Hydropower

HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS –** With a total capacity of 723 GW_e (21% of the world's electric capacity), hydropower generates about 3190 TWh per year, which is equivalent to 16% of global electricity generation. Hydropower plants provide at least 50% of the total electricity supply in more than 60 countries. They also provide other key services such as flood control and irrigation. Hydropower plants consist of two basic configurations based on ■ **dams** with reservoirs and ■ **run-of-the-river** plants (with no reservoir). The dam scheme can be subdivided into ■ **small dams** with night and day regulation, ■ **large dams** with seasonal storage, and ■ **pumped storage** reversible (generating and pumping) plants for energy storage and night and day regulation, according to electricity demand.

■ **COSTS –** The investment costs of large (>10 MW_e) hydropower plants range from \$1750/kW_e to \$6250/kW_e and are very site-sensitive, with an average figure of about \$4000/kW_e (US\$ 2008). The investment costs of small (1–10 MW_e) and very small (≤1 MW_e) hydro power plants (VSHP) may range from \$2000 to \$7500/kW_e and from \$2500 to \$10,000/kW_e, respectively, with indicative, average figures of \$4500/kW_e and \$5000/kW_e. Operation and maintenance (O&M) costs of hydropower are between 1.5% and 2.5% of investment costs per year. The resulting overall generation cost is between \$40 and \$110/MWh (typical \$75/MWh) for large hydropower plants, between \$45 and \$120/MWh (typically, \$83/MWh) for small plants, and from \$55 to \$185/MWh (\$90/MWh) for VSHPs.

■ **POTENTIAL AND BARRIERS –** Important technical potential for new hydropower capacity remains in Asia, Africa and South America. A realistic figure would be from 2.5 to 3 times the current production. In the IEA Energy Technology Perspectives Scenarios, (i.e. ACT and BLUE scenarios), hydropower capacity is projected to more than double (up to 1700 GW_e) between now and 2050 and the hydro-electricity production is projected to reach about 5000-5500 TWh per year by 2050. However, future hydropower production could be affected by climate change. The potential impact is not yet really understood and must be investigated in more detail. Key issues and challenges for new hydropower projects include the general scarcity of water and land resources in most parts of the world, the social and environmental impact of large hydropower plants, and the long distances between new resources and consumers (Latin America). These challenges are likely to limit the hydropower potential.

PROCESS AND TECHNOLOGY STATUS – With a total installed capacity of 723 GW_e (21% of the world's electric capacity), hydropower generates approximately 3190 TWh per year, equivalent to 16% of global electricity generation. Hydropower plants provide at least 50% of the total electricity supply in more than 60 countries. They also provide other key services such as flood control, irrigation and potable water reservoirs. Hydropower is an extremely flexible electricity generation technology. Hydro reservoirs provide built-in energy storage that enables a quick response to electricity demand fluctuations across the grid, the optimisation of the electricity production, and the compensation for losses of power from other sources. Hydropower plants consist of two basic configurations based on **dams with reservoirs,** and the **run-of-the-river** scheme (with no reservoir). The dam scheme can be subdivided into **small dams** with night and day regulation, **large dams** with seasonal storage, and **pumped storage** reversible plants (for pumping and generation) for energy storage and night and day regulation according to electricity demand. Small-scale hydropower is normally designed to run in-river. This is an environmentally friendly option, because it does not significantly interfere with river flow.

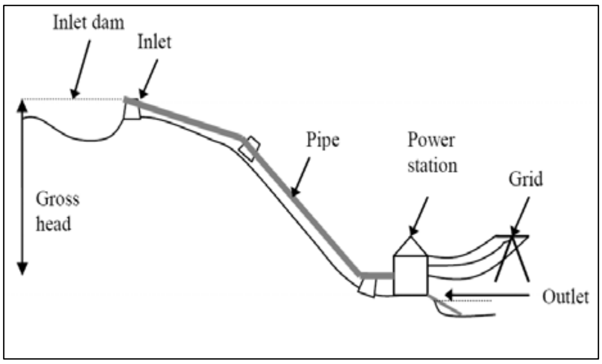

Fig. 1 - Generic scheme of hydropower plants based on a dam (Bøckman et al, 2006)

