity generation. Hydropower is an important energy source in a few countries. Relatively recently, gas-fired power plants (Combined Heat and Power, CHP) were added to the existing generating mix, some of which already is used for co-generation or district heating.

With a few exceptions, development of new hydropower capacity is expected to remain fairly modest. Most of the growth will come from expansion and renovation of existing hydropower plants that need repair after difficult economic years. Still, there are opportunities for expanding hydroelectricity in countries where undeveloped potential sites exist. Most of the data presented in this Chapter is based on (Hydro Power & Dams, 2002) and (Black & Veatch, 2002).

Section 8.2 briefly summarises the hydropower development in so-called EU Accession Countries. Section 8.3 covers the hydropower capacity and potential of two other Eastern European countries, viz. Bulgaria and Romania. Finally, the hydropower capacity and generation as well as the technical potential of the countries of interest are summarised in Section 8.4.

8.2 EU Accession Countries

The EU Accession Countries consist of eight Eastern European countries (see next paragraphs) and Cyprus and Malta. The latter are also considered in order to complete the overview of the EU Accession Countries.

Cyprus and Malta
Only one pilot project for hydroelectric generation has been identified on Cyprus up to now. Cyprus has no rivers, only small torrents. Dams in these torrents are mainly used for collection of drinking water. The pilot project concerns a small plant of 650 kW near one of Cyprus' dams that needs to be refurbished (Poullikkas, 2003). Thus, the potential of hydropower is almost negligible. The technical potential of 23.5 TWh mentioned in (Hydro Power & Dams, 2002) appears to be a mistake.

On Malta too, hydropower does not present a significant renewable energy source.

Czech Republic
At the end of 2001, roughly 1,200 small hydro plants were operational in the Czech Republic. They have an aggregate capacity of 283 MW. This is approximately 30 percent of the total hydropower capacity of 913 MW. The total generating capacity in the Czech Republic amounts to 15,443 MW (Internet source 344).

The current total generation of hydropower plants is about 1.75 TWh/a. The technical hydropower potential is put at 3.4 to 4.0 TWh/a, including approximately 1.6 TWh/a for small hydro. There is no hydropower capacity under construction or planned.

Estonia
The potential of hydropower in Estonia is very small, around 150 - 500 GWh/a. The river with the largest discharge rate is the Narva River, which forms the eastern border with Russia. The operational hydropower capacity is 1.2 MW. A further 3 MW is under construction, while new hydro plants with an aggregate capacity of approximately 10 MW are in the planning stage.

New hydropower plants are mainly plants of several hundreds of kW's. Large hydropower projects are considered not to be feasible for environmental and economic reasons. In Estonia, electricity from hydropower costs about twice as much as power generated by existing plants based on oil shale (Internet source 345). It has to be acknowledged that power plants fired with oil shale produce high emission levels of GHGs and substantial air pollution. The average cost of new hydropower capacity is estimated at € 900 - 1,300/kW (REC Tasen, 2002).

Hungary
Today, hydropower generates less than one percent of Hungary's electricity (Internet source 346) There are three commercial hydropower plants in operation, of 4.4 MW, 28 MW and 11.4 MW (total 44 MW). The annual generation is 200 GWh. The technical potential is considered to be 4.6 TWh/a. Plans were made during the last few years for further hydro construction, but environmentalists have tried to impede these new developments.

Latvia
In 1999, hydropower plants represented nearly 73% of Latvia's total installed generating capacity of 2,1 GW. The generation of hydropower amounting to 3.3 TWh/a accounts for 68% of all power produced in Latvia (Internet source 347). Three plants in cascade in the Daugave River produce most of the hydroelectric power. These plants have recently been modernized and reconditioned having a total capacity of 1,517 MW (Latvenergo, 2003). Furthermore, there are more than 70 small power plants with an aggregate capacity of 65.5 MW. Currently, there are 40 small plants under construction while about 27 are planned. The small hydro potential is considered to be 16.7 GWh/a. The total technical hydro potential is around 4 TWh/a.

Lithuania
Except a large pumped-storage hydropower plant, there is only one relatively large hydropower plant in Lithuania with a capacity of 101 MW, viz. at Kaunas, on the Nemunas River (Internet source 348). There are several small private plants with an aggregate capacity of 11 MW. Together they produce 339 GWh annually. A further 6 MW is under construction, while 16 MW is planned. The potential of small hydro is estimated at 500 GWh/a. The total technically feasible potential is 2.6 TWh/a. The cost of new small low-head hydropower plants under construction at existing reservoirs is put at $ 1,200-1,600/kW.

Poland
Most of the Polish hydropower plants are located in the southern and western part of the country. There is 1,431 MW of pumped-storage hydropower capacity, while the pure hydropower capacity is 790 MW. The capacity of small hydropower amounts to 156 MW (ECBREC, 2000). The current total hydro production is around 2.5 TWh/a. The technical potential is 12 TWh/a, of which 500 GWh/a based on small hydro.

There is more than 68 MW under construction, mainly small hydropower plants (Internet source 349). There are no definite plans for further projects. Due to the economic state of the country, the completion of dams under construction has been delayed.

Slovakia
The total capacity of large hydro (exclusive of pumped storage) is 1,709 MW, while there are 186 small hydro plants in operation with a total capacity of 63 MW. Along the Váh River more than 850 MW of hydro capacity has been installed, together with a pumped-storage hydropower capacity of 735 MW. The largest run-of-the-river plant is on a canal parallel to the Danube River with a capacity of 720 MW. The current average hydro generation is 3.8 TWh/a.

Slovakia has a substantial unused hydropower potential (Internet source 350). There is a small hydro potential of 1.2 TWh/a, and a further 44 small plants are planned with a total capacity of 71 MW. Six of these will be constructed between 2002 and 2005, adding 16 MW to the total capacity. The total technical hydropower potential is between 6.6 and 10 TWh/a.

Slovenia
At the end of 1999, Slovenia had an installed hydropower capacity of 846 MW, accounting for approximately 31% of the total generating capacity of 2.65 GW (Internet source 351).

The Drava River is the main source of hydroelectric power in Slovenia. The capacity of current hydropower plants in operation is 846 MW, of which 81 MW in 431 small plants. Slovenia is working to upgrade hydropower plants since 1993. The first stage, which is nearly complete, involved raising the installed capacity of three hydropower plants at the Drave River by a combined 34 MW. The installed capacity at Vuhred and Ozbalt will be increased by 31 and 39 MW, respectively. In total, upgrading of plants more than 40 years old can increase their aggregate capacity from 228 MW to an estimated 389 MW.

A new 5 hydropower plant cascade - of which one for pumped-storage - with a total installed capacity of 175 MW is currently under construction at the lower Sava River (Verbundplan, 1999). The first plant, Bostanj, is currently under construction while the other four plants (among which the pumped-storage hydropower plant) do not have a definite schedule.

The total technical potential of hydropower in Slovenia is 7.8 TWh/a, representing an installed capacity of about 2,000 MW. Currently, 75 MW of hydro capacity is under construction and another 249 MW is planned. Concerning small hydro: five small plants are under construction, total 1 MW. Hundred small hydro plants are planned, with a total capacity of 15 MW, and renovation of all the small hydro plants could ad as much as 150 MW in generating capacity.

8.3 Selected other Eastern European countries

Bulgaria
Currently, 2,057 MW of hydropower is installed in Bulgaria, together with a pumped-storage hydropower capacity of 1,098 MW. Around 178 - 325 MW is installed in power stations smaller than 30 MW (Internet source 352). The annual electricity generation depends strongly on seasonal effects and varies from 2.53 TWh in 1998 to a maximum of 3 -3.5 TWh in a year of mean precipitation rate (Doukov, 2001). Hydropower plants with a capacity of 160 MW are under construction in Gorna Arda, and at least 200 MW is planned. The total technical potential is estimated at 15 TWh/a. The potential for small hydro is unknown, but 7 small plants are currently under construction and 72 are planned, adding 42 MW to the total capacity.

