

An aerial photograph of a large concrete dam situated in a deep, narrow canyon. The dam is a curved, gravity-style structure with a spillway on the right side. Behind the dam, a large reservoir of dark blue water is visible, surrounded by the reddish-brown, layered rock walls of the canyon. The landscape beyond the reservoir is a vast, flat desert plain under a clear blue sky.

***And what is a man without energy?
Nothing - nothing at all.***

Mark Twain

Part 1. Energy for Water Supply	308
1a. Energy use in water supply and sanitation services	308
<i>Extraction, conveyance and treatment</i>	308
<i>Distribution</i>	308
<i>Consumer end-use</i>	308
<i>Wastewater collection</i>	308
Box 9.1: Water conservation versus energy conservation	
1b. Approaches to energy and water efficiency	309
<i>Identifying water/energy efficiency opportunities</i>	309
<i>The systems approach</i>	310
Box 9.2: Energy conservation in the Moulton Niguel Water District, California	
1c. Desalination	310
Table 9.1: Volume of desalinated water produced, selected countries, 2002	
Box 9.3: Desalination using renewable energy, Greece	
1d. Solar energy for water supply	312
<i>Solar pumping</i>	312
<i>Solar water purifiers</i>	312
<i>Heating water for domestic use</i>	312
Part 2. Water for Energy Generation	313
2a. Hydropower in context	313
Box 9.4: World Summit on Sustainable Development: Energy targets	
Table 9.2: Grid-based renewable power capacity in 2003	
Box 9.5: Climate change and atmospheric pollution: Power generation from fossil fuels	
Fig. 9.1: Global generation of electricity by source, 1971-2001	
Fig. 9.2: Total primary energy supply by source, 2002	
Box 9.6: The development of hydropower in Africa	
2b. Focus on small hydropower (SHP)	319
Box 9.7: Small hydropower in China	
Table 9.3: Status of small hydropower stations in China in 2002	
Box 9.8: Small hydropower in Nepal	
2c. Pumped storage	319
Box 9.9: Palmiet pumped storage scheme, South Africa	
2d. Sustainable hydropower solutions	320
<i>Piggybacking alternative energy sources</i>	320
Box 9.10: Hydro Tasmania, Australia	
<i>Adding hydropower capacity to existing infrastructure</i>	320
Box 9.11: Hydropower generation in Freudenau, Austria	
<i>Extending the life and improving the efficiency of hydropower schemes</i>	321
2e. Environmental impacts of thermal power generation including water use	321
Table 9.4: Carbon intensity of electricity production in 2002	
Part 3. Governance of Energy and Water Resources	324
3a. The continuing debate on large hydropower	324
3b. Renewable energy and energy efficiency: Incentives and economic instruments	325
<i>International and national mechanisms implemented with the Kyoto Protocol</i>	325
Box 9.12: Renewable Obligation Certificates: A policy instrument promoting renewable energy	
<i>The case of rural electrification</i>	325
<i>Improving energy efficiency</i>	326
Box 9.13: Distributed generation: Power supply in the future	
3c. Policy-making for co-management of water and energy resources	327
Table 9.5: Access to electricity and water in 2000	
Table 9.6: Hydropower: Capability at the end of 2002	
References and Websites	335

9

CHAPTER 9

Water and Energy

By

UNIDO

(United Nations Industrial Development Organization)

Key messages:

Water and energy are two highly interconnected sectors: energy is needed throughout the water system, from supplying water to its various users, including urban people, to collecting and treating wastewater. On the other hand, water is essential to producing energy, from hydropower to water cooling in power stations.

In the context of a growing world population, leading to increasing demands and competition for water and energy, it is time to integrate the management of these resources. This chapter takes stock of the various possibilities to be explored in order to enhance water and energy efficiency and ensure sustainable development.

While much progress has yet to be made for ensuring universal access to water supply and sanitation, even more progress is needed to provide electricity for all. In order to achieve these challenging and urgent targets, water supply and energy production systems both need improvements that do not jeopardize the environment.

- There are very strong links between water and electrical power usage which at present are not fully taken into account in policy-making, management and operation of both water and electricity generation systems. The consequence is that many opportunities for both energy and water savings are being lost.
- Access to electricity for many poor people in lower-income countries continues to lag a long way behind access to an improved water supply. Access to electricity plays a big role in poverty alleviation, improved health and socio-economic development. Accelerating access to electricity for the poor, although not one of the Millennium Development Goals (MDGs), was one of the targets set at the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002.
- Concern about the impact on the environment of traditional methods of electrical power generation is driving the introduction of a variety of non-polluting, renewable energy sources. However, economies of scale on large thermal and hydropower plants, existing transmission/distribution grids plus government subsidies for these traditional systems, put the renewable approaches at a cost disadvantage. A wide range of renewable electricity production options is now available, together with a growing range of incentives and economic instruments to promote their use and also to promote increased efficiency of energy usage.
- Hydropower is available at different scales from very large systems to small systems. It is very flexible, permits rapid start up and can augment both thermal power plant base loads at peak times and compensate for fluctuating renewable supplies, as well as providing stand-alone generating capacity for smaller and remote communities. There is some controversy over whether large hydropower schemes are renewable power sources, but run-of-river systems are and there are now many options to increase sustainability.
- The supply of water and wastewater services of all kinds to urban areas generally involves high electrical energy consumption. However, by taking a total system approach to energy management in these systems, including energy audits, it is possible to achieve big energy savings. Desalination of saline and brackish water for urban water supply is growing as technology improvements bring significant decreases in costs.
- Experience has shown that the simultaneous analysis of water and energy use at the policy level can enable significant increase in productivity in the use of both resources. Water conservation can lead to large energy savings, as can taking full account of energy efficiency approaches in water policy decisions.

This page from top: Kut Al Amara dam, Iraq; Glen Canyon Dam, Arizona; Villagers draw water from a pump powered by solar panels, Tata, Morocco; Water pipeline transporting water up to a valley accumulation station

Right: The Blue Lagoon is an artificial lake fed by the surplus water drawn from the geothermal power station at Svartsengi, Iceland. Captured at 2,000 m below ground, the water reaches the surface at a temperature of 70°C, at which point it is used to heat neighbouring cities

Water and electricity use are inextricably linked. Large quantities of water are used for cooling in many electricity generating methods, such as coal and nuclear power stations. Hydropower, while not a consumptive use of water, often requires the construction of reservoirs and other large engineering works, which modify the aquatic environment. Conversely, large amounts of electrical power are used to pump water from its sources to the places it is used, especially in irrigated agriculture and municipal water systems.

Further links between the water and energy sectors are created by the frequent inefficiency and wastage in the way both resources are used. There are serious inefficiencies in many parts of the world in electricity generation, transmission, distribution and usage. Likewise, there are inefficiencies and leaks in water distribution systems. It follows that substantial efficiency gains in water use will reduce electric power requirements, which in turn will lead to more savings of water otherwise used in power generation.

A great deal of the infrastructure for both power and water in middle- and lower-income countries is poorly maintained. There is also a serious lack of the infrastructure needed to extend necessary power and water services to the many people presently unserved. Access to electricity for the poor lags far behind access to drinking water supply in many countries. For example, in sub-Saharan Africa, only 25 percent of the population have access to electricity, while 83 percent of the urban population and 46 percent of the rural population have access to a water supply (see **Table 9.5** at the end of this chapter).

Thus there is great pressure on governments in developing countries to build power stations and to deliver more electricity for domestic use and industrial development. Yet increasing power generation through burning coal, oil and gas presents its own set of sustainability issues linked to the generation of carbon dioxide (CO₂) and the greenhouse effect. The majority of electricity worldwide is generated by fossil fuel power stations from which emissions exacerbate the problems of climate variability and changes, raising the intensity of natural disasters, which mainly impact the poor. Moving away from a carbon-rich power-generating environment to more sustainable generation methods and reducing the inefficiencies mentioned earlier will help to alleviate this problem.

In the rapidly growing urban environments in developing countries, energy costs draw budgetary resources from other municipal functions, such as education, public transportation and health care. Without the provision of reliable sustainable energy supplies, it is unlikely that the Millennium Development Goals (MDGs) of reducing hunger, providing safe drinking water, providing sanitation and improving health will be achieved.

Access to electricity for the poor lags far behind access to drinking water supply in many countries...in sub-Saharan Africa, only 25 percent of the population have access to electricity...





...the energy required by the end uses of water is far greater than in the other steps of the urban water cycle

Part 1. Energy for Water Supply

In many countries, agricultural irrigation, groundwater pumping, interbasin transfers, and urban water supply and sanitation systems are major electricity users. Improving water use efficiency and introducing water conservation measures can therefore significantly reduce energy use. This section sets out to show how the two issues are interlinked, focusing upon urban water supply, and how the two systems should be co-managed, with future implications for both water and energy policies.

1a. Energy use in water supply and sanitation services

Nearly all modern urban water and wastewater systems require energy in all phases of the treatment, delivery, collection, treatment and disposal cycle. Where historical systems once depended on surface water sources, gravity distribution systems and dilution for wastewater treatment, the water needs of growing urban areas need additional energy input to safeguard human health.

Extraction, conveyance and treatment

The first step of the urban water cycle is extraction, conveyance and treatment. The most widely used sources of potable water are surface sources and groundwater wells. The use of a particular source in a region depends on the availability and the cost of water extraction. Surface sources such as lakes, rivers and reservoirs typically require some treatment to achieve potable quality. The quality of the water body and the desired level and type of treatment are key variables in energy inputs required at this step. Groundwater sources have a more direct energy requirement, since energy is needed to pump the water up out of the ground, usually from bore. The amount of energy required by a pump and motor system to extract groundwater depends on the depth of the water table beneath the ground. It is important to note that water recycling and reuse, including a treatment step, is generally far less energy-intensive than developing any new physical source of water, other than local surface water.

Distribution

Distribution of potable water is often the most variable step in the urban water cycle. Ideally, the water source is at a higher elevation than the intended destination. In this case, gravity is used to distribute water and no energy input is required. In most cases, though, varied topography requires energy input through booster pumps to generate sufficient pressure in the system to distribute water to communities at higher elevations. Pumped storage,¹ which is further discussed later in this chapter, is often used at this stage to take advantage of off-peak

energy rates, converting pumping mechanical energy to potential energy by storing water at higher elevations. There are areas where conveying water can be highly energy intensive. Since water conservation saves all of the upstream energy inputs as well as the end-use energy inputs, water conservation in areas with energy intensive water supplies will save substantially more energy than water conservation in other areas.

Consumer end-use

Once water is delivered for consumer use, additional energy inputs come from heating and cooling water. Residential and commercial consumers heat water for bathing, radiant heating and dishwashing and cool water for air conditioning. Industrial consumers vary widely in their needs for heated and cooled water based on the industrial application and their process needs. However, the energy required by the end-uses of water is far greater than in the other steps of the urban water cycle. While there are efficiency improvements that can reduce the energy inputs required at each stage of the water use cycle, the greatest energy and water savings come from reducing water consumed by various end-uses (see **Box 9.1**). Water conservation at the end-use stage eliminates all of the upstream energy required to bring the water to the point of end-use, as well as all of the downstream energy that would otherwise be spent to collect, treat and dispose of this water.

Wastewater collection

Like distribution, wastewater collection is ideally done using gravity systems. When this is not possible, pumps are used to boost the wastewater to treatment facilities. In combined sanitary and storm-water sewers, precipitation affects the energy requirements of collection systems and heavy rains sometimes overwhelm the available infrastructure.

Wastewater treatment requires energy to remove contaminants and prepare the water for discharge or reuse. In aerobic wastewater treatment, the largest energy input is in the aeration system itself. Some types of wastewater

1. This involves pairs of reservoirs with a significant height difference. Water is pumped up when there is spare capacity in the network and then allowed to flow down again and generate power at times of peak demand.

treatment require very little energy (e.g. lagoons) but large amounts of land. In urban areas where land is scarce, more energy is required to treat large amounts of wastewater in a treatment plant requiring less land area. Opportunities exist to recover some of the energy embodied in the organic material present in wastewater, by recovering methane gas through anaerobic treatment and then using this fuel to power the treatment facility. Indeed, some wastewater treatment plants even provide electricity to the national grid.

