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World Energy Resources

Charting the Upsurge in Hydropower Development

2015

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1. Introduction

There has been a major upsurge in hydropower development globally in recent years. The total installed capacity has grown by 27% since 2004, with an average growth rate of 3% per year. The rise has been particular in emerging markets where hydropower offers not only clean energy, but also provides water services, energy security and facilitates regional cooperation and economic development. The drivers for the upsurge in hydropower development are the increased demand for electricity, energy storage, flexibility of generation, freshwater management, and climate change mitigation and adaptation solutions. On the one hand, there has been significant progress in terms of sustainability practices of the sector and acceptance by external stakeholders such as NGOs and the financial community, which had previously hindered development of new projects. On the other hand, criticism of hydropower continues in some stakeholder groups, especially where new developments impact local communities or where river flows affect vulnerable habitats.

It is in this context that the World Energy Council (WEC) has undertaken an analysis of the current state of the hydropower sector and the associated issues and opportunities to inform decision makers. This work will also feed into WEC's flagship publications, the World Energy Resources and the World Energy Scenarios. The key messages emerging from the World Energy Resources - Hydropower report are highlighted below

Key messages

- Supplying 16.4% of global power supply in 2013, hydropower has experienced an upsurge in development activity over the past decade, reaching 1000 GW of total installed capacity, with 40 GW installed in 2013 alone.

- Globally, an estimated 10,000 TWh/year of undeveloped potential remains for new development. Together with improved performance of existing assets, hydropower growth is expected to continue its current trend over the next several decades.

- As a renewable energy, hydropower can serve as a tool for climate mitigation, where it is an accepted offset for fossil fuel technologies under UNFCCC methodologies. It can also provide climate change adaptation services through its ability to store water, contributing to flood control and drought alleviation in some circumstances.

- Infrastructure for hydropower projects can also be used for freshwater management and projects with reservoir storage generally provide a variety of value-added uses. Multi-purpose uses for reservoirs, including irrigation, flood control, navigation, and recreation, can help support the public acceptance of new storage projects.

- Hydropower provides energy storage and other ancillary services that contribute to the more efficient management of the electricity supply system and balancing of the grid.

- Water availability is a local issue, therefore governments must take a leading role in addressing the vicious cycle of increasing water and energy demand. Co-operation between the energy and water sectors is important, as is driving the operational efficiencies of the major energy and water consumers, particularly electricity generators.

- As so many water resources span across more than one country, government decisions, policies and co-operation with neighbouring countries, are crucial to the success of such projects. Governments further have the responsibility to ensure that sustainability requirements – economic, social and environmental – are met and that benefits, especially for local communities are realised.

- Opening up new markets through cross-border trade and power pools and devising appropriate market conditions, such as renewables incentives, clearer price signals for ancillary services and flexible generation, could all have a positive impact on hydropower development.

- Project developers and owners of hydropower projects will increasingly be expected to demonstrate climate resilience at the financial and regulatory approval stages. This may include provision of improved data analysis on climate change impacts, increased flexibility in project design to accommodate uncertainty, increased storage volumes, and revised operational regimes.

Summary

As a mature technology, hydropower provides over 16% of global electricity production[1]. Since 2004, hydropower development has been on the increase, as emerging markets recognise the benefits that it can bring. In addition to low-cost electricity supply, hydropower provides energy storage and other ancillary services that contribute to the more efficient management of the electricity supply system and balancing of the grid.

An important new driver for global development is hydropower's role as a flexible generation asset as well as an energy storage technology. Storage hydropower (including pumped storage) represents 99% of the world's operational electricity storage[2]. With the increased deployment of variable renewable energy technologies such as wind and solar, hydropower is increasingly recognised as an important system management asset capable of ensuring reliable supply.

Infrastructure for hydropower projects is also used for freshwater management, and projects with reservoir storage generally provide a variety of value-added uses. In these instances, hydropower typically brings a financial justification for investment in public benefits such as water supply, flood protection, drought management, navigation, irrigation and recreation. Given the major investment required for hydropower, and the potential impact on local environments, politicians and the

[1] REN21 - Renewables 2014 Global Status Report and International Hydropower Association
[2] IEA – IEA Technology Roadmap: Hydropower

general public may be more inclined to support projects that offer multiple benefits beyond electricity. This also highlights the need for a holistic approach, thorough and wide consultation process and proper management of the project to deliver optimal benefits to all stakeholders.

