Issue Brief
HYDRO

SCOPE

This *Issue Brief* covers *large* and *small hydro* schemes, and includes *pumped storage.*

Ocean & wave and *tidal power* are included in the *Non-hydro Renewables Issue Brief.*

- *Ocean & wave* power involves inherently different technologies that are not mature today. Its policy treatment is generally separate to that of hydro.
- Although *tidal power* has a very similar technology to that of land-based hydro, it is generally included in the *other renewables* category within leading scenarios and statistics publications. Its generation is very small relative to that of hydro.

SHARE OF ELECTRICITY GENERATION

Hydropower generated 16% of the world's electricity in 2002.[1] It dominates electricity generation (just under 70% in 2002) in Latin America and many southern African countries and represents 10-20% of generation in most other regions of the world.

Hydropower is a major contributor to renewable energy production, representing 89% of worldwide production in 2002. In 2002, 801 GW of installed hydro capacity worldwide generated around 2,610 TWh of electricity.[2]

In 2004, the International Energy Agency (IEA) projected that hydro capacity would increase by 63% in the period 2002-2030. New hydro plants will continue to be built but not at a high enough rate to maintain the current share of electricity generation: this is projected to fall to 13% in 2030. Major schemes are currently being implemented in many countries, including China, India, Iran, Brazil and Turkey.

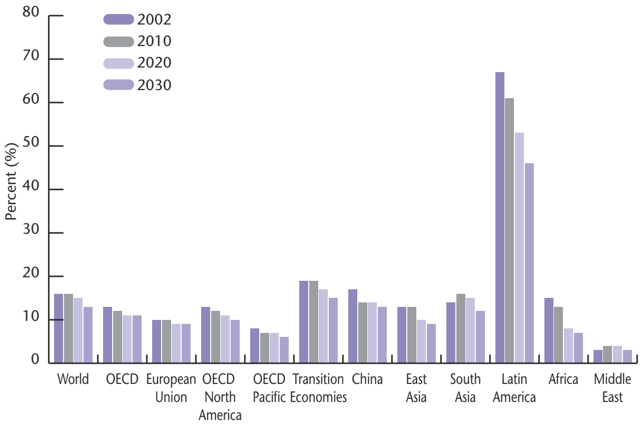

Figure 1: Share of electricity generation: Hydro

Source: International Energy Agency. *World Energy Outlook.* 2004.

RESOURCE AVAILABILITY

Hydro resources are widespread and are often available where further development of water and energy resources are most needed. It is estimated that two-thirds of the world's economically feasible potential is still to be exploited. The majority of this unexploited potential is in developing countries (principally in Africa, Asia and South America).[3] China currently has more installed capacity than any other country. It has used only around one quarter (115 GW in 2005)[4] of its huge potential 450 GW[5] to date: it is the main contributor to hydro development today, and government figures indicate that it will add more than 12 GW of new capacity each year until 2020, reaching a total capacity in 2020 of 300 GW.[6] China also has the world's largest facility with its 22.4 GW Three Gorges project.

Algeria has many reservoirs and dams but no hydropower facilities, and there are more reservoirs worldwide that have been developed to manage water resources (primarily for irrigation) than there are reservoirs which are used for power generation. One constraint on development is the geographical separation between potential supply and demand, which involves the development of costly infrastructures (long transmission lines, roads, etc.). The Grand Inga scheme has the potential to provide some 44 GW of hydropower at a site on the Congo River,[7] sufficient for the whole of South Africa's demand; however, the risks of investing in the countries along the Congo have deterred investors to date.

Developed countries have already largely exploited their most interesting sites. Maintaining generation from these sites is an important part of maintaining the share of renewables in electricity generation. Where additional potential exists, water and renewable energy policies often impede its development. Developed countries are now beginning to focus on rehabilitation and uprating (increasing capacity or/and generation, optimization and safety) programs. Such schemes have not been commonly developed to date but offer significant potential improvements. In some countries, proposed uprating schemes for one large hydro plant offer an increase in renewable generation of the same order as the generation from all other (non-hydro) renewables.

CURRENT TECHNOLOGIES

Scheme Types

Hydropower uses the energy of flowing water, without depleting it, to produce electricity. Hydro plants can supply both peak and base load power. Depending on the context and the type of scheme, either one or both modes are used.