1b. Approaches to energy and water efficiency

Because of the interconnectedness of water and energy, it is vital to manage them together rather than in isolation. The energy savings from water conservation and the water savings from energy efficiency are inextricably linked, and these linkages should be considered when determining the best course of action from an economic, social or environmental perspective. Energy efficiency in the water and wastewater industry saves money in operations and maintenance costs, reduces capital costs of new supply, improves solvency and operations capacity of water utilities, improves service coverage, reduces emissions and improves water quality, among a host of other related benefits.

In order to support larger efforts to reduce energy use in water and wastewater systems, larger-scale energy and water management should be entrusted to the local level for implementation. The term 'watergy' efficiency has

been coined to describe the combined water and energy efficiencies which are available to municipalities and water users (see **Box 9.2**).

Involvement of the energy utility provides the needed support for implementing energy efficiency measures and ensuring that efforts to reduce energy and water waste are sustainable as a business practice. Energy efficiency in any water utility never has a beginning or an end. To sustain its energy savings, a water utility must continue to monitor its energy use and set goals for improvement.

Identifying water/energy efficiency opportunities

Energy and water audits are used to identify areas of concern in water and wastewater systems. The boundaries of the system to be audited are usually chosen based on budgetary considerations and areas that are presumed to yield the largest energy savings for the investment.

Major areas that are frequently identified as water/energy savings opportunities in water supply systems include the following:

- Repairing leaks from valves, distribution pipes, etc. Many urban water distribution systems in developed cities were installed more than fifty years ago, and leaks caused by corrosion of pipe material or other problems



Small-scale hydro-energy generation in Lao Cai, Viet Nam

BOX 9.1: WATER CONSERVATION VERSUS ENERGY CONSERVATION

Energy intensity measures the amount of energy used per unit of water. Some water sources are more energy intensive than others; for instance, desalination requires more energy than wastewater recycling. Water conservation technology may either increase or decrease energy intensity. Yet when water planners make decisions, they should look not just at energy intensity, but also at the total energy used from source to tap. In the case of water conservation, some programmes may consume a lot of energy at one stage in the energy/water use cycle, but still decrease the amount of energy used overall. The following three examples illustrate the interplay between energy intensity and total energy use:

- Water conservation may increase energy intensity and increase total energy use: A particular irrigation technology could reduce water use by 5 percent but require so much energy to operate that it increases the energy intensity by 10 percent. This would increase total energy use by 4.5 percent.
- Water conservation may increase energy intensity and decrease total energy use: The average high-efficiency dishwasher increases the energy intensity of dishwashing by 30 percent, but reduces water use by 34 percent. As a result of using less water (and therefore less energy to convey water from the source to the dishwasher) the net total energy needed to wash dishes declines by 14 percent.

- Water conservation may decrease energy intensity and decrease total energy use: The average high-efficiency clothes washer reduces water use by 29 percent, compared to average low-efficiency machines, and simultaneously lowers energy intensity by 27 percent. Energy intensity declines, because mechanical aspects of the machines are also improved. By reducing total water use as well as energy intensity, total energy use is reduced by 48 percent.

Source: NRDC, 2004.

Pumping systems are significant energy consumers in most water distribution systems, and the potential for substantial energy reduction exists in most water facilities throughout the world

Mobile solar water-heating equipment provided by an environmental centre in a slum area, Johannesburg, South Africa

can lead to the loss of significant amounts of potable water. Distribution system losses increase the energy intensity of water supply by requiring utilities to treat and convey water that will be lost. Losses vary significantly among urban water suppliers and range as high as 30 percent in developed cities. In developing cities, the proportion of water lost to leakage may be even higher, typically 40 to 60 percent. (Only about 2 percent of this lost water goes to unmetered uses, such as firefighting and construction.)

- Correct sizing, design and maintenance of the pump and motor system. Pumping systems are significant energy consumers in most water distribution systems, and the potential for substantial energy reduction exists in most water facilities throughout the world. Small improvements in efficiency can be achieved by installing the most efficient pump equipment available. More significant, however, is the saving potential through optimizing the entire pumping system, including the pump, motor, drive, controls, piping, valves and any other ancillary equipment. Similarly, for large systems made up of multiple pumps in parallel or series, opportunities exist for optimizing control strategies. This type of optimization can be carried out through adopting the systems approach.

The systems approach

The cost-effective operation and maintenance of a pumping system requires attention not only to the needs of the individual pieces of equipment, but also to the system as a whole. A 'systems approach' considers both the supply and demand sides of the system and how they interact, essentially shifting the focus from individual components to total system performance. Often, operators are so focused on the immediate demands of the equipment that they overlook the broader question of how system parameters are affecting the equipment. For example, the frequent replacement of pump seals and bearings can keep a maintenance crew so busy that they overlook the system operating conditions that caused the problems in the first place. **Box 9.2** provides an example of the systems approach as applied in California.

1c. Desalination

Ninety-seven percent of the world's water is too salty for consumption or agriculture. Desalination is not a new

concept, as it has been practised since biblical times. However, the process typically consumes large quantities of energy in order to produce drinking water from seawater or polluted water, making energy cost the major determinant of the desalination cost. Hence desalination technology has tended to be used in water-scarce countries where energy is cheap and plentiful. (see **Table 9.1**) Some 65 percent of the world's desalination plants are located in the Arabian Gulf countries.

Desalination can be achieved either by removing salt from water, or by removing pure water from a saline or polluted source. For producing large quantities of freshwater from a saline source, it is necessary to remove the water from the salt. This process leaves behind a highly concentrated saline solution, or brine, which must be disposed of as a waste product, often in the sea.

Traditionally, thermal desalination or distillation has been the most commonly used technology for producing large quantities of freshwater from seawater. Different thermal desalination processes require different magnitudes and combinations of heat and electricity. The economic efficiency of desalination plants is improved by combining the purposes of power and water production. Most of the

Table 9.1: Volume of desalinated water produced, selected countries, 2002

Country	Desalinated water (million m ³ /year)
Kazakhstan	1,328.0
Saudi Arabia	714.0
United Arab Emirates	385.0
Kuwait	231.0
Qatar	98.6
Libyan Arab Jamahiriya	70.0
Algeria	64.0
Bahrain	44.1
Oman	34.0
Malta	31.4
Egypt	25.0
Yemen	10.0
Tunisia	8.3
Morocco	3.4
Iran, Islamic Rep.	2.9
Jordan	2.0
Mauritania	1.7
Turkey	0.5
Sudan	0.4
Somalia	0.1
Djibouti	0.1

Source: FAO's AQUASTAT, 2003.



BOX 9.2: ENERGY CONSERVATION IN THE MOULTON NIGUEL WATER DISTRICT, CALIFORNIA

The Moulton Niguel Water District, located in southern California, has a water system capacity of 181 million litres per day and a wastewater system capacity of 64 million litres per day. The water district began investigating energy efficiency measures when facing significant increases in energy costs. The water district staff used the systems approach when evaluating both their water and wastewater facilities. Changes implemented included the following:

- installing an energy management system using programmable logic controllers that activate and de-activate pumps at seventy-seven district pumping stations to take advantage of off-peak electricity rates
- installing variable frequency drives onto the wastewater pumps to reduce motor wear, improve control over lift station wastewater levels, and help prevent stagnant sewage in pipes

- specifying high-efficiency (95 to 97 percent) electric motors for all new construction, while establishing a policy to replace existing motors as they fail or approach the end of their useful life.

The annual savings attributed to these efficiency improvements is over US \$330,000, representing a reduction in electricity costs of approximately 25 percent.

Source: Alliance to Save Energy, (www.ase.org).

BOX 9.3: DESALINATION USING RENEWABLE ENERGY, GREECE

Research being carried out in Greece has linked a reverse osmosis unit for membrane desalination to a wind generator and a solar photovoltaic array, in order to create a unit that can be used in remote areas where there is no potable water and no electricity grid. The unit currently produces 130 litres per hour (L/h) of potable water from seawater containing

approximately 37,000 parts per million (ppm) of total dissolved solids (TDS), while processing 1,000 L/h of seawater. The recovery ratio is approximately 15 percent, which is low compared to other systems. During a Greek summer, the unit can operate for an average of eight hours per day on solar energy, while in winter the operating time drops to an average of five hours

per day; however, the operating time is boosted when wind energy is available. This is a promising technology for helping remote coastal areas to improve access to drinking water supplies.

Source: Martinot, 2004.

desalination plants operating in the Middle East and elsewhere are dual-purpose multistage flash distillation plants that produce both water and electricity, using oil as the energy source. However, oil price rises undermine the economic performance of these plants, even in the Arabian Gulf region. As a result, nuclear power is increasingly being considered as a viable energy source for thermal desalination plants, particularly in countries that have local uranium reserves. The advantages include fuel price stability and the long-term availability of the fuel, but these need to be balanced against the well-known drawbacks of high initial investment costs and the disposal of spent nuclear fuel.

Reverse osmosis (membrane desalination) is an electrically-driven process that uses special membranes through which water molecules may pass under pressure, leaving behind larger molecules, including salt. The capital cost of reverse osmosis units is dropping, and they are now the most common choice for new desalination plants. The water utility Thames Water in the UK is currently investing £300

million (US \$539 million) in a reverse osmosis plant to treat water from the tidal estuary of the River Thames. The plant, due for completion in 2007, will serve 900,000 customers in London, producing up to 150,000 m³/day of drinking quality water. This technology can be combined with renewable energy processes, as shown in **Box 9.3**.

Some countries, such as Spain, increasingly prefer the desalination option to environmentally damaging inter-basin transfers, in order to bring water to arid coastal areas. However, before advocating moving forward with large-scale desalination, it must be recognized that relatively little is yet known about its impact on marine and coastal environments. Few studies have been conducted on marine resource impacts from the large-scale desalination facilities in the Middle East. The range of potential adverse environmental impacts that may arise from new desalination facilities include the impacts from construction, waste discharge, injury and death of aquatic life from water intakes, and the secondary impacts of

Countries such as Spain are increasingly choosing the desalination option in preference to environmentally damaging inter-basin transfer...



Reverse osmosis desalination unit in the Virgin Islands, United States

increased energy consumption. These must all be explored and adequately addressed before the development of desalination facilities begins. In most cases, water conservation and water recycling offer cheaper and better alternatives. The heavy energy cost of desalination also suggests the need to consider desalination plants as an emergency water supply, to be used during water demand peaks or droughts, rather than as a base supply.

1d. Solar energy for water supply

Small and inexpensive solar units are now available for many water-related applications, including pumping, water purification and solar water heating.

Solar pumping

Solar power can be used to help achieve the MDG of providing safe and accessible drinking water in countries that have plenty of sunlight. The great potential of solar pumping is to bring freshwater to villages that have no electricity and pump groundwater. There are many different types of solar pumps now available for various applications. At present, sales of solar pumps are largely to developed countries, because the prices of the systems are still rather high, but they are dropping rapidly as demand grows.

Solar water purifiers

The simplest and cheapest solar water disinfection system has been named SoDis (Solar Disinfection), and is designed for use at the household level. It improves the microbiological quality of drinking water by using solar ultraviolet-A (UV-A) radiation and heat to inactivate the pathogens that cause diarrhoea. The system uses commonly available plastic soft drink bottles. Contaminated water is filled into the transparent plastic bottles and exposed to full sunlight for six hours. The water must be relatively clear, and the bottles must be clean and unscratched. The required heating can be achieved by placing the bottles on a corrugated iron sheet or on a rooftop.

A more sophisticated solar water disinfection system called Naiade has been developed for use in developing countries. It produces safe drinking water from polluted water in a sustainable manner, without the use of chemicals, by means of UV irradiation. The unit weighs 44 kg and can produce on average up to 2,000 litres per day of high-quality drinking water. Water from a well or surface source is poured into the unit, either by hand or pipe. The water passes through a sieve, which removes large impurities, then through two filters, which remove

microscopic particles (including nematodes), and finally under an ultraviolet lamp. The ultraviolet light kills bacteria, viruses and worm eggs. It can be activated by the use of an electric battery, by the connection to electricity mains or by using a 75-watt solar panel. Maintenance and management of the unit is simple: if the filters become blocked, they can be easily cleaned by hand, which needs to be done daily.