Small hydro is often used for distributed generation applications the same as diesel generators or other small-scale power plants, and also to provide electricity to rural populations. A generic scheme of a hydropower plant based on a dam and reservoir is shown in Figure 1 (Bøckman et al, 2006). OECD countries produce currently half of the global hydroelectricity. However, non-OECD share is likely to increase quickly as most of the hydropower potential still to be developed is located in non-OECD countries. China, for example, with the completion of the Three Gorges dam, is in the process of adding some 18.2

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GW_e to the existing capacity. Figure 2 presents a characterisation of different types of small hydropower plants by head height, discharge, (flow-rate) and capacity. Large flow-rate and small head characterise large run-of-the-river plants, equipped with **Kaplan** devices. By contrast, low discharge and high head are typical in mountain-based dam installations, which are driven by **Pelton** devices. Intermediate flow-rates and head heights are usually equipped with **Francis** turbines.

Pumped storage plants consist of two or more natural or artificial (dams) reservoirs at different heights. When the electricity generation exceeds the grid demand, the energy is stored by pumping water from the lower to the higher reservoir. During the electricity peak-demand periods, water flows back to the lower reservoir through the turbine, thus generating electricity. In these kinds of plants, reversible Francis devices are used for both water pumping and electricity generation. The electricity storage efficiency is typically around 80%. Pumped storage plants can be combined with intermittent renewable electricity sources. They can also be the optimal complement of nuclear-based electricity that are designed for base-load operation and offer limited capability to adapt to daily and seasonal load fluctuations. Pumped storage capacity worldwide is currently about 100 GW_e, corresponding to about 2% of global generation capacity. No new capacity was added recently in Europe although approximately 9 GW_e of new storage capacity is planned (Schwab, 2007). Globally, there is potential for approximately 1000 GW_e of pumped storage capacity, equal to about half of the real global hydropower potential (Taylor, 2007).

Hydropower generation plants do not produce significant CO_2 emissions other than those emitted during their construction. Some reservoirs may emit methane from the decomposition of organic materials. While this is a rare problem, it can be avoided by proper reservoir design (Scanlon, 2007).

Hydropower is a mature technology. Many plants that were built in the early decades of the 20th century are currently still in operation, although most of them have undergone rehabilitation, modernisation or redevelopment. The era of large hydropower projects began in the 1930s in North America and has since spread worldwide. Today's large projects, either under construction or planned, are located in China, India, Turkey, Canada and Latin America. Significant potential remains around the world for both developing a large number of small hydropower projects and for upgrading existing power plants and dams. Current hydropower plants can be categorised into three areas: ■ Large hydropower (>10 MW_e); ■ Small hydropower (≤ 10 MW_e), with mini-hydro (100 kW_e to 1 MW_e) as a subcategory; and ■ Uprating potential at existing hydropower plants and dams. The market of large hydropower plants is dominated by a few manufacturers of large equipment and a number of suppliers of auxiliary components and systems. Over the past decades, no major breakthroughs have occurred in the basic machinery, however, computer technology has led to significant improvements in many areas such as monitoring, diagnostics, protection and control. Manufacturers and suppliers need to invest significant resources into research and development to meet advances in technology and market competition. Also, large hydropower plants may have a considerable impact on environmental and social-economic aspects at a regional level. Therefore, the link between industry, R&D and policy institutions is crucial to the development of this energy sector.

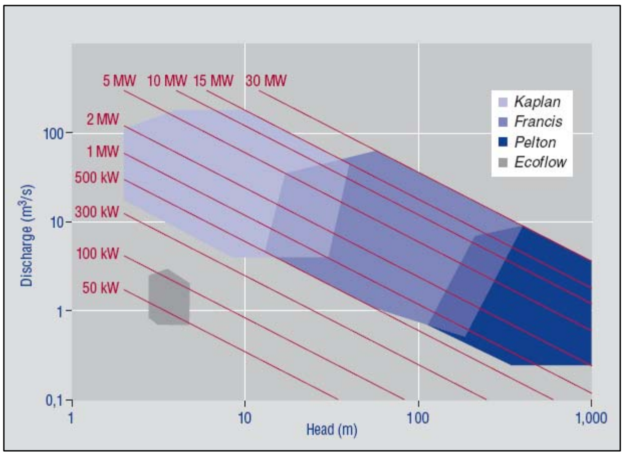

Fig. 2 - Types of small hydropower by head height, discharge, or capacity (Voith Hydro, 2009)