In the ‘National Strategy for Energy and Energy Efficiency until 2010’ an additional hydro capacity of 280 MW is foreseen for the period 2006 - 2010 (Doukov, 2001). Hydropower projects planned are Yadenitsa Dam, Tsankov Kamak Hydroelectric Facility, Gorna Arda Cascade and Sreden Iskar Cascade. In November 2000, the French joint venture Mecamidi-Sofia won a tender to buy the Pirinska Bistritsa 49.2 MW two-dam hydropower cascade. The government hopes that the investor's involvement in the project will help attract further foreign investment into the power sector (Internet source 353).

Recently, a consortium of France’s SIIF Energies and the Bulgarian arm of France’s Mecamidi started construction on a small hydropower plant near the town of Montana. A joint venture for the construction and the operation of the hydropower plant, Ogosta Mecamidi, has already been set up. The plant will become part of Bulgaria’s energy grid (Internet source 354).

Romania
In 1999, hydropower plants accounted for 36 percent of Romania’s electricity generation. Some 360 hydropower plants are in operation with an aggregate capacity of 6,210 MW. They produce 16 TWh/a in an average year. Total 317 plants - with a total capacity of 1,069 MW - have a capacity of less than 30 MW. There are 32 small plants with an average capacity of some 3.5 MW each, and an aggregate capacity of 110 MW. The potential of small hydro is unknown.

There is a large undeveloped hydropower potential in Romania (Internet source 355). The technically feasible potential is put at 11.4 GW, or 34.5 TWh/a.

After being temporarily abandoned in view of the economic situation after 1990, a further 170 MW is currently under construction again and 500 MW is planned. This concerns 21 hydropower projects with a total investment cost of $ 1.2 billion. SC Hidroelectrica is trying to attract foreign investors for these projects. The mean cost for hydropower plants under construction is $ 1,800 to 2,000 per kW.

The largest hydropower plant in Romania is the Portile de Fier I (Iron Gates I) plant, it is also the largest run-of-the-river plant in Europe. This plant is located on the Danube River on the Romanian-Serbian border and has 12 turbines, 6 are operated by Romania and the other 6 are operated by Serbia. The Romanian part has a capacity of 1,050 MW. This capacity will be raised to 1,200 MW at the end of 2005 (from 175 MW to 200 MW per turbine).

8.4 Summary of EU Accession Countries, Bulgaria and Romania

Table 8.1 presents an overview of the hydropower capacities, generation, and technical potentials of EU Accession Countries and the two other Eastern European countries: Bulgaria and Romania.

Table 8.1 *Hydropower (potential) in EU Accession Countries, Bulgaria, and Romania*

Country	Existing capacity			Current Generation	Technical potential	
	Large-scale	Small-scale (<30 MW)	Total		Capacity	Generation
	[MW]	[MW]	[MW]	[GWh]	[MW]	[GWh]
Bulgaria	1,874	183	2,057	3,250	9,500	15,000
Czech Republic	630	283	913	1,750	2,000	3,980
Estonia	-	1.2	1.2	4	150	500
Hungary	39.4	4.4	43.8	200	1,000	4,590
Latvia	1,517	65.5	1,582	3,300	1,900	4,000
Lithuania	111	11	122	339	950	2,600
Poland	630	156	786	2,500	3,800	12,000
Romania	5,141	1,069	6,210	16,000	13,400	34,500
Slovakia	1,709	63	1,772	3,800	4,650	10,000
Slovenia	765	81	846	3,800	2,000	7,750
Total	12,416	1,917	14,333	~ 35,000	~ 39,500	~ 95,000

9. WESTERN EUROPE

9.1 Introduction

In Western Europe - the European Union (EU), Norway, Switzerland and Iceland - the scope for additional hydropower is limited, as the most economic sites have already been developed and further expansion is hindered by environmental concerns. The EU only supports so-called ‘small’ hydro (<10 MW), as ‘large’ hydropower is regarded as being economic and as mature technology, that should not receive market distorting subsidies. In some countries, governments forbid further development of (large-scale) hydropower due to environmental considerations.

Countries with large amounts of hydro generation in absolute terms are Norway, France, Sweden, Italy, Austria, Switzerland, and Spain. Since power generation and distribution is more and more liberalised, the contribution of hydro (and renewables in general) to the total electricity generation on a national scale cannot be easily deduced from data of individual power producers. A number of them have merged into bi-national or multinational companies. Still, Figure 9.1 gives a useful impression of the relation between total electricity generation and renewable generation - most of which is hydropower - in case of large power producers (Statkraft, 2001).

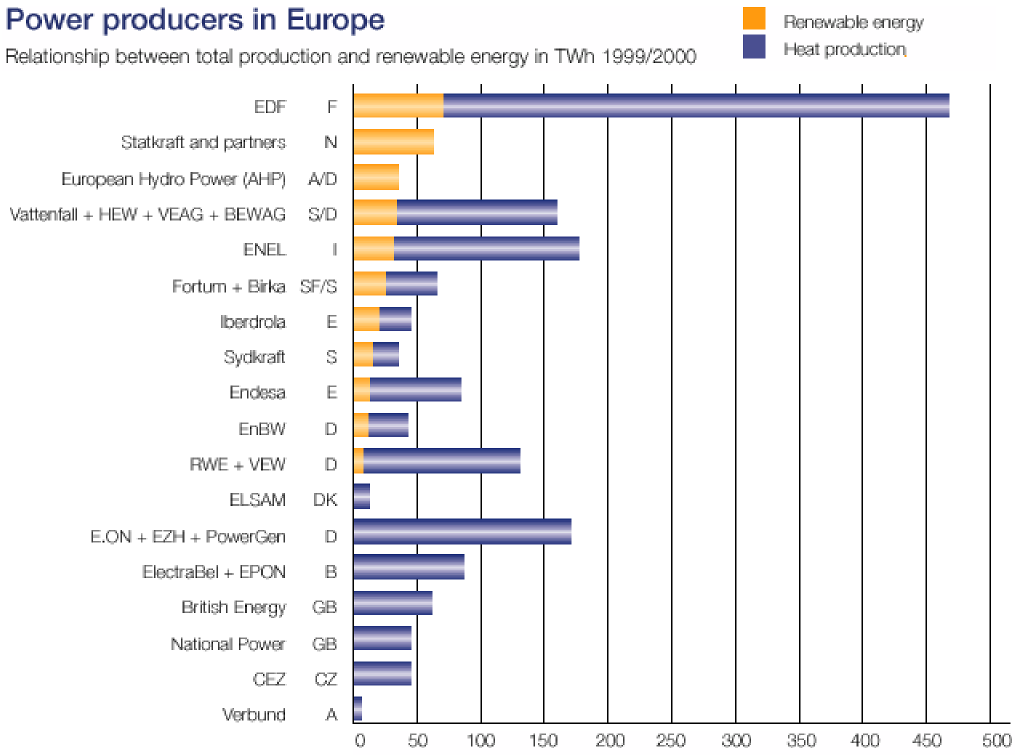

Figure 9.1 *Relationship between thermal and renewable power generation (TWh) for large power producers in Western Europe*

Source: Statkraft Annual Report 2001.

As there are very few hydropower plants of more than 10 MW under construction or planned in Western Europe, the content of this Chapter differs from the preceding ones. Section 9.2 shows the contribution of hydropower to total power generation. It presents estimates of the potential of hydropower by country, taking into account country-specific economic aspects as wells as considerations of conservation of landscape and environment. Section 9.3 addresses the ultimate potential of hydropower, based on the technical potential and possible effects of climate change.