Heating water for domestic use

Solar thermal capacity for domestic hot water and space heating is growing rapidly. Worldwide, the sector grew by 16 percent in 2003, while in China it grew by 30 percent. Although some developing countries are located in warm or tropical climates where hot water is not of primary importance, in many areas, especially those that are mountainous, there is a considerable demand for hot water. Solar water heaters are especially useful in the tourism sector and the hotel industry, as well as laundries, hospitals and clinics. Where solar water heaters displace electrical ones, they play a significant role in reducing peak electricity demand and reduce the negative environmental impact of fossil fuel use. Appropriate policies and economic incentives need to be put in place to stimulate the spread of this technology.

By 2003 there were about 29 million domestic solar water heaters installed worldwide, 21 million of which were in developing countries. Several million are located in China and India, while Egypt and Turkey have hundreds of thousands of households served by solar water heaters. In Barbados there are over 35,000 solar water heaters installed (33 percent of all households). Each unit saves about 4,000 kWh per year. This represents a considerable foreign exchange savings on the import of diesel fuel for the island, in addition to avoiding carbon emissions. It has been calculated that these solar water heaters replace 30 to 35 MW of additional electric generating capacity that would otherwise have to be installed in Barbados.

The success of solar water heaters in Barbados was supported through various governance mechanisms. A 30 percent consumption tax was put on electric water heaters; furthermore, the cost of electricity is relatively high in Barbados, which is also an incentive. Homeowners can gain concessions on their mortgages by installing solar water heaters. In Australia, each solar water heater with an electricity equivalent of 1 MWh over its lifetime receives between ten and thirty-five green certificates. These certificates have an economic value (US \$18 in 2002),

By 2003 there had been about 29 million domestic solar water heaters installed worldwide, of which 21 million were in developing countries

since electricity suppliers are obliged to purchase a certain share of electricity from renewable energy sources, which they can prove by presenting a corresponding number of green certificates. In other countries, different means have been used to foster the use of solar water heaters,

including direct grants. In Namibia, the government requires solar water heaters to be installed in the construction of all new government housing, while in India, the government has introduced accelerated depreciation for commercial and public applications of solar water heaters.

Part 2. Water for Energy Generation

Hydropower, and small hydropower (SHP) in particular, is recognized as a flexible and affordable renewable energy source. Its role in electricity generation, especially in rapidly developing countries, is crucial. The World Commission on Dams (WCD, 2002) focused attention internationally on the negative environmental and social impacts of large dams, which raised questions about the environmental sustainability of large hydropower projects. However, only about 25 percent of the world's large dams are involved in producing hydropower. The rest were built for other purposes, mainly for irrigation, but also for water storage, for recreation and for assisting in river transport. Conversely, many large hydropower projects are run-of-river projects, which do not necessitate the building of a dam, while the role of small, mini- and micro-hydropower schemes is becoming increasingly important in the energy security of many countries, led by the example of China. It is therefore important to disassociate a discussion of the role of hydropower from the debate over large dams, while not glossing over the environmental and social considerations involved in the choice of technology.

2a. Hydropower in context

Governments have a pressing need to provide, at an affordable price, the convenience and reliability offered by electricity. The role of energy, and electricity in particular, in meeting development targets was discussed in depth in the first edition of the *UN World Water Development Report*. Statistics show that for many developing countries, access to electricity lags behind access to an improved water supply (see **Table 9.5** at the end of the chapter). Although improving access to electricity is not one of the MDGs, it was a target at the Johannesburg Plan of Implementation adopted at the World Summit on Sustainable Development (WSSD) in 2002 (see **Box 9.4**). Electricity plays a key role in reducing poverty, promoting economic activities and improving quality of life, health, and education opportunities, especially for women and children.

Since 1970, as worldwide demand for electricity has steadily increased, governments have met this demand through increasing thermal (gas, oil, coal and nuclear), as well as hydropower generation capacity. Although the share of hydropower in total world energy supply was only 2.2 percent in 2002, hydropower accounted for 19 percent of all electric power generated (see **Figures 9.1 and 9.2**).

Over the same time period, there has been a perceptible increase in the use of other renewable energy sources (geothermal, solar photovoltaics, wind, and combined heat and power² [CHP]). **Table 9.2** shows the renewable power capacity in all countries and in developing countries in 2003. Environmental concerns, particularly over climate change and nuclear waste disposal, as well as safety and security of supply, have prompted governments to introduce policies aimed at accelerating the penetration of renewables and CHP (see **Box 9.5**). Total worldwide investment in renewable energy rose from US \$6 billion in 1995 to approximately US \$22 billion in 2003, and is increasing rapidly.

The economies of scale available to the thermal and hydropower options and the existence of transmission and distribution grids continue to give them a significant cost advantage when compared with renewables. Both the thermal and hydropower options, particularly when used together, offer the load-following capability and reliability demanded by electricity consumers. Subsidies of all types have historically been used worldwide to establish a top-down energy supply system favouring thermal and large hydropower generating plants of ever-increasing capacity. However, both thermal and large hydropower options bring



Electricity plays a key role in reducing poverty, promoting economic activities and improving quality of life, health, and education opportunities...

2. CHP is the simultaneous generation of electric power and steam used for heating.

BOX 9.4: WORLD SUMMIT ON SUSTAINABLE DEVELOPMENT: ENERGY TARGETS

- 'Take joint actions and improve efforts to work together at all levels to improve access to reliable and affordable energy services for sustainable development sufficient to facilitate the achievement of the Millennium Development Goals, including the goal of halving the proportion of people in poverty by 2015, and as a means to generate other important services that mitigate poverty, bearing in mind that access to energy facilitates the eradication of poverty' (Target II.9).
- 'Assist and facilitate on an accelerated basis ... the access of the poor to reliable, affordable, economically viable, socially acceptable and environmentally sound energy services, taking into account the instrumental role of developing national policies on energy for sustainable development, bearing in mind that in developing countries sharp increases in energy services are required to improve the standards of living of their populations and that energy services have positive impacts on poverty eradication and improve standards of living' (Target II.9g).
- 'Diversify energy supply by developing advanced, cleaner, more efficient, affordable and cost-effective energy technologies, hydro included, and their transfer to developing countries on concessional terms as mutually agreed. With a sense of urgency, substantially increase the global share of renewable energy sources with the objective of increasing its contribution to total energy supply... ensuring that energy policies are supportive to developing countries' efforts to eradicate poverty, and regularly evaluate available data to review progress to this end' (Target III.20e).
- 'Assist developing countries in providing affordable energy to rural communities, particularly to reduce dependence on traditional fuel sources for cooking and heating, which affect the health of women and children' (Target VI.56d).
- 'Deal effectively with energy problems in Africa, including through initiatives to... support Africa's efforts to implement NEPAD objectives on energy, which seek to secure access for at least 35 percent of the African population within twenty years, especially in rural areas' (Target VIII.62j).

Source: UN, 2002.

BOX 9.5: CLIMATE CHANGE AND ATMOSPHERIC POLLUTION: POWER GENERATION FROM FOSSIL FUELS

In the industrialized world, the future of fossil fuel-based electricity generation will be largely determined by requirements for reducing greenhouse gas emissions. Targets established under the Kyoto Protocol to the UN Framework Convention on Climate Change amount to an aggregate reduction shared among all Parties to the Protocol of at least 5 percent from 1990 levels by 2008–12. As its Kyoto commitment, the European Union (EU) agreed to an 8 percent reduction shared between its Member States. The EU has also established a plan whereby sources from which emissions are to be capped may trade their emissions allowances (the EU Emissions Trading Scheme). The majority of

capped emissions sources under this scheme are coal-based power plants.

The EU Large Combustion Plant Directive establishes limits for emissions to air for nitrogen oxides, sulphur dioxide and particulates (dust) from combustion plants with a thermal input of 50MW or more. Similar environmental legislation is in place in the United States, other Organisation for Economic Co-operation and Development (OECD) Member States and several developing nations. Limits on emissions of heavy metals and organic pollutants from fossil fuel combustion can also be expected. Today, flue gas filtration and other emissions control

technologies have enabled new fossil fuel-fired power plants to meet these requirements.

Unlike oil and gas, worldwide coal reserves are plentiful and sufficient for the next 200 years. Coal deposits are widely distributed geographically, and coal is traded internationally. Several developing nations can be expected to continue using coal for decades to come. China is adding 15–20 gigawatt-equivalents (GWe) of new coal-fired capacity each year. Decarbonization of fossil fuels, particularly coal, is being developed as an interim measure, together with carbon sequestration, bridging the gap towards a fully renewable energy system.

Table 9.2: Grid-based renewable power capacity in 2003

Generation type	Capacity in all countries (gigawatts)	Capacity in developing countries (gigawatts)
Small hydropower	56.0	33.0
Wind power	40.0	3.0
Biomass power*	35.0	18.0
Geothermal power	9.0	4.0
Solar photovoltaics (grid connected)	1.1	<0.1
Solar thermal power	0.4	0
TOTAL RENEWABLE POWER CAPACITY	141.5	58.0
For comparison:		
Large hydropower	674.0	303.0
Total electric power capacity	3,700.0	1,300.0

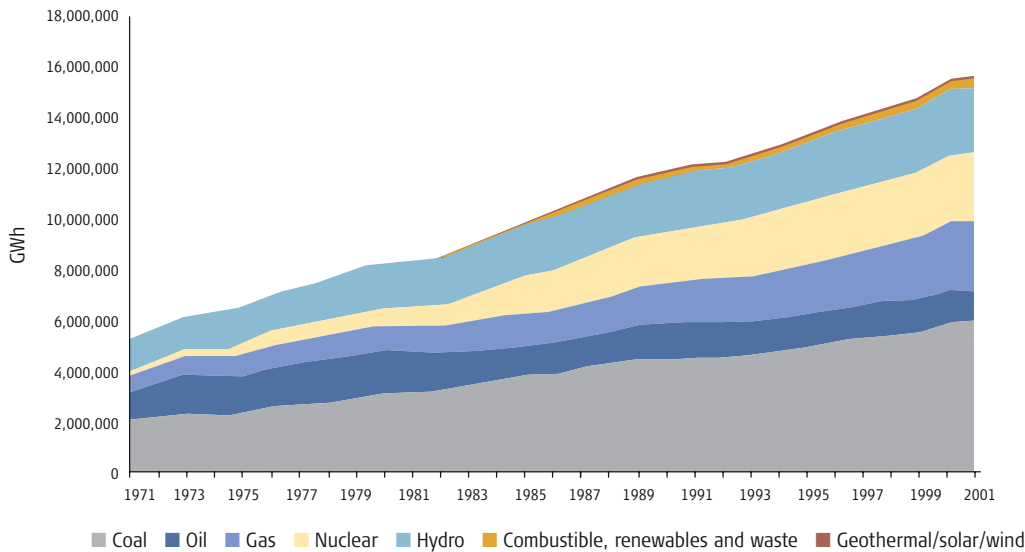
* Excluding municipal solid waste combustion and power from landfill gas.

Source: Adapted from Martinot, 2002.



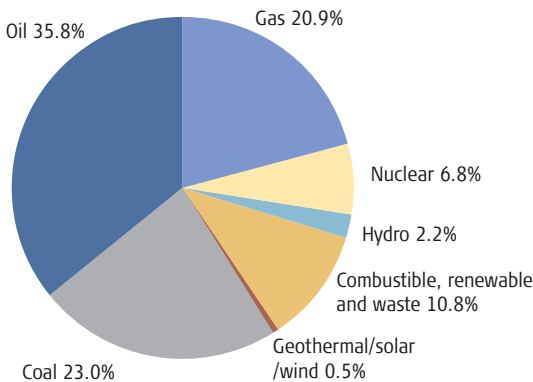
Solar power plant in Whitecliffs, Australia

Figure 9.1: Global generation of electricity by source, 1971–2001



Source: International Energy Agency, 2004.

Figure 9.2: Total primary energy supply by source, 2002



Source: International Energy Agency, 2005.