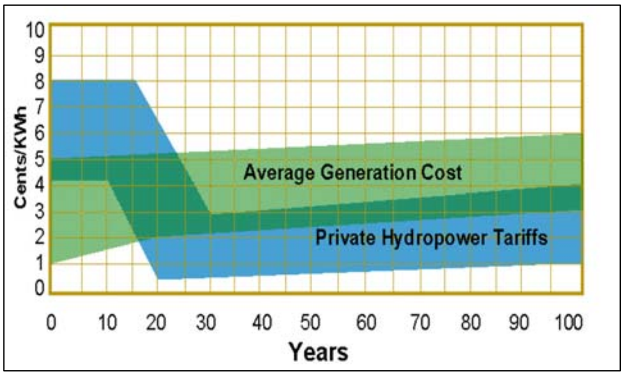

Fig. 3 - Hydro generation cost and investment amortisation (Jianda and Xiaozhang, 2003)

Unlike large plants, small hydropower installations comprise a huge variety of designs, layouts, equipment and materials. Therefore, state-of-the-art technologies, knowledge and design experience are the key to fully exploiting local resources at competitive costs and with no significant environmental impact. Uprating is the way to maximise the energy produced from existing hydropower plants and may often offer a cheaper opportunity to increase hydropower production. Gains of between 5% and 10% are realistic and cost-effective

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targets for most hydropower plants. The potential gain could also be higher at locations where non-generating dams are available. Investment in repowering projects, however, involves risks, not only technical, but also risks associated to the re-licensing of existing installations, often designed several decades ago, with limited records of technical documentation. As a result, significant potential is left untapped. However, today's technologies allow for an accurate analysis of geology and hydrology, and precise assessments of potential gains.

COSTS – Existing hydropower is one of the cheapest ways to generate electricity. Most plants were built a long time ago and the initial investment for dams and hydro-geological infrastructure has been fully amortized. After the amortization, the remaining costs are associated to operation and maintenance (O&M) and the possible replacement of main machinery after several decades of operation (Figure 3). Small hydropower plants may be operated for around 50 years without substantial replacement costs.

Hydropower investment costs for new installations vary considerably between industrialised and developing countries. In developing countries and emerging economies the construction of hydropower plants usually involves substantial civil work (dams, deviation of rivers, etc.), the cost of which largely depends on labour costs, which is substantially lower than in industrialised countries. The total investment costs largely depend on site features and availability of grid connections. Generating costs usually range from \$20/MWh to \$60/MWh. Figure 4 shows the specific investment cost in 2003 US dollars, of hydropower in China and India (Lako et al, 2003). Figures 5-7 show the specific investment costs of hydropower projects in a number of Asian countries (Lao PDR, Nepal, and Vietnam), South and Central America, and Africa and Turkey, respectively. Although data are provided in 2003 US dollars (Figures 4–7), the investment costs in developing countries are significantly lower than in industrialised countries because of different social and labour conditions. Naturally, lower investment costs, e.g. from \$1250/kW$_e$ to \$2500/kW$_e$ in China, translate into lower generation costs.

In industrialised countries, costs largely depend on site features and plant size as well, but the basic level is significantly higher: Large hydro plants range from \$1750 to 6250/kW$_e$ (typical average cost is \$4000/kW$_e$); Small hydro plants are from \$2000 and \$7500/kW$_e$ (\$4500/kW$_e$); Very small hydro plants (≤ 1 MW$_e$): are between \$2500 and \$10,000/kW$_e$ (\$5,000/kW$_e$). In 2009, Hydro-Quebec (Canada) was given permission to build a number of hydro projects totalling 4500 MW$_e$, with a total price of US\$ 23 billion