9.2 Practical potential

9.2.1 Introduction

In Section 9.2.2, the 'practical potential' of hydropower in Western Europe is presented. This potential gives an estimate - admittedly subjective - of the amount of hydropower (in MW's and TWh's) that may become available, taking into account the *economically feasible hydro potential*, as well as legal or regulatory hurdles for development of (large-scale) hydropower.

9.2.2 Practical potential in (key countries of) Western Europe

Norway

Norway possesses Western Europe's largest hydro resources, both in terms of its current installed capacity and of its economically feasible potential. Its gross theoretical capability is put at 600 TWh/a, of which about 200 TWh/a is technically feasible (Hydro Power & Dams, 2002). The economically feasible hydropower potential is put at 179.7 TWh/a. Hydropower fulfils virtually all of Norway's electricity needs in an average year. Of Norway's economically exploitable potential, 113 TWh is developed. New generation licenses have been granted for an additional 1.9 TWh. Therefore, 114 TWh will be available in the near term, which is 64 percent of the economically feasible potential.

Environmentally important rivers with a hydropower production potential equalling 35.3 TWh have been protected against hydropower development by means of four Protection Plans for Watercourses.

The economically exploitable capability applicable to small-scale hydro schemes is reported to be 14 TWh/a (Internet source 356, 357).

France

France is Western Europe's second largest producer of hydro-electricity, after Norway. The country's technically feasible capacity is nearly exhausted: no hydropower plants are under construction and only about 50 MW of new capacity is planned.

At the end of 1999, the total installed capacity of small-scale (<10 MW) plants was just over 2,000 MW. There were, on the other hand some 280 hydro plants of greater than 10 MW, with an aggregate installed capacity of about 23,000 MW.

Sweden

Sweden has one of the highest hydro potentials in Western Europe: its gross theoretical capability is reported to be 176 TWh/a, of which 130 TWh/a is technically feasible. The economically feasible potential is put at 90 TWh/a. The average annual capability of the hydro capacity installed at the end of 1999 was 64 TWh, about 71% of the economic potential. Hydropower provides nearly half of Sweden's electricity.

The construction of new hydro plants has virtually stopped, on account of environmental and political considerations. Future activity is likely to be very largely confined to the modernisation and refurbishment of existing capacity.

Finland

Finland's supreme administrative court has rejected power company Kemijoki Oy's appeal against an earlier decision by lower administrative courts to refuse permission to build a large hydroelectric scheme in eastern Lapland. The controversial proposal now appears to be dead.

Behind a proposed dam, 237 km^2 of land rich in bird life would have been submerged. The region, which includes the Kemihaara Mires, was controversially excluded from Finland's proposed 'Natura 2000' sites. The Environment Minister of Finland believes that the area should now be considered for addition to Finland's conservation network.

The decision has met different reactions. Nature conservationists consider it as a landmark in their work aimed at raising the profile of environmental considerations in major planning decisions. However, local politicians in eastern Lapland criticised the decision as a blow to employment prospects and the Industry Minister of Finland also regretted it, claiming that the project would have provided a vital source of emission-free renewable energy (Internet source 358).

Iceland

The technically feasible hydro potential of Iceland is 64 TWh/a and the economically feasible potential 44 TWh/a. In 2002, the total hydropower capacity of Iceland was 1,174.5 MW, of which 1,107 MW in large plants (Internet source 359) and 67.5 MW in small, mini and micro hydropower plants. The latter 84 small hydropower plants produce 250 GWh annually. In 2001, all hydropower plants generated 6.6 TWh. There is no pumped-storage hydropower in Iceland.

In November 2001, the Vatnsfell project was finished, with 2 x 45 MW turbines and an average annual generation of 430 GWh. The specific investment cost of hydropower capacity under construction is around $ 1,300/kW.

A proposed hydropower project in eastern Iceland, which would be built to power an aluminium smelter, still faces resistance from environmental groups. The power from the Kárahnjúkar plant would be used by Alcoa to produce 295 kton of aluminium annually. The annual output will be around 4.45 TWh, 93% of which would be required for the aluminium smelter (Internet source 360, 361).

Table 9.1 shows the existing capacity, as well as estimates of additional and maximum potential of hydropower in Western European countries, in terms of MWs. Table 9.2 shows the same potentials in terms of electricity generated (TWh/a).

Table 9.1 *Existing, 'additional' and 'total potential' of hydropower in Western Europe*

Country	Small hydro (<10 MW)			Large hydro (>10 MW)			Total hydro		
	Exist. [MW]	Add. [MW]	Total [MW]	Exist. [MW]	Add. [MW]	Total [MW]	Exist. [MW]	Add. [MW]	Total [MW]
AU	837	1,105	1,942	10,835	124	10,959	11,672	1,229	12,901
BE	60	66	126	43	-	43	103	66	169
CH	273	754	1,027	13,230	-	13,230	13,503	754	14,257
DE	1,402	550	1,952	1,980	-	1,980	3,382	550	3,932
DK	11	-	11	-	-	-	11	-	11
ES	1,530	1,118	2,648	11,193	148	11,341	12,723	1,266	13,989
FI	304	148	452	2,577	640	3,217	2,881	788	3,669
FR	2,016	1,261	3,277	22,916	-	22,916	24,932	1,261	26,193
GR	49	101	150	3,052	471	3,523	3,101	572	3,673
IC	67.5	-	67.5	1,107	185.5	1,292.5	1,174.5	185.5	1,360
IR	34	39	73	199	-	199	233	39	272
IT	2,201	648	2,849	14,370	3,098	17,468	16,571	3,746	20,317
LU	39	-	39	-	-	-	39	-	39
NL	2	17	19	35	-	35	37	17	54
NO	889	962	1,851	26,652	2,044	28,696	27,541	3,006	30,547
PO	257	513	770	3,507	737	4,244	3,764	1,250	5,014
SE	943	557	1,500	15,489	-	15,489	16,432	557	16,989
UK	177	73	250	1,299	93	1,392	1,476	166	1,642
Total	11,091	7,912	19,003	128,484	7,541	136,025	139,575	15,453	155,028

Table 9.2 *Existing, 'additional' and 'total potential' of hydropower in Western Europe*

Country	Small hydro (<10 MW)			Large hydro (>10 MW)			Total hydro		
	Exist. [TWh/a]	Add. [TWh/a]	Total [TWh/a]	Exist. [TWh/a]	Add. [TWh/a]	Total [TWh/a]	Exist. [TWh/a]	Add. [TWh/a]	Total [TWh/a]
AU	4.16	5.50	9.66	34.26	0.39	34.65	38.42	5.89	44.31
BE	0.18	0.21	0.39	0.14	-	0.14	0.32	0.21	0.53
CH	0.72	1.97	2.69	34.65	-	34.65	35.37	1.97	37.34
DE	6.90	2.71	9.61	12.00	-	12.00	18.90	2.71	21.61
DK	0.03	-	0.03	-	-	-	0.03	-	0.03
ES	4.96	3.62	8.58	23.53	0.31	23.84	28.49	3.93	32.42
FI	1.09	0.53	1.62	12.08	3.00	15.08	13.17	3.53	16.70
FR	7.49	4.68	12.17	70.06	-	70.06	77.55	4.68	82.23
GR	0.15	0.32	0.47	4.30	0.66	4.97	4.45	0.98	5.43
IC	0.25	-	0.25	6.15	1.00	7.15	6.40	1.00	7.40
IR	0.09	0.10	0.19	0.72	-	0.72	0.81	0.10	0.91
IT	8.35	2.46	10.81	34.11	7.35	41.47	42.46	9.81	52.27
LU	0.10	-	0.10	-	-	-	0.10	-	0.10
NL	0.01	0.06	0.07	0.09	-	0.09	0.10	0.06	0.16
NO	3.89	4.21	8.10	110.20	8.45	118.65	114.09	12.66	126.75
PO	0.61	1.21	1.82	10.66	2.24	12.90	11.27	3.45	14.72
SE	3.85	2.27	6.12	63.77	-	63.77	67.62	2.27	69.89
UK	0.54	0.22	0.76	4.10	0.29	4.39	4.64	0.51	5.15
Total	43.37	30.07	73.44	420.82	23.69	444.51	464.19	53.76	517.95