Freshwater management is especially important in the context of climate change. As a renewable energy source, hydropower offers a contribution to climate change mitigation. As water management infrastructure, it is also expected to play an increasing role in climate change adaptation, where it will be called upon to help respond to expected increases in extreme weather events, including more intense and frequent flood incidents and longer periods of drought.

These multiple services and benefits have reinvigorated interest in hydropower and have altered perceptions of its importance. There have also been significant advances in sustainable development practices in the sector - the sector now has a widely recognised and broadly supported tool to assess hydropower project sustainability, as well as to promote improved sustainability performance across the sector[3]. These factors have combined to improve acceptance and willingness of policymakers and the financial sector to engage in hydropower utilisation, through enabling policy frameworks and, crucially, providing investment and financial support to both public and private entities.

Global status in 2014

Hydropower is the leading renewable source for electricity generation globally, supplying 76% of all renewable electricity. Reaching 1000 GW of installed capacity in 2013, it generated 16.4%[4] of the world's electricity from all sources. With 40 GW of new installed capacity in 2013, the annual increase in capacity was greater than that for both wind and solar (35 and 39 GW respectively).

Since 2004, hydropower development has seen resurgence, particularly in emerging markets and less developed countries. Significant new development is concentrated in the markets of Asia, Latin America and Africa, where hydropower offers an opportunity to bring much needed electricity supply to under-served populations and a growing industrial base, while at the same time providing a range of complementary benefits associated with multi-purpose projects.

[3] Hydropower Sustainability Assessment Protocol: http://www.hydrosustainability.org/
[4] IHA/REN21

Figure 1 – Global total hydropower generation since 1980

Source: IHA, EIA, REN21 - Renewables 2014 Global Status Report

In Figure 1, the history of hydropower growth is demonstrated. The blue arrow represents a general historic increase in hydropower following growing demand for electricity worldwide.

From 1999 through 2005 (illustrated by the orange arrow), hydropower development was largely halted worldwide, reflecting the impact of the World Commission on Dams (WCD), which was convened to review the development effectiveness of large dams and develop guidelines for the development of new dams. The report, published by WCD in 2000, challenged existing practices and proposed stringent guidelines for dams, which in turn caused a sharp decrease in investments while the sector and the financial community considered how to respond to increased expectations.

From 2005 onwards (green arrow), hydropower development has seen an upswing in development, which can be partly attributed to the impact of intensive efforts by the International Hydropower Association (IHA) and hydropower companies to negotiate sustainability guidelines for the sector. Additionally, growing investments in and by emerging economies (i.e. BRICS, particularly China), continued interest in renewable energy, particularly with storage capacity. Participation in Carbon Markets / Renewable Energy Credits has also contributed to the upswing.

The question of hydropower's role as a renewable energy source, irrespective of size has also now been settled by international policy groups as well as the scientific community. In 2004, the Bonn International Conference on Renewable Energies (a declaration signed by 154 countries) and the United Nations Beijing Declaration on Hydropower and Sustainable Development both recognised hydropower as an important renewable energy source. Furthermore, the IPCC Special Report on Renewable Energy indicates that classification of hydropower projects according to size is an administrative construct, and that size is not a 'technically or scientifically rigorous indicator of impacts, economics or characteristics'[5].

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[5] IPCC SRREN

Table 1 shows the nations with the largest hydropower capacities in the world. In recent years China has taken centre stage for hydropower capacity, accounting for 26% of global installed capacity as of 2013, far ahead of Brazil (8.6%), USA (7.8%) and Canada (7.6%). China has strengthened its dominant position by adding 29 GW in 2013, well over three times the new capacity of the next five countries combined.

China is expected to maintain its lead in 2015 as well, with new developments completed at Xiloudu (13.9 GW), Xiangjiaba (6.4 GW), and Nuozhadu (5.9 GW). Total capacity in China is expected to reach 350 GW of pure hydropower and 70 GW of pumped storage by 2020[6]. Chinese companies are also playing leading roles in developing hydropower beyond China's own borders; in Laos, Cambodia, Myanmar and other Asian countries, as well as increasing their presence in Africa and Latin America.

Beyond China, significant new deployment took place in the emerging markets of Asia including concentrations in Russia, India, Turkey and Vietnam. Asia has the largest remaining unutilised potential, estimated at 7,195 TWh/year[7], making it the likely leading market for future development. Concentrated development is expected to continue apace in India, Turkey, Bhutan and Nepal.