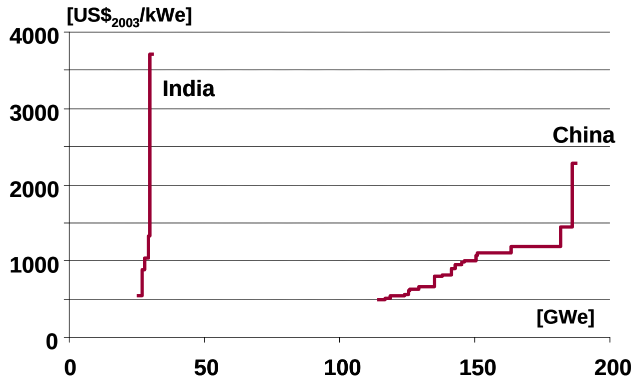

Fig. 4 - Hydropower investment cost in China and India (Lako et al., 2003)

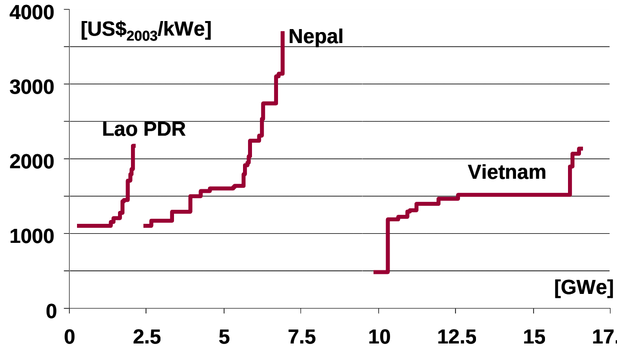

Fig. 5 - Hydropower investment cost in Asian countries (Lako et al, 2003)

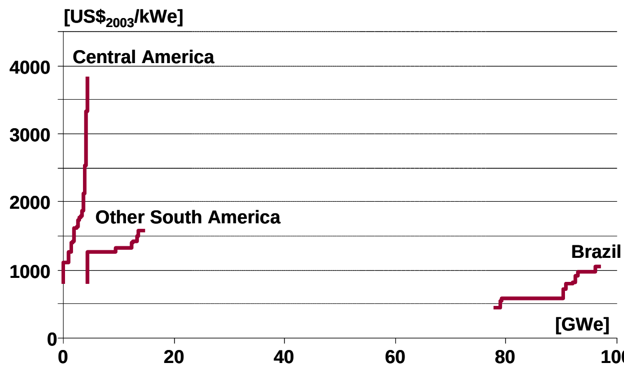

Fig. 6 – Hydropower investment cost in Central and South America (Lako et al, 2003)

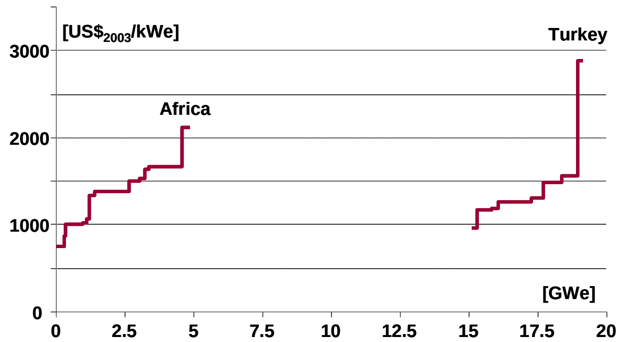

Fig. 7 - Hydropower investment cost in Africa and Turkey (Lako et al, 2003)

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(Hydro-Quebec, 2009). Similar investment costs ($5,000/kW$_e$) are reported for the Susitna plant (680 MW$_e$) in Alaska (HDR, 2009). O&M costs are estimated between 1.5% and 2.5% of investment costs per year. Estimated generation costs are in the range of $40–110/MWh (av. $75/MWh) for large hydro, $45–85/MWh (av. $65/MWh) for small hydro, and $55–185/MWh (av. $90/MWh) for VSHP.

The cost of pumped storage systems also depends strongly on site configuration, not to mention the operation service. The investment cost may be up to twice that of an un-pumped hydropower system. However, depending on cycling rates, the generating cost may be similar to that of un-pumped systems as a pumped storage system receives a substantial income from pumping during the night and generating during peak demand periods, based on a corresponding electricity price differential.