Table 9.2 shows that there is still scope for additional hydropower, particularly in:

- Norway (~ 12.7 TWh/a)
- Italy (~ 9.8 TWh/a)
- Austria (~ 5.9 TWh/a)
- France (~ 4.7 TWh/a)
- Spain (~ 3.9 TWh/a)
- Portugal (~ 3.5 TWh/a)
- Finland (~ 3.5 TWh/a).

Hydropower is the main source of electricity in Norway, and it is used on an extensive scale in France, Sweden, Italy, Austria, Switzerland, Spain and Iceland. In some countries construction of 'large-scale' development of hydropower (based on dams) is very difficult because of a conflict with environmental considerations (preservation of riverine ecosystems, landscape, tourism, etc). Thus, large-scale hydropower sites may remain undeveloped, and policy is focused on small hydropower or upgrading of existing hydropower plants. In Navarra (Spain), the investment cost of mini hydro is estimated at € 1,263/kW (Dresdner Kleinwort Wasserstein, 2000).

9.3 Ultimate potential of hydropower

9.3.1 Introduction

The technical potential of hydropower represents the capacity or generation that ultimately may be developed, if economic and environmental considerations are neglected. This potential is somewhat hypothetical, as the cost of hydropower matters and environmental considerations are very important in Western Europe. Still, it may be interesting to compare the practical potential - presented in Section 9.2 - with the technical potential (9.3.2). Also, the effect of climate change on the hydropower potential is shortly addressed, based on a recent publication (9.3.3).

9.3.2 Practical vis-à-vis technical potential

Table 9.3 shows the development of hydropower in Western Europe for two cases. Case one is the ‘potential’ generation based on the practical potential from Section 9.2. Case two, called ‘maximum’ generation, refers to the technical potential from ‘Hydro Power & Dams, 2002’. Table 9.3 also shows the ‘potential’ and ‘maximum’ share of hydro in total power generation.

Table 9.3 *Hydropower generation compared to total power generation in Western Europe*

Country	Hydropower generation			Total power generation	Hydropower’s share of total power generation (based on power generation in 2000)		
	Current generation [TWh/a]	‘Potential’ generation (practical) [TWh/a]	‘Maximum’ generation (technical) [TWh/a]	[TWh/a]	Current share [%]	‘Potential’ share without increase in demand [%]	‘Maximum’ share without increase in demand [%]
AU	38.42	44.31	>53.7	60.7	63.3	73.0	>88
BE	0.32	0.53	>0.53	80.2	0.4	0.7	>0.7
CH	35.37	37.34	41.0	65.3	54.2	57.2	62.8
DE	18.90	21.61	24.7	533.6	3.5	4.1	4.6
DK	0.03	0.03	0.03	34.6	0.1	0.1	0.1
ES	28.49	32.42	70.0	215.2	13.2	15.1	32.5
FI	13.17	16.70	>19.7	67.3	19.6	24.8	>29
FR	77.55	82.23	>82.2	516.7	15.0	15.9	>16
GR	4.45	5.43	15.0	49.9	8.9	10.9	30.0
IC	6.40	7.40	64.0	7.9	82.5	93.7	>100
IR	0.81	0.91	1.18	22.7	3.6	4.0	5.2
IT	42.46	52.27	69.0	263.3	16.1	19.9	26.2
LU	0.10	0.10	0.12	1.1	9.2	9.2	11
NL	0.10	0.16	0.2	86.0	0.1	0.2	0.2
NO	114.09	126.75	200	141.8	80.5	89.4	>100
PO	11.27	14.72	24.5	42.2	26.7	34.9	58.1
SE	67.62	69.89	130	142.0	47.6	49.2	91.6
UK	4.64	5.15	N/A	65.3	7.1	7.9	N/A
Total	464	~518	~800	2396	19.4	21.6	~33.5

Two conclusions may be drawn from the comparison between practical and technical hydropower potential according to Table 9.3:

- If the demand for electricity in Western Europe would remain on the level of the year 2000 (which is a ‘big if’), the share of hydropower in the total power generation mix could rise from 19.4% to approximately 21.5% in the medium term.
- The technical potential is approximately 50% higher than what is practically deemed achievable. The ‘maximum’ share would be approximately 33.5% of the current total power generation. However, development of the technical potential would completely overrule considerations of protection of environment and landscape in countries like Austria, Greece, Italy, Norway, Portugal, Spain, Sweden, Switzerland, and Iceland.

9.3.3 Effect of climate change on hydropower potential

Recently, three researchers from the Center for Environmental Research of the University of Kassel and ISET[12], Kassel, published an analysis on the potential of hydropower in Europe today and in the future (Lehner, 2003). Their primary question was: ‘In which European countries can we expect a significant increase or decrease of the potential to generate hydroelectricity due to climate change?’ In order to answer this question, they developed a spatially consistent methodology to arrive at comparable results for all of Europe.

Just like other researchers, they observe that Nordic countries show potential for additional hydropower. However, schemes for building additional large-scale hydropower plants are not existent in Sweden (due to public opposition) and only a small increase of the installed hydropower capacity is expected in Norway (for similar reasons). Furthermore, they observe that in some cases (e.g. Italy) there is evidence that some hydropower plants could be constructed or are in

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[12] Institut für Solare Energieversorgingstechnik.

the planning stage for the near future. They conclude that the prediction of the development of hydropower in (Western) Europe[13] is difficult. However, hydropower plants will probably continue to be operated and their number and capacities may be increased.

With regard to the possible effects of climate change in the second half of the 21st century (2070 rather than 2020) on the potential of hydropower the following conclusions may be drawn:

- Nordic countries may profit from possible climate change due to increased precipitation, viz. Norway and Iceland, and - to a lesser extent - Finland and Sweden.
- Some countries in the middle of Europe seem to be not affected by possible climate change, particularly Austria and Germany.
- Some other countries in Southern Europe may be negatively impacted by possible climate change, viz. Greece, Italy, Portugal and Spain.

Climate change may also positively affect the hydropower potential of Baltic countries and – to a lesser extent, but more important in quantitative respect - Russia. However, some middle and southern European countries like Poland and Ukraine, and Albania, Bulgaria, Romania, other countries of the Balkan and Turkey, respectively, could be strongly negatively affected.

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[13] The authors not only consider Western Europe, but also Eastern Europe. In Eastern Europe and the former Soviet Union (FSU) most of the development of hydroelectricity in the short and medium term is expected to occur as expansion and refurbishment of existing hydropower plants, as the persistent economic problems interfere with the construction of new hydropower plants.

10. GLOBAL SUSTAINABILITY AND LOCAL ISSUES

10.1 Introduction

In the development of hydropower projects consideration of fairness and equity are very important. The chairman of the Japan Commission on Large Dams (JANCOLD), Mr Nishida, in the presentation 'Dam Development in the 21st Century' put it this way: (Internet source 359).