...hydropower offers great benefits and holds a unique place in the range of energy options for electricity generation which are currently available

environmental problems and potentially unacceptable social consequences, such as the displacement of inhabitants for the construction of large dams, which now constrain their deployment. Hence more sustainable approaches, small-scale alternatives and distributed generation are gaining ground in many countries.

In 2001, hydropower generated 2,740 terawatt hours (TWh), or 19 percent of the world's electricity. This is the equivalent of 2.1 billion metric tons of CO₂ emissions, if that energy had been generated by oil, gas or coal power stations. The usage of hydropower varies greatly from country to country. Twenty-four countries generate more than 90 percent of their electricity through hydropower, whereas others generate none at all. Europe makes use of 75 percent of its hydropower potential, while Africa has developed only 7 percent. This is seen to be the possible future cornerstone of Africa's development, including significant export potential, with plans to establish a continent-wide electricity grid (see **Box 9.6**). At the end of this chapter, **Table 9.6** shows countries' capability for providing energy through hydropower.

There are several different types of hydropower, each suitable for different needs and circumstances:

- **Reservoirs:** This type of hydropower involves the construction of a dam (large or small) and the formation of a reservoir. Such construction is usually multi-purpose, both for water supply and for electricity production. This type of hydropower brings maximum flexibility of supply and maximum efficiency.
- **Pumped storage:** This involves pairs of reservoirs with a significant height difference. Water is pumped when there is spare capacity in the network and then allowed to flow down again and generate power at times of peak demand. It uses more power than it generates, but is essential as a flexible reserve and can make an electricity network more efficient.
- **Run-of-river:** This form of hydropower uses the stream's flow and has little or no reservoir capacity for storage or regulation. In social and environmental terms, it is seen as preferable to reservoir construction. Smaller hydropower schemes (including micro- and

BOX 9.6: THE DEVELOPMENT OF HYDROPOWER IN AFRICA

Africa is a heavy user of traditional (non-commercial) energy, namely biomass. Per capita electricity consumption is particularly low in Central, East and West Africa. In 2000, it was calculated that there were 7,730 megawatts (MW) of surplus installed generating capacity in the southern African grid. Hydropower presently provides 22 percent of electricity generation in Africa; nuclear power provides 2 percent, while thermal power stations provide 70 percent. However, reliance on hydropower is 80 percent or greater in Cameroon, the Democratic Republic of the Congo, Ghana, Mozambique, Rwanda, Uganda and Zambia. Because of the enormous potential of Africa's great rivers, particularly the Zambezi and the Congo, hydropower is seen as the motive force for future development in Africa.

Mozambique

Mphanda Nkuwa is a very large hydropower project by international standards. The planned capacity is 1,300 MW, making it slightly smaller than Cahora Bassa, which was commissioned in the mid-1970s and has an installed capacity of 2,075 MW. The site is located on the Zambezi River between Cahora Bassa and Tete. Mphanda Nkuwa is rated as one of the most attractive undeveloped hydropower projects in the world. The hydrological risk has been limited and well documented with long time-series of water flows. The geological risk is low and the dam site can be developed at a cost of US \$640 per kilowatt of installed capacity. Since existing upstream dams, such as Cahora Bassa, Kariba and Kafue Gorge, regulate the Zambezi River, the project can be developed as a run-of-river hydropower plant requiring a small reservoir relative to its size, with very limited negative environmental impact.

Democratic Republic of Congo

The estimated cost of the 3,500 MW Inga III power station to be built on the Congo River is US \$3,74 billion. The planned transmission lines of the so-called Western Corridor – with the termination points being up to 3,500 km from Inga – will require a further investment in the region of US \$652 million. In addition, two 1,500 MW converter stations that will cost US \$842 million are planned as part of the project. The aim is to have Inga III and the Western Corridor on line by 2015. This would open the way for further development of the Inga site, namely the Grand Inga project (a run-of-river project) with a generating capability of up to 39,000 MW. The economic feasibility of Grand Inga is seen to be dependent upon a continental market developing throughout Africa, with power ultimately being exported to North Africa and possibly even to Europe.

Source: UNECA, 2004.

pico-hydro) are usually run-of-river projects, but the technology is increasingly being applied in large schemes where the topography makes it feasible, as fast-flowing water is required.

Conventional hydropower (other than pumped storage) is vulnerable to droughts and seasonal fluctuations in rainfall. However, its value to the electricity system of a country is that it brings great flexibility. Electric power

cannot be stored, yet demand is constantly fluctuating in response to both predictable and unpredictable events.

Hydropower can be used at peak periods to supplement supply from less flexible thermal and nuclear power stations. Water can be held indefinitely in a reservoir and then released exactly when it is needed to produce power (pumped storage). It is particularly valuable in tandem with other renewable sources, such as solar or wind power, whose outputs wax and wane

BOX 9.7: SMALL HYDROPOWER IN CHINA

China is well known for its large hydropower schemes, such as the Xiaolangdi power station on the Yellow River, which generates 1,800 megawatts (MW) of electricity, and the planned power station of the newly completed Three Gorges Dam on the Yangtze River, which will generate up to 16,000 MW. However, China has also attracted international attention due to its small hydropower (SHP) development, focusing on rural electrification.

Approximately one half of all commissioned SHP plants worldwide are located in China. Although the total feasible development potential of SHP is approximately 100,000 MW throughout China, the majority of the rapid recent development has been located in the southeast and southwest of the country. By the end of 2002, China had installed 28,489 MW of capacity through building 42,221 SHP plants. The unique features of China's SHP policy can be characterized by the following features:

- its decentralized approach
- its use of local grid structures (or mini-grids)
- the specific policies and strategies it adopts, particularly the overarching SHP policy of self-construction, self-management and self-utilization
- the popularization of a share-holding investment system
- its utilization of cost-effective SHP technology and equipment, the use of indigenous equipment manufacturers, and the prioritization of training.

SHP now accounts for about 30 percent of China's overall hydropower capacity. Three hundred million people in China now use SHP-derived electricity. The improvement in access to electricity in remote rural areas has been dramatic: 28 million people in China had no electricity in 2000, and that figure had dropped to 10.15 million by the end of 2002.

Nearly half of China's SHP generators are linked to local mini-grids (especially in mountainous areas), while only 10 percent are connected to the national grid. The remainder of SHP stations operate in isolation. Forty-four percent of China's SHP projects fall into the sub-category of micro-hydro, with capacity of less than 100 kW. Another 46 percent are mini-hydro, with a capacity up to 500 kW. The larger SHP projects – with a capacity between 500 kW and 25 MW – make up the remaining 10 percent of the projects, but account for 75 percent of the electricity output.

The construction of SHP-based local grids to serve specific rural supply areas is a unique electricity supply system developed by China. The rate of electrification in villages and rural households rose from 78.1 and 65.3 percent in 1985 to 97.7 and 97.5 percent in 2002, respectively. The quality of electricity supply was improved, and tariffs were reduced to be equal with that of urban centres. There are two types of SHP stations: those invested, owned and managed by local government and small Independent Power Producers (IPPs) developed with private investment. The recent

disposition of SHP stations in China, according to installed capacity, operation mode and ownership can be seen in **Table 9.3**.

The rapid development of SHP in China can be attributed to the following:

- **Preferential policies:** The Chinese Government introduced many preferential policies for SHP, such as tax reductions, soft loans/grants from government, encouragement of private firms to invest in SHP stations and policies protecting water supply areas and property ownership. The ratio of central government investment in SHP to that of the private/individual contribution is only 1:24.
- **Indigenous manufacturing capability:** In view of the fact that equipment costs form the largest percentage of the total cost of SHP development – unlike in large hydro, where civil works generally takes a higher proportion – the Chinese government decided to promote local manufacturing in order to reduce the overall cost of developing SHP stations.
- **Recognizing the advantages of SHP over large hydropower:** China has known for a long time that SHP has its own peculiar advantages that cannot be achieved through large hydropower generation.

Source: International Networking on Small Hydropower (www.inshp.org).

Pumped storage reservoirs are smaller than conventional reservoirs and less controversial, since they are less dependent on the topography

Table 9.3: Status of small hydropower stations in China in 2002

		<i>SHP stations by Installed Capacity</i>			
	Types	Micro	Mini	Small	Total
Station	Number	18,944	19,606	4,427	43,027
	percent	44.0	45.6	10.4	100
Installed capacity	MW	687	7,171	8,404	26,262
	percent	2.6	27.3	70.1	100
Annual output	GWh	1,860	20,245	65,036	87,141
	percent	2.1	23.2	74.7	100
		<i>SHP stations by Operating Mode</i>			
	Mode	National Grid	Local Grid	Isolated	Total
Station	Number	4,722	20,465	17,840	43,027
	percent	10.9	47.6	41.5	100
Installed capacity	MW	6,412	17,869	1,981	26,262
	percent	24.5	68.0	7.5	100
Annual output	GWh	20,097	60,792	6,252	87,141
	percent	23.1	69.8	7.2	100
		<i>SHP stations by Ownership</i>			Total
	Ownership	State ownership	Others		
Station	Number	8,244.0	34,783	43,027	
	percent	19.2	80.8	100	
Installed capacity	MW	17,500	8,762	26,262	
	percent	66.6	33.4	100	
Annual output	GWh	62,954	24,187	87,141	
	percent	72.2	27.8	100	

Source: International Networking on Small Hydropower (www.inshp.org).

BOX 9.8: SMALL HYDROPOWER IN NEPAL

In Nepal, where almost 83 percent of the land is mountainous, grid extension is not usually cost-efficient, due to the high cost and the low load factor inherent in supplying power to remote and scattered settlements. Small-scale hydropower of less than 100 kW (micro-hydro), and less than 5 kW (pico-hydro) can be used in circumstances where hydrological conditions (availability and gradient of water flow) are adequate. Some 2,000 SHP generators represent a capacity of 13 MW as well as supplying mechanical power. Another forty small projects run by the Nepal Electricity Authority provide 19 MW of installed capacity. The Government, in its tenth five-year plan (2002-2007), has set itself a target of producing a further 10 MW of electricity from decentralized micro-hydro schemes, thus providing off-grid electricity to 12 percent of

the population, mostly in rural mountainous areas, who are currently unserved. Generally, micro- or pico-hydro electrification schemes in Nepal are privately or community-owned. Since it requires a significant amount of capital investment and organization to establish a micro-hydro scheme, it is more common for a community to get together and raise capital to build a scheme that serves their village than for a micro-hydro plant to be built privately. Community-owned schemes are also more likely to receive support from non-governmental organizations. However, a government subsidy is provided irrespective of who owns the project. A wide range of technology is used in micro- and pico-hydro schemes throughout the country. Very small hydropower schemes such as Peltric Sets, pioneered by a Nepalese manufacturer,

Kathmandu Metal Industries, are extremely popular because of their simplicity and low capital investment. The units are very small (often less than 2 kW) vertical shaft Pelton turbine and induction generation modular units, which require very little construction to install. Polythene pipes, generally used for water supply and irrigation purposes, guide water into the turbine from a canal, directly from the river or occasionally from a small reservoir. As of 2001, about 700 such projects were installed in various parts of Nepal. For larger electrification projects of up to 100 kW, Pelton and Crossflow are the most popular turbines. There are almost twenty manufacturers of micro- and pico-hydro turbines and other components in the country. All the required hardware is manufactured locally in Nepal.

Source: IT Power (www.itpower.co.uk).

with the weather. In addition, hydropower's fast response time enables it to meet sudden fluctuations almost instantaneously. Hence hydropower offers great benefits and holds a unique place in the range of energy options for electricity generation that are currently available.

2b. Focus on small hydropower (SHP)

There is no universal international consensus on the definition of what counts as small hydropower. A generally accepted definition is a hydropower plant up to 10 MW, but in the US and Brazil, for example, the limit is up to 30 MW. At the smaller end of the SHP scale, the definitions are subdivided: mini-hydro at less than 500 kW; micro-hydro at less than 100 kW, and pico-hydro at 10 kW or less.

SHP plants have considerable longevity, as has been demonstrated by the successful rehabilitation of numerous projects. The costs of a project are almost entirely in up-front capital, with fixed and predominantly small running and maintenance costs throughout a long lifetime. There can also be further benefits like greater control over flooding, irrigation, water storage and supply.