POTENTIAL AND BARRIERS – The IEA reports a global, technically-feasible hydro-electricity potential of some 14,000 TWh per year. About 6000 TWh per year is considered to be a realistic, cost-effective economic target (Taylor, 2007). Around 808 GW$_e$ of hydropower capacity are currently in operation or under construction worldwide. Most of the remaining resources to be developed are located in Africa, Asia, and Latin America. The global technical potential of small hydropower is estimated between 150 and 200 GW$_e$. Only about 20% of this potential has been exploited. Large hydropower projects can be controversial because they may affect water availability in large regions, inundate valuable ecosystems, be responsible for the relocation of populations, and require large electricity transmission infrastructure. New, less-intrusive low-head turbines are being developed for smaller reservoirs. Hydropower usually depends on rainfall in the upstream catchment area and reserve capacity may be needed to compensate for periods of low rainfall. This may increase the investment cost. Major hydropower issues include public acceptance, high initial investment costs and long payback periods, long approval and construction cycle, and long lead time to obtain or renew concession rights and grid connections. Other barriers such as stringent environmental standards for water management can also hamper hydropower development. Coherent policies and simplified administrative procedures are needed. Significant advances in hydropower technology promise further developments. By contrast, the implementation of these advances is slow and R&D investment is insufficient. This is partially due to the misperception that hydropower is a mature technology with no significant prospects for further developments. While increasing energy supply from hydropower does not require technological breakthroughs, significant R&D, capital investment and governmental support are required to improve technology and public acceptance. Table 1 provides R&D priorities for large and small hydropower (IEA, 2008). R&D and technical advances are also required for small hydropower, notably equipment design, materials, control systems. One priority is the development of cheaper technologies for small-capacity and low-head applications, to enable the exploitation of smaller resources.

Table 1 - Technology advances for hydropower (IEA, 2008)

	Large hydro	Small hydro
Equipment	Low-head tech.s, incl. in-stream flow; adv. equipment and materials	Low-impact turbines for fish populations; low-head tech.s; In-stream flow tech.s
O&M	Maintenance-free and remote operation	Package plants with limited O&M
Storage and hybrid tech.		Wind-hydro and Hydrogen-hydro systems

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Table 2 – Summary Table: Key Data and Figures for Hydropower Technology

Technical Performance	**Typical current international values and ranges**		
Energy input Output	Hydro power Electricity		
Technologies	Very small hydro power (VSHP, up to 1 MW_e)	Small hydro power (SHP,1 – 10 MW_e)	Large hydro power (LHP, >10 MW_e)
Efficiency (turbine, Cp max),%	Up to 92	Up to 92	Up to 92
Construction time, months	6 – 10	10 – 18	18 – 96
Technical lifetime, yr	Up to 100		
Load (capacity) factor, %	40 – 60 (50)	34 – 56 (45)	34 – 56 (45)
Max. (plant) availability, %	98	98	98
Typical (capacity) size, MW_e	0.5	5	50
Existing) capacity, GW_e	45		678
Environmental Impact			
CO_2 and other GHG emissions, kg/MWh	Negligible		
Costs (US$ 2008)			
Investment cost, incl. IDC, $/kW	2,500 – 10,000 (5,000)	2,000 – 7,500 (4,500)	1,750 – 6,250 (4,000)
O&M cost (fixed & variable), $/kW/a	50 – 90 (75)	45 – 85 (65)	35 – 85 (60)
Economic lifetime, yr Interest rate, %	30 10		
Total production cost, $/MWh	55 – 185 (90)	45 – 120 (82.5)	40 – 110 (75)

Data Projections	**2010**			**2020**			**2030**	
Technology	VSHP	SHP	LHP	VSHP	SHP	LHP	VSHP	SHP
Net Efficiency (LHV)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Investment cost, incl. IDC, $/kW	5,000	4,500	4,000	4,500	4,000	3,600	4,000	3,600
Total production cost, $/MWh	90	82.5	75	81	75	67.5	73	67.5
Market share, % of global electricity output		16–17			18–20		20–21 (total)	

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