Table 1 – Top hydropower capacity as of 2013, by country

Source: REN21, 2014

	Production (TWh)	Total Capacity (GW)	Added Capacity in 2013 (GW)
China	905	260	28.7
Brazil	415	85.7	1.7
USA	269	79.0	0.3
Canada	388	76.1	0.1
Russia	175	46.7	0.7
India	143	43.7	0.8

Latin America is another key market for hydropower development. Brazil leads the continent in both installed capacity and new capacity additions, with 85.7 GW installed capacity in total. Hydropower forms the backbone of Brazil's electricity system, supplying over 75% of the country's needs, although this figure is expected to decline due to a reducing number of sites available to develop and increased investment in fossil fuel generation. However, Brazil looks set to continue hydropower development with plans for construction of up to 19 GW in the next ten years. Recent developments in Brazil include the partial commissioning of the Jirau (3750 MW) and Santo Antonio (3150 MW) projects on the Madeira River, both planned to be fully commissioned in 2015. Other Latin American countries with significant hydropower capacity include Argentina, Chile, Colombia, Paraguay, Peru and Venezuela.

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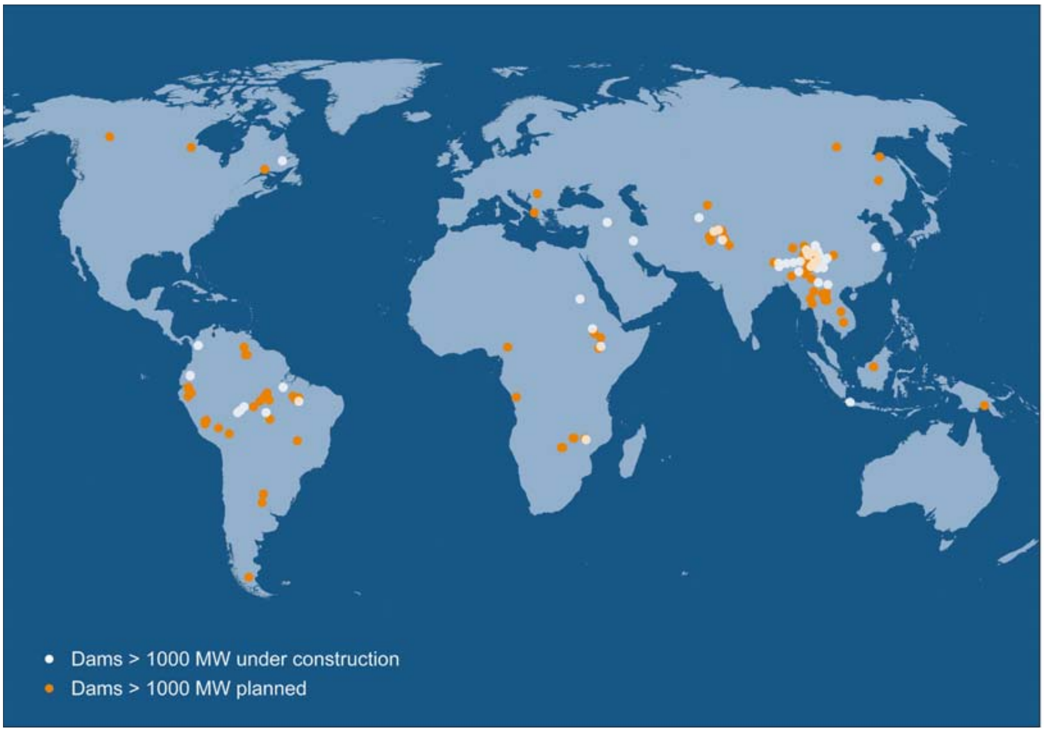
[6] China 12th 5-Year Plan (2011-2015)
[7] IHA

Africa is expected to be a major market for future hydropower activity. With the average electrification rates at only 45%[8] in 2012, hydropower offers real opportunities for providing electricity on the continent using largely local or regional resources. Significant undeveloped potential remains across all of Africa, with only an estimated nine percent of reported hydropower potential developed to date[9]. In particular, the markets of Democratic Republic of Congo, Angola, Ethiopia and Cameroon have significant undeveloped potential. Regional African co-operation bodies, including the Eastern Africa Power Pool, the Western Africa Power Pool and the Southern Africa Power Pool, have the potential to drive further development of hydropower where domestic resources can be developed for export to neighbouring countries with strong demand.

In contrast, Europe and North America are already highly developed markets, where modernisation, uprating and conversion of existing hydropower facilities are the key drivers of hydropower development. Greenfield development is less active than in previous years, although a small number of new projects were being developed in 2014, including the 695 MW Keeyask project in Canada and 2000 MW of pumped storage capacity under construction in Portugal.