When SHP plants require a reservoir, it has been found that they use much more reservoir space per unit of power than larger hydropower plants. On average, plants of less than 100 MW capacity use 249 hectares per megawatt (ha/MW), while the biggest projects, producing between 3,000 and 18,000 MW, occupy only 32 ha/MW.

The introduction of electricity in remote communities in developing countries with difficult terrain has been possible only by way of decentralized small-scale hydropower schemes. Lighting of homes and surrounding areas is the major application of electricity generated from such projects, and provides both economic and social benefits. Examples of small hydropower in use in Asia can be seen in **Boxes 9.7 and 9.8** and **Table 9.3**. The use of SHP can contribute to poverty alleviation through sustainable socio-economic development, increasing employment opportunities for local people, improving rural living standards, and promoting environment-friendly development.

2c. Pumped storage

Pumped storage works like a giant rechargeable battery, a reserve source of power available at any time regardless of the weather. Pumped storage does not depend on rivers or rainfall as it uses the same water over and over again. When there is spare electrical capacity in an electricity system, at night, for example, it is used to pump water from a low reservoir to a high one. Then, at times of peak demand, the water is allowed to flow down again, generating extra power to supplement the grid. Pumped storage reservoirs are smaller than conventional reservoirs and less controversial, since they are less dependent on the topography. They are particularly effective in countries with limited water supplies, such as South Africa (see **Box 9.9**). Japan, the biggest user of pumped storage hydropower, has even been



The Atatürk Dam (Turkey) is the largest in a series of 22 dams and 19 hydroelectric stations built on the Euphrates and Tigris rivers

BOX 9.9: PALMIET PUMPED STORAGE SCHEME, SOUTH AFRICA

The Palmiet pumped storage scheme, just outside Cape Town, has two complementary functions: it provides a flexible electricity reserve for the South African national network and helps to supply freshwater to Cape Town. The project consists of two reservoirs with a height difference of 285 metres and a connecting conduit passing through a hydropower station with a reversible turbine.

Using surplus electricity from the national grid, the reversible turbine pumps water uphill through a two-kilometre chain of steel-lined tunnels to the higher reservoir at quiet periods every weekday, and for thirty-three hours during the weekend. Then, during

the working days when demand for power from South Africa's industries and people is at its highest, the water is allowed to flood back down through the turbines, generating electricity to pump back into the grid. The higher reservoir also has a separate outlet through which spare water can flow down the other side of the mountain range, into the large Steenbras reservoir, effectively transferring water from one catchment area to another. From there it is fed into the Cape Town city supply, contributing a total of 25 million cubic metres a year.

Built between 1983 and 1988, Palmiet has played a vital role in providing stability to South Africa's electricity supply. More than 90 percent

of the country's electricity comes from coal-fired power stations, which are relatively inflexible and cannot easily cope with demand fluctuations.

Palmiet, which has a capacity of 400 MW, and South Africa's other pumped storage plant, the 1,000 MW Drakensberg project, together account for only 1.5 percent of total electricity production. However, they help the system to absorb any shocks from breakdowns or surges in demand and allow the thermal power stations to run at constant, energy-efficient levels of output (see **Chapter 14**).

Source: International Hydropower Association (www.hydropower.org).

BOX 9.10: HYDRO TASMANIA, AUSTRALIA

Hydro Tasmania, which is Australia's biggest hydropower producer with 2,300 MW of capacity, has a project to build wind farms generating 1,000 MW. The plan is dependent on the Basslink undersea cable connecting Tasmania with the rest of Australia and is scheduled to be completed around the beginning of 2006. Hydro Tasmania will then be able to use its joint wind-hydro production on the offshore territory to supply peak power to the industries of Victoria State, Australia's biggest electricity network, on the mainland. The state-owned company would be able to guarantee supply,

as its hydropower projects on Tasmania would provide backup if weather conditions made wind generation impossible.

The scheme was created by the Australian Government's Mandatory Renewable Energy Targets (MRET), designed as a first step towards reducing the country's greenhouse gas emissions and heavy dependence on coal-fired power stations. Under this initiative, Australia's regional authorities would have to obtain at least 2 percent of their energy from renewable sources by 2010. Those that fail would be fined

or would have to purchase tradable Renewable Energy Certificates from renewable power producers such as Hydro Tasmania.

The synergy between hydropower and other energy sources not only enables an increase in the penetration of renewables into the energy market, but by meeting peak demand, it also reduces the need for additional investment in base load generation.

Source: International Hydropower Association (www.hydropower.org).

experimenting with seawater pumped storage, but the technical difficulties have made this approach economically unappealing (see **Chapter 14**).

The world's pumped storage capacity amounted to 103 GW by 2003, which represents about 13 percent of total hydropower capacity. Japan and the US account for 24 and 20 percent of this amount, respectively. Italy, France and Germany also have substantial pumped storage capacities.

Pumped storage units can start up in very few minutes in an emergency to provide the necessary reserve capacity. This allows coal-fired stations to operate at constant levels of output, thus functioning more efficiently and reducing CO₂ emissions; however, pumped storage has an efficiency level of 70 to 75 percent and uses about a quarter more electric power than it creates. In a system with a substantial proportion of thermal plants, this is more than compensated by the increase in efficiency of the oil, gas and coal generators as well as the subsequent reduction in the amount of greenhouse gases they emit.

Pierre Bénite dam, France



2d. Sustainable hydropower solutions

There are three options for increasing electricity generation through hydropower, which are especially sustainable, and cost-effective: piggybacking an alternative energy source, adding hydropower capacity to existing infrastructure and extending the life and increasing the operating efficiency of existing hydro power projects.

Piggybacking alternative energy sources

Hydropower's flexibility and reliability of operation make it ideally suited to working in tandem with alternative energy sources, which means that it can play an essential role in the development of these young industries. Few of these can yet provide the steady, guaranteed supply of power an electricity network requires, but when piggybacked with hydropower, they can be effective suppliers of electricity to a system, providing financial incentives for developing these sectors.

When wind turbines or solar panels are injecting energy into a grid, hydropower units can reduce their own output and store extra water stocks in their reservoirs. These stocks can then be used to increase hydropower output and fill the gap when the wind drops or the sun is covered by clouds and input from these sources falls. This is well illustrated by the large combined wind and hydro project in Tasmania (see **Box 9.10**).

Adding hydropower capacity to existing infrastructure

It must be remembered that only about 25 percent of the world's dams are involved in producing hydropower. Water supply and energy policies were often poorly coordinated in the past, often with a reluctance to plan across sectors and cater for both uses. In Africa, the continent with the least developed hydropower potential, only about 7 percent of dams have hydropower as their main purpose. This leaves a window of opportunity for adding hydropower capacity to existing dams.

The hydropower industry now offers an array of different types of equipment suitable for this purpose. This is also relevant in parts of the world where hydropower potential is largely developed already, such as in Europe (75 percent) and North America (69 percent). An extra 20,000 MW of generating capacity could be added in the US by installing generating units in some 2,500 dams that at present have none. Many authorities are looking at new ways to add hydropower-generating capacity without building new dams (see **Box 9.11**). As the most suitable sites from a physical, political and financial point of view have been used, it becomes harder to win approval for any project on a new site, as hostility to dams is still strong among some environmental groups. In these conditions, adding generating capacity to existing dams is an attractive option.

Extending the life and improving the efficiency of hydropower schemes

The structural elements of a hydropower project, which tend to take up about 70 percent of the initial investment cost, have a projected life of about 100 years. On the equipment side, some refurbishment can be an attractive option after thirty years. Advances in hydro technology can justify the replacement of key components or even complete generating sets. Typically, generating equipment can be upgraded or replaced with more technologically advanced electro-mechanical equipment two or three times during the life of the project, making more effective use of the same flow of water.

A turbine commissioned in the 1970s, for example, might have a peak operating efficiency of 80 to 85 percent, whereas a modern turbine would raise this to 90 to 95 percent. The long life of hydro and extremely low running costs make even a modest improvement in output financially attractive. A number of techniques short of replacing the whole turbine can be used to increase output – using computerized testing and simulation, for example. Changing the shape of turbine runner blades has been effective, for example, at Arapuni in New Zealand, where productivity was increased considerably after an efficiency upgrade in 2002.

There are three principal ways of improving operating efficiency within existing hydropower projects, which allow for more electricity generation from the same scheme:

- Improving water management and allowing plants to operate at their optimal level of efficiency, by adjusting flows to maximize the available ‘head’ (drop) at each site. The only costs may be the testing of equipment performance and staff training.
- Installing equipment that is designed to have a higher efficiency over a wider range of water flows through the turbine. This is particularly significant for small projects for which the volume of water flow may vary sharply during rainy and dry seasons, and even during the same day, depending on rainfall.
- Increasing the flow to the turbines and reducing losses, through minor changes to the hydraulic passages. This solution involves some civil engineering works. An example is the Manapouri scheme in New Zealand, which was completed in 1971. In 2002, a new 10-kilometre tailrace tunnel was commissioned to carry the water away from the turbines. The improved design of the tunnel enabled the output to be substantially increased.

2e. Environmental impacts of thermal power generation including water use

Where electricity transmission and distribution grids are established, thermal power is currently the major alternative to hydropower for base-load electrical power generation. In a thermal power plant, heat is generated from either the combustion of fossil fuel (coal, oil or gas), or through nuclear fission of radioactive material. The heat is used to raise steam, which generates electrical power by means of a steam turbine mechanically connected to an electricity generator. Water and steam circulate between the steam generator (boiler) and the steam turbine in a closed circuit.

Steam exiting the turbine must be condensed, and, since condensation employs cooling towers, where cooling water is lost due to evaporation, there are water resources issues associated with the deployment of thermal power generation. Where surface water is used for cooling and returned directly to the river or lake from where it is sourced (once-through cooling), the return water will be several degrees warmer, resulting in temperature changes capable of affecting aquatic ecosystems (see **Chapter 5**). In addition, a typical power plant using once-through cooling technology can kill tons of fish each year by trapping fish against intake screens or drawing fish into the facility.



Coal-fired power station in Bergheim, Germany

The long life of hydro and extremely low running costs make even a modest improvement in output financially attractive

BOX 9.11: HYDROPOWER GENERATION IN FREUDENAU, AUSTRIA

One example of creative thinking in hydropower generation is in Freudenau on the Danube in Austria. This run-of-river facility in the heart of Vienna was completed in 1998. The project is comprised of six giant Kaplan turbines, with installed capacity of 172 MW, enough to power about half the homes in the city. As well as generating hydropower, it provides flood protection, has helped to raise groundwater under Vienna and has restored water levels

in two blind arms of the river. It improves navigation in related canals and includes two large locks for river traffic on one of Europe's busiest waterways.

The owner, the state-controlled utility Verbund, later added modern Matrix turbines to the navigation locks. These sets of small turbines capture the energy from water that would normally be discharged through gates and

valves, producing an additional 5 MW of power. This is a small amount compared with the total output of the project, but it is significant in itself, especially as it could be added without the disruption of creating a fresh site for electricity generation.

Source: International Hydropower Association (www.hydropower.org).

Water availability is now driving the development of cooling technology for thermal power application

In a thermal plant, cooling is essential for efficient operation of the steam turbine and forecovery/recirculation of the highly purified water, which must be returned in closed circuit to the steam boiler. Power plant operating costs and lifetime (normally thirty to forty years) will be seriously affected if cooling water availability becomes constrained. Coastal plants can obtain cooling water from the sea. However, coal-fired plants are frequently located close to the coal deposit ('mine-mouth' plants) to reduce coal transportation costs, in which case they are heavily dependent on the availability of local cooling water.

In several major coal-producing countries, including China, parts of India and South Africa and the US, coal deposits are located in arid areas. In the US, about 40 percent of daily freshwater usage is for power generation. Most of this is returned to the source; about 2 percent is consumed/evaporated. Water availability is now driving the development of cooling technology for thermal power application.