'We want to make a fair judgement: whether it is a net loss to us to develop a dam and change the environment of the surrounding area, or there is a net gain even if a dam is developed and some part of the environment is damaged. The benefit of developing a dam is not that difficult to quantify. It is chiefly the energy generated by the hydropower plant and the water supplied and used by people living in the city and on commercial farms. But the benefit we get from protecting a specific part of the environment is not easy to assess. In many cases it is a matter of value judgement. That is a source of dispute about dam development and its negative effects. This complicates the matter and there seems to be no way to reconcile the difference in the value people put on the same things. We want to conserve the environment but at the same time we cannot put an infinite value on the conservation'.

The following subsections provide additional information and thoughts on the evaluation of hydropower projects and their impacts. Section 10.2 gives insight in the performance of a number of hydroelectric projects compared to the original design data. Section 10.3 addresses the issue of large-scale vis-à-vis small hydropower, and Section 10.4 the environmental challenges of hydropower.

10.2 Hydro power plant performance

The performance of the hydropower plants in terms of yearly average output (GWh/a) may seem trivial. However, the performance of hydropower plants tends to deviate from initial estimates to a variable extent. Studies from the World Commission on Dams (WCD) suggest that hydropower has performed reasonably well in terms of power generated. In some cases, plants have performed even better than expected. However, a positive outcome tends to obscure two important issues.

First, the volatility of hydropower generation may be high. Peaks and troughs in hydropower generation may persist over time as climate cycles ebb and flow. Although average output (in GWh/a) may be more or less on target, a project may encounter difficulties, particularly if dry periods occur at project inception. Such variations may be substantial, and sometimes very large indeed for Latin American countries affected by El Niño.

A second difficulty is that sometimes the installed capacity and the total power generation are as expected, but the dependable capacity is less than anticipated (Internet source 360). Generally, there is a striking difference between the nominal capacity and the 'firm' capacity of a hydropower station. The performance of a few hydropower projects that have been evaluated thoroughly is highlighted below.

Grand Coulee

When completed in 1942, Grand Coulee was the largest hydroelectric dam in the world and remains the largest in North America. It was considered proof of America's unrivalled power to harness nature and was dubbed 'The Eighth Wonder of the World'. With an installed capacity of 6,494 MW, Grand Coulee powered economic growth in the US northwest. Half a century later, however, many people are concerned with the dam's environmental impacts, particularly on salmon species whose migration is blocked by dams (Internet source 361).

Kariba

The 1,250 MW Kariba Dam, constructed in 1955-1959 on the Zambezi River (Zambia-Zimbabwe border), is one of the largest hydropower complexes in Africa. At the time of construction, it was the largest dam in the world: 617 m long, 128 m high, 13 m wide at the top and 24 m at the base. Power is supplied to the Copperbelt in Zambia and to parts of Zimbabwe. Construction necessitated displacement of 57,000 people. In 1960-61, Operation Noah captured and removed the animals threatened by the lake's rising waters (Internet source 362, 363).

Tarbela

Construction on the Tarbela Dam in Pakistan started in 1968. The original schedule for construction and commissioning was 7.25 years. The first four units started generating in early 1977, on average twenty months later than scheduled. In 1993, the installed capacity of Tarbela amounted to 3,478 MW, 67% more than the planned 2,100 MW (Internet source 364)

Aslantas

The Aslantas Dam was constructed on the Ceyhan River in the Turkish Province of Adana, and completed in 1984. Aslantas had a projected capacity of 138 MW and a projected generation capability of 500 GWh/a. The capacity proved to be equal to the projected capacity. However, the output turned out to be 652.7 GWh/a[14], 31% more than the predicted value of 500 GWh/a. However, the annual power generation is extremely variable and ranges from 60 to 200% of the predicted 500 GWh/a (Internet source 365).

Tucuruí

The 4,275 MW Tucuruí Hydroelectric Plant was the first large hydropower plant in the Brazilian portion of the Amazon Region. Construction began in 1975 and was finished in 1984. Upgrading of Tucuruí by adding 11 375 MW turbines, thereby increasing the total installed capacity to 8,370 MW, will be completed in 2005.

Social and environmental costs received virtually no consideration when decisions were made. The Tucuruí dam predated Brazil's 1986 requirement of an Environmental Impact Assessment (EIA) and Environmental Impact Statement (EIS). Despite great advances in Brazil's environmental impact assessment system since Tucuruí was built, EIA/EIS continue to function as a formality to rubberstamp decisions that have already been taken based on other criteria.

Tucuruí's reservoir partially flooded three municipalities, 14 villages, two Indian reservations and 160 km of federal highways. Besides local Indians, some 29,000 non-Indians had to be resettled (Internet source 366, 367, 368, 369).

Pak Mun

Construction of the 136 MW Pak Mun Dam in Thailand started in June 1990. Commercial operation began in November 1994. The difference between the original projection of power generation and the actual generation has to do with peak load. It had not been envisioned that the projected output of 280 GWh could not be used in peak hours. However, allowing for a four-hour daily peak demand period which was the convention at the time, the maximum possible annual peak load generation that could have been expected from the 136 MW installed capacity at Pak Mun was only 199 GWh, or about 70% of the claimed possible total output.

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[14] Based on generation during the past 15 years.

The benefits of power, irrigation, and fishery were quantified in the original project document, which presented Pak Mun as a multipurpose development project with claims to other unquantified benefits including tourism and navigation.

The distributed impact of the project on the local community or on Thailand's northeastern region cannot be determined in isolation of other concurrent factors affecting the development, in particular major irrigation schemes underway upstream on the Mun's tributaries. The village census database dating from the baseline year of 1992 or earlier suggests that there have been dramatic and general improvements in the quality of life and the economic potential in the project area, both in absolute terms and in relative terms compared to the rest of the province.

Total 4.8 times the original estimate has been paid out for compensation, resettlement and environmental impact mitigation, representing 17.1% of the costs of Pak Mun.

Glomma and Laagen

The Glomma and Laagen Basin is an illustrative case of hydropower development and experience in the context of a run-of-the-river basin system with upstream basins. Most of the hydropower dams in the basin were built prior to hydropower dams in other parts of Norway. Hydropower development in the Glomma and Laagen basin reflects a history of more than 100 years. The main construction period was from 1945 to 1970. Most regulation dams and power stations in the basin were built more than 30 years ago in a context quite different from the present.

The last hydropower license process handled by the Norwegian Parliament was a project involving further development of the Øvre Otta River in the western part of the basin. The project was a symbol for hydropower proponents and opponents, and included conflicts nationally and locally. Although flood mitigation was cited as a major reason for constructing the regulation dams, there were no specific targets set for flood control in terms of predictions to reduce flood levels, flooded area or damage (Table 10.1) (Internet source 356).

Table 10.1 *Upgrading hydropower stations Glomma and Laagen during the last 20 years*

Hydropower station	Year	Installed capacity			Annual generation		
		Initial [MW]	Planned [MW]	Current [MW]	Initial [GWh]	Planned [GWh]	Current [GWh]
Røstefossen	1987	1.9	3.1	3.1	10.3	16.5	20
Kongsvinger	1988	20.9	20.9	20.9	106	129	120
Eidefoss	1983	1.5	12.0	12.0	9.1	71.4	75
Nedre Vinstra	1990	200	300	300	1,073	1,097	N/A
Rånåsfoss	1983	61.8	99.0	99.0	356	486	N/A
Solbergfoss	1985	118	215	215	687	878	890
FKF	1985	22.0	212	212	800	1,087	N/A
Glomma and Laagen		426.1	862	862	3,042	3,765	N/A

The assessments of both the technical-economic parameters and the social and environmental parameters of all above discussed examples shows that some hydroelectric projects may be considered as a nightmare (from an ecological point of view), whereas others perform well from virtually all aspects taken into account. Table 10.2 shows the performance indicators for the seven hydro projects considered.