The type of scheme depends on the "head" of the water resource available ("head" being the distance water falls between the inlet and outlets of the hydro plant). Hydropower plants are generally classified within 3 categories:

1. Storage (high head);
2. Run of the river (medium and low head);
3. Pumped Storage.

Storage schemes are usually located in mountainous areas and constitute:

- A dam which impounds the flow of a catchment area to create a reservoir;
- A tunnel and/or penstock to discharge the water to the powerhouse;
- A powerhouse equipped with several turbines, which transform the energy of the flowing water into electricity before the full release of water in a downstream channel.

The maximum power generated per unit can reach 850 MW per turbine (Three Gorges) – China), with heads up to 1,848 meters (Cleuson Dixence – Switzerland). River diversion is sometimes used to increase head.

Run of the river schemes are by definition implemented along a river, without storage capacity (low head, up to 30 meters) or with storage capacity (medium head, up to 250 meters). The dam crossing the river creates an artificial head, which enables the turbines, located in the powerhouse at the toe of the dam, to produce electricity. *Run of the river* schemes tend to be of smaller capacity than *storage* schemes but, depending on the site topology, a higher dam can be implemented, necessitating reservoir creation. The 305 meter high Jinping I scheme in China is the highest scheme under construction. *Run of the river* reservoirs can be very large – the Three Gorges dam in China will have a 45 km^3 reservoir.

Pumped storage schemes are typically situated in a high-head site. The basic principle is very similar to conventional *storage* schemes – the difference is that the powerhouse is equipped with pump-turbines, which can pump the water from the lower reservoir back up to the upper reservoir. Even though *pumped storage* plants are net consumers of electricity (more electricity is needed to pump the water up than is generated by the turbines as it comes back down), they both improve electricity system stability (i.e., control the voltage and frequency at which the grid supplies electricity) and are economic: they use electricity from base load power plants (nuclear or thermal) when demand and generation costs are low and provide peaking energy when demand and generation costs are high.

Scheme Sizes

Hydropower is extremely flexible, with schemes ranging from a few kW to 22,400 MW (Three-Gorges in China). Schemes can be developed to meet local needs, based on the resource available and taking account of the market and any constraints. Large schemes account for the majority of generation but the contribution of smaller schemes is significant. In China, some 42,000 hydropower plants with less than 50 MW of installed capacity currently provide one-third (31 GW, 98 TWh) of the hydro contribution.[8]

Small schemes are easily installed and maintained. They are an extremely important tool for sustainable social and economic development in areas which have water resources but which have no or inadequate access to electricity.

Why Schemes are Developed

The development of hydropower is almost always part of a larger water management scheme. Other than generating electricity, schemes generally aim to provide one or more of the following:

1. Flood Control
2. Irrigation
3. Drinking Water
4. Multi-purpose – 1 and/or 2 and/or 3 above plus any from:
    a. Tourism
    b. Water sports
    c. Fishing
    d. Water quality improvement
    e. Cooling for thermal or nuclear power plants
    f. Other.

Storage schemes are generally multi-purpose; *run of the river* is used for flood control. *Figure 2* below illustrates the nature of schemes by continent and by use. Many dams do not have any electricity generation. Only about 10% of dams have "hydropower" as their main use; considerably more dams have "irrigation" or "multi-purpose" as their main use.

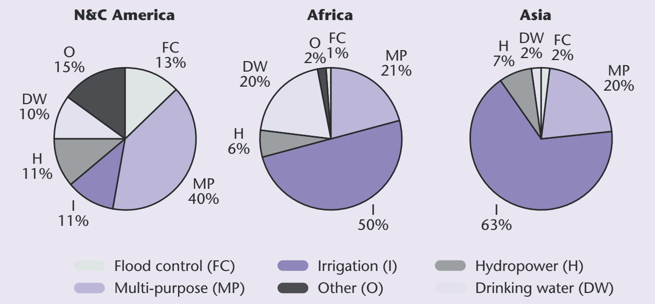

Figure 2: Dam uses by continent

Source: International Commission On Large Dams (ICOLD)

Costs and Efficiency

The construction costs of hydropower projects are very site specific. Large western schemes cost at least US$ 1,200/kW to construct; projects in developing countries cost between US$ 800-2,000/kW.[9] The majority of large conventional schemes are remote from demand centers and thus often require long transmission line construction (included in the cost given above). Medium and large schemes have project lead times of 5-10 years; the costs of small schemes tend to be at the higher end of the range but they can be implemented within periods as short as 1 year. Pumped Storage schemes can take advantage of existing infrastructure or can be built at very favorable sites – resulting costs are thus typically lower than conventional schemes (as low as 400 GW).[10]

Hydro projects are capital intensive and must be viewed as long-term investments. There are schemes in operation today that are over 100 years old, and schemes are generally built with expected lifetimes of at least 50 years. Appropriate dam monitoring allows the preservation of safety conditions throughout this lifetime. Operating costs are low, and reflect the need to maintain both the plant (notably the turbines) and the reservoir (notably to eliminate excess silt build up). Once the initial investment has been repaid, hydro schemes constitute a resource, which can deliver financial, economic, environmental and social benefits over very long periods. In order to better optimize and share the costs and benefits of a multi-purpose project, public-private partnerships may be required.