It is important to distinguish between water diversion and consumptive use. The former indicates the amount of water removed from a water body (river or lake), the bulk of which is returned to the water basin albeit at an elevated temperature that gives rise to some environmental concerns. Consumptive use indicates the actual amount of resource loss, because this is the amount of water evaporating in the cooling process and not returned to its original source. Technologies are available to control water temperature discharged from the thermal power cooling systems, as well as to reduce consumptive use to virtually zero, but applying those technologies incurs additional costs.

In addition to impacts on the aquatic environment through the discharge of cooling water, fossil fuel (especially coal-based) power generation is also responsible for air pollution. Emissions of oxides of sulphur and nitrogen are responsible for acid rain, the deposition of which results in the degradation of ecosystems, as well as damage to agricultural production and to buildings. As a result of these measures, the use of low sulphur coal, the deployment of dust filters, flue gas desulphurization and nitrogen oxide control technologies are common practice at modern fossil fuel generating plants. Atmospheric emissions from coal combustion are now the major challenge confronting a continued deployment and development of coal-fuelled power plants.

The greenhouse gas emission reduction targets agreed under the Kyoto Protocol will limit releases of CO₂, the major greenhouse gas contributing to climate change. CO₂ emission mitigation will be considerably more expensive to implement than controls on acid deposition. This will also have a pronounced effect on the competitive position of coal in comparison with power sources that do not generate greenhouse gases, such as hydropower and nuclear power generation options (the latter of which also has environmental concerns linked to waste storage and possible accidents).

Table 9.4 lists the fifty countries with the world's highest carbon intensities of electricity production (WRI, 2004). Cutting-edge 'clean coal' technologies, including supercritical pulverized fuel, pressurized fluid bed and integrated gasification/combined cycle (IGCC) technologies, control CO₂ emissions by generating electricity at higher efficiencies. Older coal-based technologies have efficiencies in the range of 30 to

35 percent. New clean coal technologies, particularly IGCC, reduce CO₂ emissions per unit of power generated and have the potential to achieve efficiencies of 45 percent and above. Wide-scale application of CO₂ sequestration is likely to be accompanied by an accelerated use of IGCC technology. In several OECD countries, research is underway into the capture of CO₂ from power plant flue gas, transportation and CO₂ sequestration in depleted oil/gas reservoirs, deep saline aquifers, unmineable coal beds and in the deep ocean.

An interesting observation can be made by exploring the relationship between the carbon intensity of electricity

production and the role of nuclear power in the electricity sector. In the group of twenty-five countries with the highest carbon intensity, only three countries have nuclear power in their electricity portfolios, each at a rather modest level. In the group of the next twenty-five countries, however, there are five countries with nuclear electricity, and in three of them, nuclear power provided around 30 percent of electricity in 2002. It is likely that countries with the economic means to invest in nuclear technology will increasingly turn to this solution as a means of reducing their dependence on fossil fuels, achieving energy security and reducing greenhouse gas emissions.

Table 9.4: Carbon intensity of electricity production in 2002

Country	Grams of carbon per kilowatt hour	Country	Grams of carbon per kilowatt hour
1 Estonia	328.9	26 Czech Republic	206.8
2 Moldova	314.2	27 Singapore	206.7
3 Kazakhstan	309.0	28 Lebanon	200.3
4 Qatar	300.4	29 Romania	198.5
5 Poland	286.1	30 Bahrain	187.4
6 China	259.9	31 Trinidad and Tobago	185.3
7 Turkmenistan	245.8	32 Côte d'Ivoire	184.6
8 India	240.7	33 Algeria	183.4
9 Senegal	237.1	34 Kuwait	182.6
10 Malta	234.7	35 Morocco	180.3
11 Bosnia and Herzegovina	232.0	36 Jordan	179.0
12 Cyprus	231.5	37 Ireland	178.7
13 Belarus	229.9	38 Zimbabwe	175.8
14 South Africa	229.7	39 Libya	172.6
15 Serbia and Montenegro	227.6	40 Kenya	170.0
16 Oman	222.8	41 Indonesia	166.8
17 Togo	222.2	42 Hungary	166.3
18 United Arab Emirates	220.7	43 Nicaragua	166.1
19 Greece	220.1	44 Denmark	165.6
20 Israel	215.7	45 Latvia	162.0
21 Australia	215.6	46 Russian Federation	158.8
22 Cuba	214.9	47 Bulgaria	154.8
23 Azerbaijan	212.8	48 Bangladesh	152.2
24 Brunei	208.4	49 Iran	151.8
25 Uzbekistan	207.1	50 Iraq	148.8

Note: These data cover fossil fuel generation, hydropower, nuclear power, renewables and waste. The countries listed generate the highest amounts of greenhouse gases, per unit of electricity generated, and hence have the greatest potential for applying technological solutions in order to reduce their carbon releases. Untapped hydropower options are available in China and India, as has been already discussed, as for many other countries appearing in this table. However, for countries with a high reliance on gas and coal, technological improvements in thermal power generation will become necessary.

Source: WRI, 2004.



China, India and Turkey frequently argue that their electricity requirements for economic growth and social development outweigh the environmental concerns surrounding hydropower...

Part 3. Governance of Energy and Water Resources

In the past, some hydropower projects, particularly big reservoirs, have had a negative impact on their immediate surroundings. Damage to the local environment and inadequate provision for those affected in the area have contributed to the hostility shown by some environmental and human rights organizations towards the hydropower industry. The World Commission on Dams attempted to bring the various parties together, although its recommendations were not universally welcomed (WCD, 2000). More recent guidelines published by the International Hydropower Association (IHA) in 2004 have been broadly accepted throughout the large hydropower industry, in particular the core principles of equity, participatory decision-making and accountability.

3a. The continuing debate on large hydropower

IHA argues that equitable sharing of the benefits of any power project requires a careful balance between different stakeholders and interested parties. Hydropower uses renewable water supplies, not finite fossil fuels. In contrast to nuclear power, it leaves no toxic waste to threaten future generations, and in contrast to thermal power, it emits virtually no greenhouse gases. While the vast majority of a project's costs are borne at the start, the benefits continue for 100 years or more.

Furthermore, while any negative effects of a hydropower project are inevitably borne by the local community, the benefits – in reliable electricity supplies – are shared by everyone in the nation or region.

The key to managing changes lies in advance planning and consultation with all interested parties. The IHA Sustainability Guidelines state that hydro developers planning a project should try to minimize the following:

- health dangers, particularly from water-borne diseases or malaria
- loss of homes, farms and other livelihoods
- disruption of community networks and loss of cultural identity
- changes to biodiversity in the affected area.

They should try to maximize the following:

- timely consultation at all levels
- the flow of relevant information to all those affected
- negotiated settlement of disputes
- timely and adequate payment of any compensation.

Where people or communities have to be transferred to new sites, developers should do the following:

- investigate possible alternative ways of doing the project
- ensure adequate consultation with the people to be displaced throughout the project
- guarantee equivalent or improved livelihoods at the new location
- provide better living standards and public health at the new location.

Rapidly developing countries such as China, India and Turkey frequently argue that their electricity requirements for economic growth and social development outweigh the environmental concerns surrounding hydropower, and that support for large hydropower development is a pro-poor policy. This need was recognized in the Johannesburg Plan of Implementation (UN, 2002) where hydropower is included among the 'advanced, cleaner, more efficient, affordable and cost-effective energy technologies' required by developing countries. However, several non-governmental organizations are campaigning to have large hydropower excluded from global efforts to promote renewable energy. Among the arguments advanced for this position are the following:

- including large hydro in renewables initiatives reduces the available funding for new renewable energy technologies
- there is no technology transfer benefit from large hydro, which is a mature technology
- large hydro projects often have major social and ecological impacts
- large reservoirs can emit significant amounts of greenhouse gases from rotting organic matter
- large hydro reservoirs are often rendered non-renewable by sedimentation.

This long-standing debate is still a major issue. Many large hydropower projects necessitate the construction of large dams. These are structures with a long life, which permanently alter the river downstream and affect a significant stretch of the river upstream. They are not, strictly speaking, renewable. However, as discussed in this chapter, there are also very large run-of-river hydropower projects, as well as small, mini and micro-hydropower projects, which are all renewable energy providers. It must also be remembered that the driving force for much new dam construction is irrigation, rather than hydropower generation.

The water/energy nexus can be better understood by distinguishing the issue of large dams from that of hydropower, except in the cases of certain hydropower projects that do require the construction of large new reservoirs. In these specific cases, greater transparency, accountability and oversight of the contractual process to ensure the exposure of corrupt practices are all necessary in order to promote social equity and good governance.

3b. Renewable energy and energy efficiency: Incentives and economic instruments

In the world's developed regions, electricity is delivered to the vast majority of consumers through vertically integrated utility industries based on central power generation. Over the past several decades the efforts of energy policy-makers, utility planners, regulators and generation technology developers have enabled this conventional power generation and supply system to keep pace with rising demand, but with social and environmental impacts that are increasingly considered unacceptable. The inertia within the power supply system – power plants and transmission/distribution systems have lifetimes of several decades – means that this trend will be difficult to change.

However, with a worldwide 30 percent annual growth rate, renewable-based generating capacity is currently increasing faster than the conventional power option. Accelerated interest in renewable energy can be traced to the 'oil crisis' of the 1970s, but a list of environmental concerns headed by global climate change is responsible for the recent surge in interest in clean energy.

In developing countries where affordable power is desperately needed, environmental concerns must be carefully weighed against urgent development needs. As seen earlier in this chapter, governments will be less

responsive to objections to the construction of dams for large hydropower generation or to the deployment of new, greenhouse gas-emitting coal-fired power plants, when their priority is meeting rapidly growing electricity demand. Clearly, the transition to a fully sustainable, global energy supply system needs cooperative and innovative, if not radically new, policy-making.

International and national mechanisms implemented with the Kyoto Protocol

At the international level, the Clean Development Mechanism (CDM) and Joint Implementation (JI) measures established by the Kyoto Protocol seek to provide incentives for the use of low carbon-emitting and renewable energy technologies in developing countries, through the sale of carbon credits arising from clean energy investments. Given its proven track record of decades of successful experience, it is not surprising that hydropower projects are prominent in the current portfolio of CDM and JI projects. Multilateral initiatives establish emission reduction goals and a cooperative means of achieving them. However, they will need to be accompanied by national policies to stimulate a thriving market for renewable energy resources, such as wind, biomass, solar photovoltaics and hydropower as well as for combined heat and power (CHP) generation options. For example, feed-in tariffs oblige utilities to buy renewable electricity from any developer in their service area at tariffs set by government. These are generally a little lower than the electricity retail price, facilitating a good return on investment and assuring long-term support. Renewable Portfolio Standards (RPS) require the share of renewable power purchased by a utility to increase yearly to a given percentage. An RPS creates long-term stability and demand that establishes a flourishing renewables-based generation market. Within a given country, regional discrepancies arising from cost and availability of renewable power sources can be levelled out by means of tradable 'renewable energy certificates' (called 'green certificates' in Australia). Feed-in tariffs, RPSs and tradable certificates may need the further support of long-term and stable subsidies, such as investment tax credits and accelerated depreciation (see **Box 9.12**). In effect, renewable power markets need to be driven by a combination of demand- and supply-side measures capable of keeping the costs of electricity retailers and their retail customers at a minimum.

The case of rural electrification

Rural electrification is a special case. The provision of rural electrification through rural cooperatives was employed



Aerial close-up of Tucson Electric Power's cooling towers, Arizona, United States

BOX 9.12: RENEWABLE OBLIGATION CERTIFICATES: A POLICY INSTRUMENT PROMOTING RENEWABLE ENERGY

Small-scale hydropower development stands to benefit from policy instruments designed to promote renewable energy. The largest hydropower operator in the UK, Scottish and Southern Energy, is engaged in a €360 million (US \$439 million) investment programme to upgrade its older projects over ten years. This is expected to increase UK hydropower output of some 5,000 GWh per year by 200 GWh. The programme was made possible by the British

Government's decision to allow the refurbishment of hydropower projects with a capacity of less than 20 MW to qualify for Renewable Obligation Certificates. The company had previously refurbished its larger hydro plants, for an increase in output of 6 percent at a cost of €60 million (US \$73 million). Renewable Obligation Certificates were then introduced by the British Government to encourage the development of renewable energy. Each

electricity supplier has to produce a certain proportion of its power from sources qualifying for the Certificates, or face fines for every MW it produces. The first of the smaller plants to qualify was a 17 MW capacity plant at St Fillans, upgraded in 2002 for an 8 percent increase in output and a thirty-year extension to its life.