Table 10.2 *Hydropower plant performance indicators for seven hydropower projects*

Case Study Dam	Installed capacity			Generation		
	Predicted [MW]	Actual [MW]	Actual as % of predicted	Predicted [GWh/a]	Actual [GWh/a]	Actual as % of predicted
Grand Coulee	1,575	6,494	412	7,008	8,383	119
Kariba	1,200	1,266	106	6,720	6,400	95
Tarbela	2,100	3,478	166	11,300	14,300	127
Aslantas	138	138	100	500	653	131
Tucuruí	2,700	4,275	158	16,197	21,428	132
Pak Mun	136	136	100	289	290	100
Glomma and Laagen	862	862	100	3,765	N/A	N/A

Sources: WCD Studies.

10.3 The small-hydro versus large-hydro debate

In countries with potential for large-scale hydropower, there is a debate whether large-scale hydropower is sustainable. Environmental groups generally favour small hydropower because this type of hydropower would entail less environmental degradation and loss of habitat for plants and/or animals (biodiversity). Measures favouring emerging renewable technology often exclude ‘large’ hydro, since small projects are perceived as having lower impacts.

However, it is difficult to make a fair balance between different power generation options, even if the choice would be - which is often not the case - between ‘large’ and ‘small’ hydropower. Research points out that valid comparisons must compare impacts per unit of output. The impacts of a single large hydro project must be compared with the cumulative impacts of several small projects yielding the same power and level of service. For example, small projects generally require a greater total reservoir area than a single large project, to provide the same stored water volume. Nevertheless, small hydropower is a necessary and useful complement to the electricity generation mix, particularly in rural areas (Internet source 370).

In assessing future energy production, policies gaining favour are those that emphasise sustainability and the maximum use of renewable energy to meet future needs. Hence, we cannot afford to dismiss a form of renewable energy such as ‘large’ hydropower. It is desirable to give due attention to positive and negative consequences of hydropower projects for society and the environment. This has not been done consequently in the past. Sometimes, a decision to build a specific hydropower plant has been based on wrong or at best doubtful criteria.

The IEA/Hydropower Agreement has recently completed a five-year study on Hydropower and the Environment. This study raises some points of interest with regard to (‘large’) hydropower:

- The need for an Energy Policy Framework.
- The requirement for a Decision Making Process.
- A Comparison of Hydropower Project Alternatives.
- Improving Environmental Management of Hydropower Plants.
- The Sharing of Benefits with Local Communities.

These recommendations, taken cumulatively, could form the basis of guidelines for the development and management of hydropower projects:

1. The Need for an Energy Policy Framework - Nations should develop energy policies which clearly set out rational objectives regarding the development of all power generation options, including hydropower, other renewable sources, and conservation.
2. A Decision Making Process - Stakeholders should establish an equitable, credible and effective environmental assessment process, which considers the interests of people and the environment within a predictable and reasonable schedule. The process should focus on achieving the highest quality of decisions in a reasonable period of time.

3. Comparison of Hydropower Alternatives - Project designers should apply environmental and social criteria when comparing project alternatives, to eliminate unacceptable alternatives early in the planning process.
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 operation cycle.
5. Sharing Benefits with Local Communities - Local communities should benefit from a project, both in the short term and in the long term.

Together, these five categories of recommendations constitute a sustainable approach to renewable hydropower resource development.

It may be concluded that the distinction between large and small hydropower is not very practical. According to a representative of the US 'Low Impact Hydropower Institute' such a distinction (Grimm, 2001):

- Does not address actual impacts of hydro dams.
- Is no incentive for improvements (not tied to operations).
- Addresses the majority of dams in the US, but not the majority of capacity.
- Is not easy to apply, but masks complexity.
- Is not credible with environmental community knowledgeable about hydropower.

Hydropower has to meet strict environmental criteria. If there are serious environmental objections, the plant should not be built or eventually be dismantled (as happens occasionally in the US). If a hydropower plant meets the strictest environmental considerations, its electricity could be named 'green' hydropower. This type of electricity would justify a higher price, whether it is from micro, mini, 'small' (<10 MW) or 'large-scale' hydropower (>10 MW).

10.4 Environmental challenges

In the United States, it is acknowledged by participants in the (re-)licensing process that the process to obtain a license is far more complex, time consuming, and costly than it was 30 to 50 years ago. The challenge is to issue a license that is legally defensive, scientifically credible, and likely to protect fish, wildlife, and resources. Still, hydropower should be preserved as an economically viable energy source.

Building of large dams may have controversial environmental impacts. The World Commission on Dams makes mention of five principal measures to respond to ecosystem impacts:

- Measures to avoid the anticipated adverse effects of a large dam through the selection of alternative projects.
- Measures to minimise impacts by altering project design features once a dam is decided upon.
- Mitigation measures that are incorporated into a new or existing dam design of operating regime in order to reduce ecosystem impacts to acceptable levels.
- Measures that compensate for unavoidable residual effects by enhancing ecosystem attributes in watersheds above dams or at other sites.
- Measures to restore aspects of riverine ecosystems.

For smaller hydropower plants, different aspects may be considered. In case of hydropower labelling, the following aspects are considered (Truffer, 2001):

- Upgrading of existing plants to fulfil additionality.
- Identification of low impact operation modes.
- Stakeholder involvement.
- Criteria based on environmental impact.

In Switzerland, the organisation 'Naturmade' has initiated measures to improve the environment at the hydropower station 'Höngg' (Emch, 2001). One measure was requested, viz. a proof that the fish pass is actually used by the fishes. Other proposed future eco-investments are:

- Revitalising of river banks.
- New fish pass at the powerhouse.
- Improvements in the connectivity with the side waters.

Such measures may not be very costly.

10.5 Gazing into the future

On a global scale, hydropower is an important renewable energy source. In the long term, it will meet increasing competition from 'new' renewables (wind, solar, biomass, etc.). Whether a specific hydro project will be developed or not, depends not only on the economic benefits, but also on the environmental impacts (positive and negative). Sometimes, the environmental and social impacts of (large) hydropower projects may be substantial. However, thermal power generation and nuclear power also have their drawbacks. Global climate change seems to be the main threat to biodiversity and food production. In this context, the issue is to what degree will society accept some local impacts of hydropower, in order to mitigate the global impacts of climate change and other environmental risks from thermal power generation (coal- or gas-fired power).

Western Europe is a mature market with respect to hydropower. The remaining potential is significant, but new large hydropower projects will be rare. In Western Europe (and elsewhere), policies with respect to renewable energy sources are generally in place, in view of the targets they have with regard to GHG reduction (Kyoto Protocol). Particularly in the countries that are 'mature' with regard to 'large' hydropower, the focus is on 'small' and 'green' hydropower. As the potential of new dams or relatively large run-of-river plants is limited, and some countries do not contemplate such projects, 'small' hydro will be much more common than 'large' hydro.

In developing countries the benefits of hydropower may outweigh the disadvantages, even though new projects may be more costly than usual. Or the development may require extensive electrical transmission (High Voltage Direct Current). Since GHG emission reduction becomes more important than ever, the spotlight will come back on 'large' hydropower schemes, even if they would be more costly than alternatives under 'business-as-usual' conditions (neglecting the threat of global warming). In each country in different parts of the world, the environmental consequences of ('large') hydropower are weighted against the economic and 'climate' benefits. The balance may be different, but the need to reduce GHG emissions could be in favour of new hydropower plants (Hueper, 2001)

11. POTENTIAL FOR HYDROPOWER WITH RESERVOIRS

One of the advantages of hydropower is the ability to store mechanic energy/work with high efficiency. So it is possible to cover the demand by electricity generation at the appropriate time. The water supply (day and night, winter and summer) for hydropower generation usually follows a different time pattern as the electricity demand (load). Reservoirs and pumps in hydropower systems can bridge this by pumping water from lower reservoirs to higher ones with surplus electrical energy (e.g. from wind-, coal- or nuclear power plants in the night). This energy can be recalled in very short time. By very short start-up time of its turbines, hydro plants are also an excellent resource for reserves and for frequency control.