Regarding generation efficiency, advances in recent years have raised turbine efficiencies to as high as 95% for large units. Smaller and older schemes usually have efficiencies within the range of 60 to 85%. Synchronous and asynchronous generators (which convert turbine output into electricity suitable for export to the grid), now introduce losses of only 1-2%. For *storage* plants, the hydraulic losses (due to the friction) in tunnels and penstocks decrease the global efficiency by 1-5%.

Generation Predictability

Hydro generation is not completely predictable over the medium and long term. Between seasons and over years, hydro generation depends on the weather: rainfall variations are the critical factor, with evaporation rates from reservoirs also driven by temperature, wind and other meteorological conditions. Variations can be significant both between years and within the year (see Figures 3 and 4).

In response to rainfall shortages or to increase storage capacity, certain scheme operators have implemented artificial rainfall systems called "cloud seeding": under specific conditions, clouds are seeded with silver iodide, hygroscopic salts or dry ice in order to artificially trigger rainfall. Hydro Tasmania (Australia) commenced experimentation in seeding clouds in 1964 and undertook 21 campaigns in 2004.

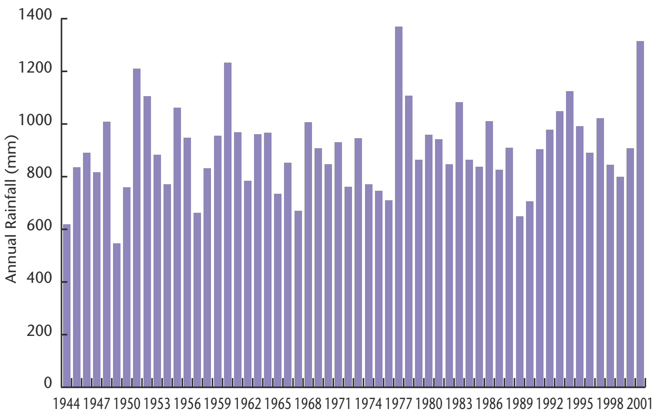

Figure 3: Annual rainfall in Haute Durance

Source: Electricité de France

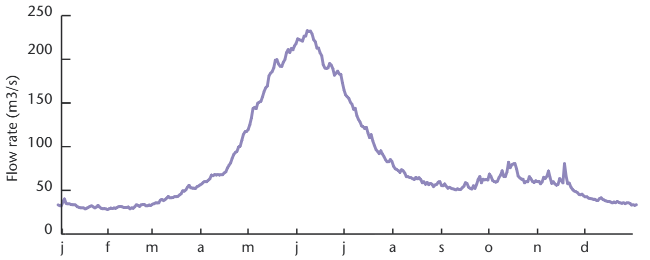

Figure 4: Average (1962-2001) monthly flow rate at the Serre-Ponçon dam

Source: Electricité de France

Benefits to the Electricity System

All hydro schemes can be rapidly connected to and disconnected from the system, either fully or partially. This "modulation" is very beneficial to the electricity system, both for system stability (voltage and frequency control) and for incorporating other plant types (both base plant and intermittent renewables such as wind and solar). Hydro plants can serve as an effective backup for the unplanned outages of other plants. Hydro is often used to provide the system services that other plants can not provide. Which ancillary services a hydro plant provides, and what combination of base, mid-merit and peak supply it generates, depend on both the type of hydro plant available to the system and on the stock of other plant types.

Plants with reservoirs offer long-term modulation; *pumped storage* plants offer even more flexibility, allowing surplus electricity to be "stored" in the form of water until required. It is difficult to separate out and value all the benefits of *pumped storage*, but a useful hypothetical scenario is that a *pumped storage* plant generating the instant electricity required to avert a major blackout could have an extremely short payback (i.e., it would pay back its costs almost instantaneously by avoiding the severe economic costs a major blackout could bring).

IMPACTS

The impacts of hydro schemes are:

- Both positive and negative;
- Of many, varied types;
- Can range from very small to very large.