Source: UNIDO, 2004.

Although environmentally friendly, and free from expensive fuel costs, renewables are often intermittent and carry a burden of high capital investment

effectively in the industrialized world between the 1930s and the 1950s. This institutional model has been employed successfully in several developing countries. The high costs of grid extension, particularly to remote parts of many developing countries, mean that isolated rural communities are usually served by diesel-based mini-grids rather than centrally operated electricity distribution networks. Electricity produced by diesel sets can be two to three times the cost of grid power in urban areas, but still cost-effective relative to grid extension. Costs of maintenance and transporting diesel fuel are high. Greenhouse gas emissions per unit of generated power from a diesel engine are particularly high.

Where renewable energy resources, in the form of solar, wind, biomass, biogas and mini-hydro are available, their use can replace or supplement diesel. Although environmentally friendly, and free from expensive fuel costs, renewables are often intermittent and carry a burden of high capital investment. Policy reforms to make capital resources more readily available for small-scale rural energy investments are needed. Micro-financing is now almost a prerequisite for rural energy development projects. Micro-finance schemes are especially important for photovoltaic and other renewable energy-based technologies. There is also a need to stimulate local manufacturing of renewable energy equipment and gradually increase domestic content.

Rural electrification has to be seen in the broader context of rural development. Even though major barriers exist, the subsidized development and deployment of renewables-based mini-grids is proceeding in many rural parts of the developing world. With improved knowledge of rural development needs and a clearer understanding of the contribution of reliable, cost-effective and clean energy

to rural development, these projects should lead to replication, commercial support, the phasing-out of subsidies and the ultimate goal of reducing poverty.

Improving energy efficiency

In the same way that innovative policies are needed to overcome obstacles to the accelerated deployment of renewable energy technologies, new approaches are required to encourage energy users to take advantage of the enormous potential for improving end-use energy efficiency. Much of the world's future energy demand will have to be met by efficiency improvements.

The market for energy efficiency products and services is far from perfect, and information is neither widespread nor clear. The potential for industrial energy system optimization remains largely unrealized. Production, not energy efficiency, is the top priority of industrial manufacturers. Plant operating budgets and capital improvement budgets are accounted for separately, so that the consequences of purchasing less efficient equipment is not linked to increased operating costs, although these can be 80 percent or more of the lifecycle cost of the equipment. These disincentives can only be reversed through integrated policy-making, including changes in tax laws, and measures for incorporating life-cycle energy costs into bidding procedures for capital projects (see **Chapters 2 and 12**).

Whereas manufacturers of energy-consuming equipment have successfully improved the performance of individual components, such as pumps, compressors, fans and steam boilers, these components only provide a service to the user when operating as part of a system. There is scope to improve energy efficiency and reduce greenhouse gas

BOX 9.13: DISTRIBUTED GENERATION: POWER SUPPLY IN THE FUTURE

Electricity power generators – conventional and renewable alike – sell their product through distribution grids or networks. In the future, renewable energy will be provided from large numbers of individually small and frequently intermittent (such as combined heat and power [CHP] and wind) power generators. The network needs increasingly to be managed as an interlinking mesh, rather than a unidirectional funnel of energy, so that suppliers can continue to provide continuous and reliable electricity to their customers. To attain renewables targets in established grid systems, network operators will therefore need new tools and incentives, but this will by no means present insurmountable challenges. Indeed, the wider use of on-site generation can reinforce stressed networks. Today's grids support thermal and hydro central power stations delivering 'mass-produced'

electricity to meet an agglomerated load curve. To accommodate an ever-increasing penetration of individually small power producers, new grid operating procedures and protocols are required, many of which are already available.

Distributed generation (DG) offers a promising set of solutions and benefits. DG means producing power close to the customer using a network supplied by several small generators. Operating in parallel with the main grid, DG systems provide some or all of the power required by the user, while the grid either absorbs the surplus or provides the shortfall. On-site or local CHP generation not only reduces thermal energy losses from conventional plants, but also significantly decreases the network losses arising from moving electricity long distances from remote hydro and thermal

plants. From a cost perspective, investment in local generation also avoids the high expense of constructing long-distance transmission networks that can prove vulnerable to disruption.

The function of the network is therefore evolving from a supply role to that of a buffer. All network users should be required to pay their reasonable share for the construction and maintenance of those networks according to the use made of them and according to the services provided for network reinforcement. Achieving reasonable cost-recovery arrangements is complex but manageable, and is likely to provide a further incentive for investment in generation that reduces network use.

Source: WADE (www.localpower.org).

emissions across the entire industrial sector by improving the design and operation of the systems that deliver energy to the point of use. Pumping systems alone account for 20 percent of the world's electrical energy demand and range from 25 percent to 50 percent of total energy use in some industrial operations.

One way to increase the implementation and persistence of energy efficiency measures in the industrial sector would be for industry participants to incorporate their commitments to energy efficiency into the ISO 9000/14000 quality and environmental management system (see **Chapter 8**). ISO certification has become a significant trade facilitation vehicle for developing countries, with more than 155,000 plants participating in these countries as of December 2002. Tracking energy efficiency projects and milestones in their ISO quality and environmental management system will help each company to maintain a focus on its energy efficiency commitments, provide visibility for its achievements and provide a verification of their results for project funders. All of these measures will help stimulate a significantly higher level of activity in industrial energy efficiency programmes.

3c. Policy-making for co-management of water and energy resources

Policy-makers in the water and energy sectors need to

find better ways of integrating decisions between the two sectors in order to optimize benefits, address financing barriers and identify potential new partnerships. Inclusion of energy considerations can improve water resource management decisions and avoid potentially significant but unintended energy consequences. The key indicators of the success of such co-management would be the increased availability, acceptability and affordability of both water and energy services.

A recent report based upon three detailed case studies in California has shown clearly that including energy considerations in water management decisions can lead to major energy and money savings (NRDC, 2004). The case study analysis supports two primary recommendations for how policy-makers can begin to achieve these savings, which are generally applicable in many areas beyond California:

- Decision-makers should better integrate energy issues into water policy decision-making. Looking at energy use and water use simultaneously generates valuable insights that do not arise from separate policy analyses of water and energy issues.

The report makes the following recommendations:

- modify planning tools for water resources management to include energy use and costs

...including energy considerations in water management decisions can lead to major energy and money savings...

Governments that have ratified the Kyoto Protocol are bound to reduce greenhouse gas emissions and promote clean energy investments

- improve coordination among resource management agencies to better identify and address the energy implications of water policy decisions
- conduct an energy intensity analysis of water distribution systems and identifying regions and districts where large amounts of power are required to deliver water
- develop partnerships designed to produce energy, economic and environmental benefits through voluntary water transfers away from the agricultural sector with a focus on dry-year transfers in locations where large water diversions upstream reduce downstream flows and downstream hydropower generation.

■ Both water and energy policy-makers need to give water conservation higher priority. The amount of energy required for end use is the largest component of energy use in urban water supply. Hence, policy actions that affect the end uses of water may have much larger energy implications than policy actions that affect the mix of physical water sources. Conservation has much greater stronger energy-related economic and environmental benefits than has previously been recognized. In addition, the energy benefits of water conservation can generate air quality benefits as well as climate change benefits. The report recommends the following actions:

- prioritize water conservation funding
- enforce existing water conservation requirements

- promote conservation through pricing strategies and water metering
- offer water conservation incentives.

There are serious weaknesses in the pricing of both electricity and water in many parts of the world, which send the wrong signals to consumers about the need for conservation of both of these resources (see **Chapter 12**). In addition, regulatory regimes, where these exist, are frequently not sufficiently focused on the need for efficiency of use and conservation. Frequently the cultures within the electricity and water sectors of many countries are very different, and there is rarely the level of communication required to exploit the potential synergies of the two sectors. Availability of both energy and water is essential for human survival and national prosperity. In the globalized world of the twenty-first century, energy and water supply security will require governance regimes that are sensitive to environmental and social, as well as political and economic, considerations. In the many cases of countries where water/energy resource availability and the environmental and social consequences of using both are interrelated, a strong case can be made for policies and regulations that address water and energy simultaneously. Many inefficiencies in both sectors impact not only on poverty alleviation and socio-economic development but on other sectors of water and the environment at large. Governments need to recognize the very close connection between the two sectors, in order to maximize the benefits of synergies between them.

Table 9.5: Access to electricity and water in 2000

	Population access to improved water source		Electricity production kWh (billions)	Population access to electricity (%)
	Urban (%)	Rural (%)		
Afghanistan	19	11	-	2.0
Albania	99	95	4.9	-
Algeria	94	82	25.4	98.0
Angola	34	40	1.4	12.0
Argentina	97	73	89.0	94.6
Armenia	-	-	6.0	-
Australia	100	100	208.1	-
Austria	100	100	60.3	-
Azerbaijan	93	58	18.7	-
Bangladesh	99	97	15.8	20.4
Belarus	100	100	26.1	-
Belgium	-	-	82.7	-
Benin	74	55	0.1	22.0
Bolivia	95	64	4.0	60.4



Table 9.5: *continued*

	Population access to improved water source		Electricity production kWh (billions)	Population access to electricity (%)
	Urban (%)	Rural (%)		
Bosnia and Herzegovina	-	-	10.4	-
Botswana	100	90	-	22.0
Brazil	95	53	349.2	94.9
Bulgaria	100	100	40.6	-
Burkina Faso	66	37	-	13.0
Burundi	91	77	-	-
Cambodia	54	26	-	15.8
Cameroon	78	39	3.5	20.0
Canada	100	99	605.1	-
Central African Republic	89	57	-	-
Chad	31	26	-	-
Chile	99	58	41.3	99.0
China	94	66	1,355.6	98.6
Hong Kong, China	-	-	31.3	-
Colombia	99	70	44.0	81.0
Congo, Dem. Republic.	89	26	5.5	6.7
Congo	71	17	0.3	20.9
Costa Rica	99	92	6.9	95.7
Côte d'Ivoire	92	72	4.8	50.0
Croatia	-	-	10.7	-
Cuba	95	77	15.0	97.0
Czech Republic	-	-	72.9	-
Denmark	100	100	36.2	-
Dominican Republic	90	78	9.5	66.8
Ecuador	90	75	10.6	80.0
Egypt, Arab Rep.	99	96	75.7	93.8
El Salvador	91	64	3.9	70.8
Eritrea	63	42	-	17.0
Estonia	-	-	8.5	-
Ethiopia	81	12	1.7	4.7
Finland	100	100	70.0	-
France	-	-	535.8	-
Gabon	95	47	1.0	31.0
Gambia	80	53	-	-
Georgia	90	61	7.4	-
Germany	-	-	567.1	-
Ghana	91	62	7.2	45.0
Greece	-	-	53.4	-
Guatemala	98	88	6.0	66.7
Guinea	72	36	-	-
Guinea-Bissau	79	49	-	-
Haiti	49	45	0.5	34.0
Honduras	95	81	3.7	54.5
Hungary	100	98	35.0	-
India	95	79	542.3	43.0
Indonesia	90	69	92.6	53.4
Iran, Islamic Republic.	98	83	121.4	97.9
Iraq	96	48	33.7	95.0
Ireland	-	-	23.7	-
Israel	-	-	43.0	100.0
Italy	-	-	269.9	-
Jamaica	98	85	6.6	90.0