In the future, with the market penetration of intermittent renewables and the introduction of high efficient base load power plants - ranging from combined cycle plants, via internal coal gasification plants, to fusion plants (in the second half of this century) - the importance of storage energy and thus the importance of hydropower plants with reservoirs and especially pumped-storage plants will increase.

Therefore another classification depending on the possibility of storing will be introduced:
- Run-of-river hydropower plant including pondage.
- Reservoir and mixed pumped hydropower plant.
- Pure pumped storage hydropower plant.

In the following the world potential of hydropower with storage shall be determined from the estimations of total hydropower potentials shown in Table 11.1.

Table 11.1 *World hydropower potentials*

	HEP[15] potential Theoretical [TWh/a]	Feasible HEP potential Technical [TWh/a]	Feasible HEP potential Economical [TWh/a]	HEP Installed [GW]	HEP Generation [TWh/a]
Africa	4,000	1,750	1,000	20	68
Asia (incl. Russia, Turkey)	19,300	6,700	3,600	303	735
Australasia	600	270	105	13	41
Europe (excl. Russia, Turkey	3,220	1,225	775	165	539
North & Central America	6,330	1,657	1,000	155	744
South America	7,020	2,720	1,600	101	504
World	40,500	14,320	8,100	660	2.600

When looking at the installed capacity in most countries with substantial mountain ranges the share of reservoir/pumped storage plants lies with about 50 % of the total installed hydro capacity. In more hilly countries the typical capacity share lies with 30 %.

It, however, has to be kept in mind, that plants with reservoirs typically generate with 1000 to 3000 full load operation hours per year, while with run of river plants this value mostly lies with 4000 to 5000 full load operation hours. Consequently, the share of reservoir/pumped storage plants in total hydro generation lies much lower, ranging from 5 to 28 % with an EU-15 average of 10.5 % (see Table 11.4).

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[15] HEP = Hydro Electric Power.

Table 11.2 *Hydropower generation in EU-15 countries in 2000 and 2020*

	Year	Total hydro [TWh/a]	Pumped & mixed storage [TWh/a]	Pumped & mixed share of total [%]
Austria	2000	43.3	12.3	28.4
	2020	40	11.5	28.8
Belgium	2000	1.7	1.3	76.5
	2020	2.4	1.9	79.2
Denmark	2000	0	0	0
	2020	0	0	0
Finland	2000	14.5	0	0
	2020	13.5	0	0
France	2000	71	4.8	6.8
	2020	76.5	6.5	8.5
Germany	2000	24.8	6.1	24.6
	2020	27.5	5	18.2
Greece	2000	4.2	0.6	14.3
	2020	6	0.6	10.0
Ireland	2000	1.1	0.3	27.3
	2020	1.2	0.4	33.3
Italy	2000	50.2	6.5	12.9
	2020	59.3	6.7	11.3
Luxembourg	2000	1	1	100
	2020	1	1	100
Netherlands	2000	0.1	0	0
	2020	0.5	0	0
Portugal	2000	11.6	1	8.6
	2020	15.4	2.8	18.2
Spain	2000	31.4	3.4	10.8
	2020	36.9	2.1	5.7
Sweden	2000	78		0
	2020	70.1		0
United Kingdom	2000	7.7	2.6	33.8
	2020	7.5	2.5	33.3
EU 15	2000	340.6	39.9	11.7
	2020	357.8	41	11.5

Source: Europrog

Generalising these findings, it can be estimated that about 30 - 50% (depending on topography) of the *installed hydropower* is available for energy-storage. But only *5% in more plain regions* and *15 – 30% in mixed alpine/plain regions* is available for long-term storage (more than one day) of electricity.

The resulting estimation for the global technical potential for hydropower storage is given in Table 11.3. In Table 11.4 the potential storage capacity is further split into short-term (up to one day) and long-term (more than one day) storage potential.

Table 11.3 *World hydropower storage potentials*

	Technical potential of hydropower generation [TWh/a]	Technical potential of hydropower capacity [GW]	Technical Potential of Hydro storage Generation [TWh/a]	Technical potential of hydro storage capacity [GW]
Africa	1,750	515	205	206
Asia (incl. Russia & Turkey)	6,700	2,762	784	1,105
Australasia	270	86	32	35
Europe (excl. Russia & Turkey)	1,225	375	143	150
North & Central America	1,657	344	194	138
South America	2,720	543	318	217
World	14,320	3,635	1,675	1,454

Table 11.4 *World hydropower potentials by plant types*

	Technical potential of hydropower capacity [GW]	Technical potential of run-of-river capacity [GW]	Technical Potential of short- term Storage capacity [GW]	Technical potential of long- term storage capacity [GW]
Africa	515	309	144	62
Asia (incl. Russia & Turkey)	2,762	1,657	784	1,105
Australasia	86	52	32	35
Europe (excl. Russia & Turkey)	375	225	143	150
North & Central America	344	207	194	138
South America	543	326	318	217
World	3,635	2,181	1,675	1,454

12. CONCLUSIONS

Hydropower is an abundant and reliable source of clean and renewable energy that can play a key role in combating climate change. Although there are hydroelectric projects under construction in about 80 countries, most of the remaining hydro potential in the world may be found in developing countries, particularly in South and Central Asia, Latin America, and Africa. Other countries with remaining hydropower potential are Canada, Turkey, and Russia.

Hydropower plants either are based on reservoirs, or are run-of-the-river plants. In order to reduce the dependence on the stochastic inflow, many hydropower plants feature large reservoirs and corresponding dams.

In Western Europe and the United States, the scope for additional hydropower is limited, as the most economic sites have already been developed and further expansion is hindered by environmental concerns.

In North America, hydropower is the most widely used form of renewable energy. The installed hydropower capacity amounts to 155 GW (66 GW in Canada, 80 GW in the US, and 10 GW in Mexico). Hydropower accounts for 60 percent of the electricity generated in Canada, 8 percent in the US and 19 percent in Mexico. Canada's economical hydropower potential is second only to that of Brazil in the Western Hemisphere. Canada still has several projects under construction or planned, amounting to 6.6 GW. There are proposals to develop hydroelectric projects in the Northwest Territories of Canada that would total between 12 and 15 GW.

In Mexico, three large hydropower projects with an aggregate capacity 5.7 GW are under construction or planned. Only a few small hydropower plants are under construction in the US.

Developing Asia is one of the regions in the world that has ambitious plans to continue the development of large-scale hydropower projects. China, India, Laos, Malaysia, Nepal and Vietnam, among other countries in developing Asia, have extensive plans to expand their hydropower resources, and all have plans to use large-scale hydropower to achieve their goals.

With a vast territory and a host of rivers, China has the largest hydropower resources of the world. China's installed hydropower capacity stood at 82.7 GW by the end of 2001. A large number of hydropower plants is under construction or planned, amounting to 77.7 GW. The giant 18.2 GW Three Gorges Dam with a dam height of 181 m on the Yangtze River (the country's longest river) is the world's largest hydropower project under construction. Although hydropower plants based on dams and reservoirs may require relocation of large numbers of people, China has one of the better resettlement programs in the world.