Assessing the overall impact of hydro schemes is often a difficult task, requiring an assessment of the positive benefits of one type against the negative benefits of another.

It is vital to note that impacts are not fixed by purely technical factors. Good governance could, for instance, deliver positive impacts on river systems and irrigation while bad governance could lead to negative impacts from the same scheme.

Environmental – Global

A hydro plant emits no global pollutants from generation. Indirect emissions result from *construction* activities and from *artificial reservoirs*.

It is estimated that the energy used in hydro scheme *Construction*[11] of large hydro schemes requires only 0.5% of the energy generated during the lifetime of the scheme. This is a far lower percentage than for other generation technologies. A hydro plant has no fuel cycle and indirect emissions from its maintenance are very low.

Run of the River schemes (i.e., all schemes without dams, and hence without standing water) emit no global pollutants. In common with natural lakes and with other ecosystems, artificial reservoirs emit greenhouse gases (GHGs) in the form of CO_2 and methane from the anaerobic decay of impounded biomass. A study looking at emissions from a tropical reservoir found that the CO_2 to CH_4 (methane) ratio decreased over the first 3 years to 86% CO_2 and 14% CH_4.[12] Total emissions depend on the site characteristics (size of the reservoir, climate, biomass, etc.): they mainly occur in the first few years after impoundment and then taper off. Reservoirs (and lakes) also sequester large amounts of carbon, which leads to them becoming carbon-neutral in the longer term.

Several studies are in progress to assess the net impact of reservoirs on GHG emissions.[13] Initial results show that, for northern countries, the "net"[14] emission factor per unit of electricity generated (tCO_2e/TWh) from reservoirs is about 100 times lower than for coal-fired generation and 40 times lower than natural gas combined cycle generation. Tropical areas are more sensitive to the phenomenon, but even from the small number of hydro reservoirs located in tropical regions, "net" emissions from typically sized reservoirs are significantly lower than any fossil-fuelled option. In rare cases when large reservoir areas are combined with a low yearly generation, "gross" emissions can be as high as fossil-fuelled options. Emissions factors are preliminary in nature and mitigation measures could be available.

Environmental – Local

Local gaseous pollutants are emitted only during *construction* activities and are very low per unit of electricity generated when compared to those emitted during fossil fuel electricity generation.

More significant local impacts, both environmental and economic, can result from the modification of the local environment due to the construction of a reservoir, dam, power lines and access roads. Impacts can occur to agriculture, fishing, tourism, biodiversity (the number and type of flora and fauna), navigation, sedimentation and water quality. These impacts may occur upstream and/or downstream, and can be positive, negative, or mixed. Mitigation measures such as building fish passes for preserving migration through the river, animal rescue plans during impoundment of the reservoir, structure optimization for preventing sedimentation in the reservoir, etc. can reduce those negative impacts.

Impacts vary by scheme type. The low-head run of river plants does not include a reservoir and thus has a smaller impact. Pumped storage schemes recycle water and tend to use artificial reservoirs with no initial fauna.

Social/Community

Hydro schemes can have a large social impact on local communities, bringing access to electricity, water for drinking and irrigation, roads, industry and commerce, developing the economy and enhancing quality of life.

In the case of large reservoir creation, they may lead to a large displacement of local populations. The biggest social concern about hydropower is the people who have been forced to move ("resettled") and who have not been properly compensated. A transfer of benefits (such as land use, irrigation rights and access to electricity) from certain groups of the population to others is unavoidable.

One approach to this issue is to fairly share the costs and benefits among the stakeholders of a hydro project and to ensure that affected people are better off after the project is constructed than they were before. Experience has shown that anticipating and exploring impacts early in the planning process is critical, and allows appropriate steps to avoid, mitigate and compensate to be taken.

A number of initiatives have been undertaken to guide if and how hydro schemes should be developed. The World Commission on Dams (WCD) published a decision-making framework based on its work over the period 1997-2000. The "core values" and "strategic priorities" of the WCD work have been largely accepted, but the guidelines are controversial and are seen as unnecessarily constraining by many hydro developers, governments and multilateral agencies. The Sustainability Guidelines and a Compliance Checklist developed by the International Hydro Association (IHA) are now in common use. They guide how to develop hydropower projects in an environmentally sustainable and socially equitable manner. The development of a high-quality dialogue with stakeholders (particularly NGOs) and good governance are essential.