This solar voltaic panel's energy is used to pump water, Kabekel village, Gambia

Table 9.5: *continued*

	Population access to improved water source		Electricity production kWh (billions)	Population access to electricity (%)
	Urban (%)	Rural (%)		
Japan	-	-	1081.9	-
Jordan	100	84	7.4	95.0
Kazakhstan	98	82	51.6	-
Kenya	88	42	3.9	7.9
Korea, Dem. Republic.	100	100	31.6	20.0
Korea, Rep.	97	71	292.5	-
Kuwait	-	-	32.5	100.0
Kyrgyz Republic	98	66	14.9	-
Lao Peoples Dem. Republic.	61	29	-	-
Latvia	-	-	4.1	-
Lebanon	100	100	7.8	95.0
Lesotho	88	74	-	5.0
Libyan Arab Jamahiriya	72	68	20.7	99.8
Lithuania	-	-	11.1	-
Madagascar	85	31	-	8.0
Malawi	95	44	-	5.0
Malaysia	-	94	69.2	96.9
Mali	74	61	-	-
Mauritania	34	40	-	-
Mauritius	100	100	-	100.0
Mexico	95	69	204.4	-
Moldova	97	88	3.3	-
Mongolia	77	30	-	90.0
Morocco	98	56	14.1	71.1
Mozambique	81	41	7.0	7.2
Myanmar	89	66	5.1	5.0
Namibia	100	67	1.4	34.0
Nepal	94	87	1.7	15.4
Netherlands	100	100	89.6	-
New Zealand	100	-	39.0	-
Nicaragua	91	59	2.3	48.0
Niger	70	56	-	-
Nigeria	78	49	15.8	40.0
Norway	100	100	142.4	-
Oman	41	30	9.1	94.0
Pakistan	95	87	68.1	52.9
Panama	99	79	4.7	76.1
Papua New Guinea	88	32	-	-
Paraguay	93	59	53.5	74.7
Peru	87	62	19.9	73.0
Philippines	91	79	45.3	87.4
Poland	-	-	143.2	-
Portugal	-	-	43.4	-
Romania	91	16	51.9	-
Russian Federation	100	96	876.5	-
Rwanda	60	40	-	-
Saudi Arabia	100	64	128.4	97.7
Senegal	92	65	1.5	30.1
Sierra Leone	75	46	-	-
Singapore	100	-	31.3	100.0
Slovak Republic	100	100	30.4	-
Slovenia	100	100	13.6	-

Table 9.5: *continued*

	Population access to improved water source		Electricity production kWh (billions)	Population access to electricity (%)
	Urban (%)	Rural (%)		
South Africa	99	73	207.8	66.1
Spain	-	-	221.7	-
Sri Lanka	98	70	6.8	62.0
Sudan	86	69	2.4	30.0
Sweden	100	100	145.9	-
Switzerland	100	100	66.0	-
Syrian Arab Republic	94	64	22.6	85.9
Tajikistan	93	47	14.2	-
Tanzania	90	57	2.3	10.5
Thailand	95	81	96.0	82.1
Togo	85	38	0.0	9.0
Trinidad and Tobago	-	-	5.5	99.0
Tunisia	92	58	10.6	94.6
Turkey	81	86	124.9	-
Turkmenistan	-	-	9.8	-
Uganda	80	47	-	3.7
Ukraine	100	94	171.4	-
United Arab Emirates	-	-	38.6	96.0
United Kingdom	100	100	372.2	-
United States of America	100	100	4,003.5	-
Uruguay	98	93	7.6	98.0
Uzbekistan	94	79	46.8	-
Venezuela, Bolivarian Republic	85	70	85.2	94.0
Viet Nam	95	72	26.6	75.8
Yemen	74	68	3.0	50.0
Yugoslavia, Fed. Republic	99	97	31.9	-
Zambia	88	48	7.8	12.0
Zimbabwe	100	73	7.0	39.7
World	94	71	15,346.5	-
Low-income countries	90	70	11,44.7	37.4
Middle-income countries	95	70	4,777.2	94.0
Lower middle-income countries	95	70	3,429.3	93.8
Upper middle-income countries	94	69	1,347.9	94.7
Low and middle-income countries	93	70	5,921.9	65.0
East Asia and Pacific	93	67	1,722.1	87.3
Europe and Central Asia	96	83	1,827.5	-
Latin America and Carib.	94	65	973.2	86.6
Middle East and N. Africa	96	78	481.9	90.4
South Asia	94	80	634.8	40.8
Sub-Saharan Africa	83	46	282.4	24.6
High income	-	-	9,424.6	-
Europe (European Monetary Union)	-	-	2,018.0	-

Source: World Bank, 2003.

Table 9.6: Hydropower: Capability at the end of 2002

	Gross theoretical capability TWh/yr	Technically exploitable capability TWh/yr	Economically exploitable capability TWh/yr
Algeria	12	5	-
Angola	> 150	108	65
Benin	2	1	-
Burkina Faso	1	n.a.	n.a.
Burundi	6	2	1
Cameroon	294	115	103
Central African Republic	7	3	-
Chad	n.a.	n.a.	-
Congo	> 125	> 50	-
Congo Dem. Republic	1,397	774	419
Côte d'Ivoire	46	12	2
Egypt	> 125	> 50	50
Ethiopia	650	> 260	260
Gabon	200	80	33
Ghana	17	11	7
Guinea	26	19	15
Guinea-Bissau	1	n.a.	n.a.
Kenya	> 30	9	-
Lesotho	5	2	-
Liberia	28	11	-
Madagascar	321	180	49
Malawi	15	6	-
Mali	> 12	> 5	-
Mauritius	n.a.	n.a.	-
Morocco	12	5	4
Mozambique	50	38	32
Namibia	25	10	2
Niger	> 3	> 1	1
Nigeria	43	32	30
Rwanda	1	n.a.	-
Senegal	11	4	2
Sierra Leone	17	7	-
Somalia	2	1	-
South Africa	73	14	5
Sudan	48	19	2
Swaziland	4	1	n.a.
Tanzania	39	20	3
Togo	4	2	-
Tunisia	1	n.a.	n.a.
Uganda	> 18	> 13	-
Zambia	52	29	11
Zimbabwe	19	18	-
Total Africa	> 3,892	> 1,917	-
Belize	1	n.a.	n.a.
Canada	1,284	948	522
Costa Rica	223	43	20
Cuba	3	1	-
Dominica	n.a.	n.a.	n.a.
Dominican Republic	50	9	6
El Salvador	7	5	2
Greenland	800	14	-
Grenada	n.a.	n.a.	n.a.

Table 9.6: *continued*

	Gross theoretical capability TWh/yr	Technically exploitable capability TWh/yr	Economically exploitable capability TWh/yr
Guatemala	54	22	-
Haiti	4	1	N
Honduras	16	7	-
Jamaica	1	n.a.	-
Mexico	135	49	32
Nicaragua	33	10	7
Panama	26	> 12	12
United States of America	4,485	1,752	501
Total North America	7,122	> 2,873	-
Argentina	172	130	-
Bolivia	178	126	50
Brazil	3,040	1,488	811
Chile	227	162	-
Colombia	1,000	200	140
Ecuador	167	134	106
Guyana	64	> 26	26
Paraguay	111	85	68
Peru	1,577	> 260	260
Surinam	32	13	-
Uruguay	32	10	-
Venezuela	320	246	130
Total South America	6,920	> 2,880	-
Armenia	22	8	6
Azerbaijan	44	16	7
Bangladesh	5	2	-
Bhutan	263	70	56
Cambodia	88	11	5
China	5,920	1,920	1,270
Cyprus	59	24	-
Georgia	139	68	32
India	2,638	660	-
Indonesia	2,147	402	40
Japan	718	136	114
Kazakhstan	163	62	27
Korea Republic	52	26	19
Kyrgyz Republic	163	99	55
Lao People's Dem. Republic	233	63	-
Malaysia	230	123	-
Mongolia	56	22	-
Myanmar	877	130	-
Nepal	727	394	221
Pakistan	307	263	-
Philippines	47	20	18
Russian Federation	2,295	1,670	852
Sri Lanka	9	7	5
Taiwan, China	103	20	8
Tajikistan	527	> 264	264
Thailand	18	16	15
Turkey	433	216	126
Turkmenistan	24	5	2
Uzbekistan	88	27	15
Viet Nam	300	100	90
Total Asia	18,695	> 6,844	-



Table 9.6: continued

	Gross theoretical capability TWh/yr	Technically exploitable capability TWh/yr	Economically exploitable capability TWh/yr
Albania	40	15	6
Austria	75	> 56	56
Belarus	7	3	1
Belgium	1	n.a.	n.a.
Bosnia and Herzegovina	60	24	19
Bulgaria	27	15	12
Croatia	10	9	8
Czech Republic	12	4	-
Denmark	n.a.	n.a.	n.a.
Estonia	2	n.a.	-
Faroe Islands	1	n.a.	n.a.
Finland	48	25	20
France	270	100	70
Germany	120	25	20
Greece	80	15	12
Hungary	7	5	-
Iceland	184	64	40
Ireland	1	1	1
Italy	340	105	65
Latvia	7	6	5
Lithuania	6	2	1
Luxembourg	n.a.	n.a.	n.a.
Macedonia, former Yugoslav Republic	9	6	-
Moldova	2	1	1
Netherlands	1	n.a.	n.a.
Norway	600	200	187
Poland	23	14	7
Portugal	32	25	20
Romania	70	40	30
Serbia and Montenegro	37	27	24
Slovakia	10	7	7
Slovenia	13	9	6
Spain	138	70	41
Sweden	176	130	90
Switzerland	144	41	35
Ukraine	45	24	17
United Kingdom	40	3	1
Total Europe	2,638	> 1,071	-
Iran, Islamic Republic	176	> 50	50
Iraq	225	90	67
Israel	125	50	-
Jordan	n.a.	n.a.	n.a.
Lebanon	2	1	n.a.
Syrian Arab Republic	5	4	4
Total Middle East	533	> 195	-
Australia	265	> 30	30
Fiji	3	1	-
French Polynesia	n.a.	n.a.	n.a.
New Caledonia	2	1	n.a.

Table 9.6: continued

	Gross theoretical capability TWh/yr	Technically exploitable capability TWh/yr	Economically exploitable capability TWh/yr
New Zealand	46	37	24
Papua New Guinea	175	49	15
Samoa	n.a.	n.a.	-
Solomon Islands	2	> 1	-
Total Oceania	493	> 119	-
TOTAL WORLD	> 40,293	> 15,899	-

n.a. = not applicable due to flat topography

- = information not available

Notes:

1. A quantification of hydropower capability is not available for Comoros, Equatorial Guinea, Mauritania, Réunion, São Tomé and Príncipe, Guadeloupe, Puerto Rico, St Vincent and the Grenadines, French Guiana, Afghanistan, Korea (Democratic People's Republic) and Palau.
2. As the data available on economically exploitable capability do not cover all countries, regional and global totals are not shown for this category.

Sources: *The International Journal on Hydropower and Dams*; International Hydropower Association Member Committees, 2003; *Hydropower Dams World Atlas 2003*.

References and Websites

Martinot, E. 2002. Indicators of investment and capacity for renewable energy. *Renewable Energy in the World*. Vol. Sept/Oct.

NRDC (National Resources Defense Council). 2004. *Energy down the Drain*. New York, NRDC.

UN (United Nations). 2002. Johannesburg Plan of Implementation. www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/WSSD_PlanI_mpl.pdf

UNECA (United Nations Economic Commission for Africa). 2004. *African Water Development Report*. Addis Ababa, UNECA.

US DOE (United States Department of Energy). 2004. *Improving Pumping System Performance: A Sourcebook for Industry*. Washington DC, US DOE, 2nd edition.

World Bank. 2003. *World Development Indicators*. New York, World Bank.

WRI (World Resources Institute). Climate Analysis Indicators Tool, Washington, DC.

Alliance to Save Energy www.ase.org; www.watergy.org

FAO's AQUASTAT www.fao.org/ag/agl/aglw/aquastat/main/index.stm

International Energy Agency, Energy Statistics: www.iea.org/Textbase/stats/index.asp

International Energy Agency Coal Centre: www.iea-coal.org.uk

International Networking on Small Hydropower: www.inshp.org

International Hydropower Association: www.hydropower.org/

IT Power: www.itpower.co.uk

Naiade solar water purifiers: www.nedapnaiade.com/

Solar water Disinfection (SoDis): www.sodis.ch

UNIDO: www.unido.org/

WCD (World Commission on Dams): www.dams.org

World Resources Institute: Climate Analysis Indicators Tool, Data on Carbon Intensity to Electricity Production from 2002, available online at cait.wri.org/

World Resources Institute: www.wri.org/