India's hydropower potential ranks fifth in the world. Hydropower accounts for one-quarter of India's power generated and 27 percent of the installed generating capacity, which is planned to increase to 40 percent. The installed hydropower capacity stood at 25.2 GW in May 2001, and 15.4 GW was reported to be under construction. The largest hydropower operator in India, National Hydroelectric Power Corporation (NHPC), has drawn up a plan to add over 49 GW in the next 20 years.

Nepal has a relatively large hydropower potential. The hydropower capacity under construction or planned amounts to approximately 20.5 GW, more than 80 percent of which is based on two giant hydro schemes that are under consideration.

The hydropower potential of Pakistan is concentrated in the mountainous northern half of the country. The installed hydropower capacity stands at approximately 6.5 GW and at least another 7 GW is under construction or planned.

Lao PDR (Laos) has a relatively large hydropower potential. In 2000, 627 MW of hydropower had been installed. Some 1,500 MW is under construction or planned.

Myanmar (formerly Burma) is topographically endowed with abundant hydropower resources. Existing hydropower plants constitute merely 360 MW. However, the hydropower capacity under construction or planned amounts to 4.5 GW.

The Philippines has a hydropower capacity of 2.5 GW (2001). Large hydropower projects totalling 2.2 GW have been identified, and more than 800 MW is under construction or planned.

Vietnam has a relatively large hydropower potential. The country's installed hydropower capacity is 4.1 GW. Another 5.7 GW is under construction of planned, more than sixty percent of which refer to one giant hydro scheme (the 3.6 GW Son La hydroelectric plant).

Latin America has a very large hydropower potential. Many countries rely heavily on hydropower for their electricity supply. For instance, hydropower makes up 80% of Brazil's electricity generation.

Brazil has abundant hydropower resources. Its installed hydropower capacity is more than 60 GW. The capacity under construction or planned is more than 25 GW. One of the hydropower plants under construction is the giant 11.18 GW Belo Monte power plant. Hydropower capacity under construction or planned in other South American countries - particularly Argentina, Bolivia, Chile, Colombia, Guyana, Peru, and Venezuela - amounts to 9.7 GW. Also, 4.4 GW of hydropower capacity is under construction or planned in Central American countries.

In Africa, hydropower and other renewable energy sources have not been widely established, except in a few countries. Egypt and Congo (Kinshasa) have the largest volumes of hydro capacity. Congo, Ethiopia, Ghana, Kenya, Malawi, Mozambique, Namibia/Angola, Senegal, Sudan, Tanzania, Uganda, Zambia, and Swaziland have hydropower plants under construction or planned are. The total hydro capacity under construction or planned amounts to 9.0 GW, among which the 3.5 GW Inga 3 hydroelectric scheme in Congo.

In the Middle East, hydropower accounts for 45 percent of Turkey's total installed capacity, and for 7 percent of Iran's installed capacity (2 out of 30 GW). The current installed hydropower capacity of Turkey is 11.6 GW. More than 3.6 GW is under construction or planned.

Eastern Europe is still to a large extent dependent on fossil fuels and nuclear energy for electricity generation. Development of new hydropower capacity is expected to remain fairly modest. Most of the growth will come from expansion and renovation of existing hydropower plants that need repair after difficult economic years. There are also opportunities for expanding hydroelectricity in several Eastern European countries, where undeveloped potential sites exist. The additional potential up to the technical hydropower potential of the EU Accession Countries, supplemented with Bulgaria and Romania, stands at 27 GW.

In Western Europe - defined as the 15-EU countries, plus Norway, Switzerland, and Iceland - the potential for additional hydropower is limited, due to economical and other considerations (conservation of landscape, environmental protection). These limitations may be of such overriding importance that national governments have put in place legal hindrances towards further development of (large) hydropower. Norway and Sweden are well-known examples of countries with legally binding limitations with regard to growth of hydropower. If electricity demand in Western Europe would remain stable (which is a 'big if'), the share of hydropower in total power generation could rise from 19.4 to 21.5% in the medium term. The technical hydropower potential - 240 GW or 800 TWh/a - is equal to 33.5% of the total power generated. However, development of the technical potential would overrule considerations of protection of environment and landscape in countries like Austria, Iceland, Italy, Greece, Norway, Portugal, Spain, Sweden, and Switzerland. With regard to pumped-storage hydropower, projects with an additional generating capacity of 2.5 GW (1.5 TWh/a) are identified in the EU.

The assessments of the technical-economic parameters and the social and environmental parameters of hydroelectric projects shows that some of them may be considered as a nightmare (from an ecological point of view), whereas others perform well from virtually all aspects taken into account. In countries with potential for large-scale hydropower, there is a debate whether large-scale hydropower is sustainable. Environmental groups generally favour small hydropower because this type of hydropower would entail less environmental degradation and loss of habitat for plants and/or animals (biodiversity). However, the distinction between large and small hydropower turns out to be not very practical. Measures to improve the environmental performance of hydropower plants may not be very costly.

On a global scale, hydropower is an important renewable energy source. In the long term, it will meet increasing competition from ‘new’ renewables (wind, solar, biomass, etc.). Whether a specific hydro project will be developed or not, depends not only on the economic benefits, but also on the environmental impacts (positive and negative). Sometimes, the environmental and social impacts of (large) hydropower projects may be substantial. However, thermal power generation and nuclear power also have their drawbacks. Global climate change seems to be the main threat to biodiversity and food production. In this context, the issue is to what degree will society accept some local impacts of hydropower, in order to mitigate the global impacts of climate change and other environmental risks from thermal power generation (coal- or gas-fired power).

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BOOT	Build Own Operate Transfer
BOT	Build Operate Transfer
CBK	Caliraya Botocan Kalayaan (Myanmar)
CEA	Central Electricity Authority (India)
CHP	Combined Heat and Power
DoE	Department of Energy (US)
DRC	Democratic Republic of Congo
DSI	Devlet Su Isleri (Turkey)
EdF	Electricité de France
EdL	Electricité du Laos
EGAT	Electricity Generating Authority of Thailand
EIA	Energy Information Administration (US)
EU	European Union
EVN	Electricity of Vietnam
FERC	Federal Energy Regulatory Commission (US)
FIMC	Foreign Investment Management Committee (Lao PDR)
FSU	Former Soviet Union
GAP	Güneydogu Anadolu Projesi (Turkey)
GEF	Global Environmental Facility
GHG	Greenhouse Gas
HEP	Hydro Electric Potential
HPE	Hidroeléctrica Papeles Elaborados S.A (Guatemala)
IEA	International Energy Agency
IPO	Initial Public Offering
ISET	Institut für Solare Energieversorgungstechnik (Kassel, Germany)
JANCOLD	Japan Commission on Large Dams
KfW	Kreditanstalt für Wiederaufbau
MNES	Ministry of Non-conventional Energy Sources (India)
MOST	Ministry Of Science and Technology (China)
MoU	Memorandum of Understanding
NEA	Nepal Electricity Authority
NEEPCO	Northeastern Electric Power Corporation (India)
NHPC	National Hydroelectric Power Corporation (India)
NLH	Newfoundland and Labrador Hydro (Canada)
NTPC	National Thermal Power Corporation (India)
OECD	Organisation for Economic Cooperation and Development
OECF	Overseas Economic Co-operation Fund (Japan)
SADC	Southern African Development Community
SAPP	Southern African Power Pool
SETC	State Economic and Trade Commission (China)
SHP	Small Hydro Power
SREP	Small Renewable Energy Power (Pakistan)
UNDP	United Nations Development Programme
US	United States of America
USAID	United States Agency for International Development
USIJI	United States Initiative on Joint Implementation
WAPDA	Water And Power Development Authority (Pakistan)
WCD	World Commission on Dams

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