Case Study: The Nam Theun 2 project in Laos

It is possible to develop large hydro schemes with acceptable impacts. The 24 Member World Bank Board of Directors has approved (23 votes "for", US abstention) the Partial Risk Guarantee and financing of the 1,075 MW Nam Theum 2 hydroelectric project in Laos. The World Bank's safeguard policies were applied rather than the full WCD guidelines. The Laos project demonstrates the positive impact large hydro can have on economies. The project will add 3.2% to Laos's GDP per year over the project concession period, principally through the export of power. The total investment package is around US$ 1.3 billion, equivalent to more than half of Laos's 2004 GDP.[15] About 13% of the total budget is allocated for environmental and social measures.

Small schemes often have a major positive impact on social and economic development in remote areas which have water resources but which have no or inadequate access to electricity. Their development is almost always sustainable and will thus yield projects under the Kyoto Protocol's Clean Development Mechanism (CDM). The first carbon credits issued under the CDM were for small-scale hydro products in Central America.[16]

RESEARCH & DEVELOPMENT

R&D for hydro projects is mainly focused on environmental aspects such as the improvement of turbine design for reducing fish mortality (fish-friendly turbines) or the development of new lubricating systems which have no risk of leakage, do not use any oils or use "green" oil to avoid any risk of water pollution in case of leakage.

The impacts of hydro schemes continue to receive wide attention. Current study areas include:

- Quantifying the balance of gaseous emissions from reservoirs;
- The behavior, in reservoir water and sediments, of pollutants upstream either naturally or as a result of human activity.

Matrix turbines have been developed recently for capturing the energy from water that is usually discharged through gates, valves and ship locks. With increasing incentive measures for renewable energy, innovation and new development for getting the most of water management structures will continue.

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9 Harrison. "The technology and economics of hydropower". 2003. See http://www.see.ed.ac.uk/~gph/teaching/Eng1Lecture.pdf (last accessed September 2006). Some exceptions have demonstrated that the cost can be as high as US$ 3,000/kW.

10 EDF. "Hydro power pump storage: valuable compliment to thermal power development". 2001.

11 Indirect construction emissions are dominated by the energy required to produce construction materials (principally concrete and steel) and the energy used to transport materials to the site.

12 Abril, G., F. Guerin, S. Richard, R. Delmas, 37th International Liège Colloquium on Ocean Dynamics, "CH_4 and CO_2 emissions and carbon imbalances in a 10 year old tropical reservoir", http://www.co2.ulg.ac.be/objects/2005/abril.pdf#search=%22GHG%20emissions%20from%20artificial%20reservoirs%22 (last accessed September 2006).

13 See for example Spadaro, Joseph V., Lucille Langlois and Bruce Hamilton. International Atomic Energy Agency, Bulletin 42/2/2000, IAEA Planning and Economic Studies Section, Department of Nuclear Energy, "Greenhouse Gas Emissions of Electricity Generation Chains – Assessing the Difference".

14 "Net" emissions are the emissions from the reservoir minus the amount of carbon that is sequestered in the reservoir, and taking into account what would have happened had the reservoir not been impounded.

15 World Bank. "The Nam Theun 2 Hydroelectric Project – Overview and Update". 2006.

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The World Business Council for Sustainable Development (WBCSD) brings together some 180 international companies in a shared commitment to sustainable development through economic growth, ecological balance and social progress. Our members are drawn from more than 30 countries and 20 major industrial sectors. We also benefit from a global network of 50+ national and regional business councils and partner organizations.

Our **mission** is to provide business leadership as a catalyst for change toward sustainable development, and to support the business license to operate, innovate and grow in a world increasingly shaped by sustainable development issues.

Our **objectives** include:

- **Business Leadership** – to be a leading business advocate on sustainable development;
- **Policy Development** – to help develop policies that create framework conditions for the business contribution to sustainable development;
- **The Business Case** – to develop and promote the business case for sustainable development;
- **Best Practice** – to demonstrate the business contribution to sustainable development and share best practices among members;
- **Global Outreach** – contribute to a sustainable future for developing nations and nations in transition.

Acknowledgements

This issue brief is part of *Powering a Sustainable Future: An agenda for concerted action*, a product of the WBCSD's Electricity Utilities Sector Project.

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Powering a Sustainable Future is a result of collaborative work among executives from the eight member companies of the WBCSD Electricity Utilities Sector Project. This work was convened and supported by the WBCSD Secretariat. All member companies of the project have thoroughly reviewed drafts of the report. However, this does not mean that every member company necessarily agrees with every statement in the report.

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