Figure 2 – Global distribution of future hydropower dams (under construction or planned)

Source: Zarfl et al. (2015), *A global boom in hydropower dam construction*



Recent upsurges in development notwithstanding, there still remain significant levels of unutilised potential to be developed globally. Various scenarios look at potential future development, with some indicating a potential to reach up to 2000–2050 GW of installed hydropower capacity by 2050[10]. Regionally, East Asia represents the greatest opportunity for further hydropower development, as well as Africa and Latin

[8] IEA, World Energy Outlook Special Report - Africa Energy Outlook 2014
[9] IHA
[10] IEA, IHA

America. As can be seen in Figure 2, at the country level, Indonesia, Tajikistan, Nepal, Myanmar, Bolivia, Angola, and the Democratic Republic of Congo have each used less than five percent of their estimated hydropower capacity and could also be major markets for future development.

2. Technology and markets

Types of hydropower

Hydropower is the generation of power by harnessing energy from moving water. Electricity is generated through the transformation of hydraulic energy into mechanical energy to activate a turbine connected to a generator.

It is a versatile energy source, which can respond to different requirements and take on many forms, adapting to various physical and human environments. Although hydropower plants are highly site-specific, where the local topography and hydrology will define the type of facilities that can be built, they can be broadly categorised into four main typologies:

- Storage hydropower – a facility that uses a dam to impound river water, which is then stored in a reservoir for release when needed. Electricity is produced by releasing water from the reservoir through operable gates into a turbine, which in turn activates a generator. Storage hydropower can be operated to provide base-load power, as well as peak-load through its ability to be shut down and started up at short notice according to the demands of the system. It can offer enough storage capacity to operate independently of the hydrological inflow for many weeks, or even months. Given their ability to control water flows, storage reservoirs are often built as multi-purpose systems, providing additional benefits as discussed later in this section.

- Run-of-river hydropower – a facility that channels flowing water from a river through a canal or penstock to drive a turbine. Typically a run-of-river project will have little or no storage facility. Run-of-river provides a continuous supply of electricity, thus providing base load power to the electrical grid. These facilities include some flexibility of operation for daily fluctuations in demand through water flow that is regulated by the facility.

- Pumped-storage hydropower – provides peak-load supply, harnessing water which is cycled between a lower and upper reservoir by pumps, which use surplus energy from the system at times of low demand. When electricity demand is high, water is released back to the lower reservoir through turbines to produce electricity. Some pumped-storage projects will also have natural inflow to the upper reservoir which will augment the generation achieved through pumping. Pure pumped-storage hydropower is a net consumer of electricity – its value is in the provision of energy storage, enabling peak demand to be met and other ancillary services to electrical grids.

- Marine/offshore technologies – a less established, but growing group of technologies that use power of currents or waves to generate electricity from seawater. These include hydrokinetic (river, ocean and wave), tidal barrage and tidal stream, osmotic and ocean thermal technologies. Although the technology for these uses the same basic concepts as hydropower technology, these will be covered in the Marine Energies chapter of the World Energy Resources publication.

Even though there are clear hydropower typologies, there can be overlap among the above categories. For example, storage projects can involve an element of pumping to supplement the water that flows into the reservoir naturally and run-of-river projects often provide some level of storage capability. Pumped-storage plants, such as Schluchsee in Germany, combine the off-peak surplus energy intake from the system with natural flow.

Hydropower technologies are not bound by size constraints – the basic technology is the same irrespective of the size of the development. As with all energy technologies, hydropower facilities are reported on in terms of their installed capacity. Hydropower facilities installed today range in size from less than 100 KW to greater than 22 GW, with individual turbines reaching 1000 MW in capacity.

Role of hydropower in the energy mix

Hydropower can provide base-load, peaking power and ancillary services. The project's design and equipment utilised, plus market dynamics and local regulatory requirements, will drive the type of services provided. Hydropower projects are highly site-specific, with the local topography and hydrology serving as a key defining parameter for how they might be developed.

Hydropower is traditionally developed to provide low-cost base-load power, where the constant flow of water through the generators adds reliable generation into the energy mix. It can also provide peaking power, where the ability to release water at short notice can respond to immediate needs for more power on the grid. Costs paid to generators for peaking power are traditionally higher than those paid for base-load power, reflecting the shorter duration of peak episodes, as well as the economic dynamics of supply and demand.

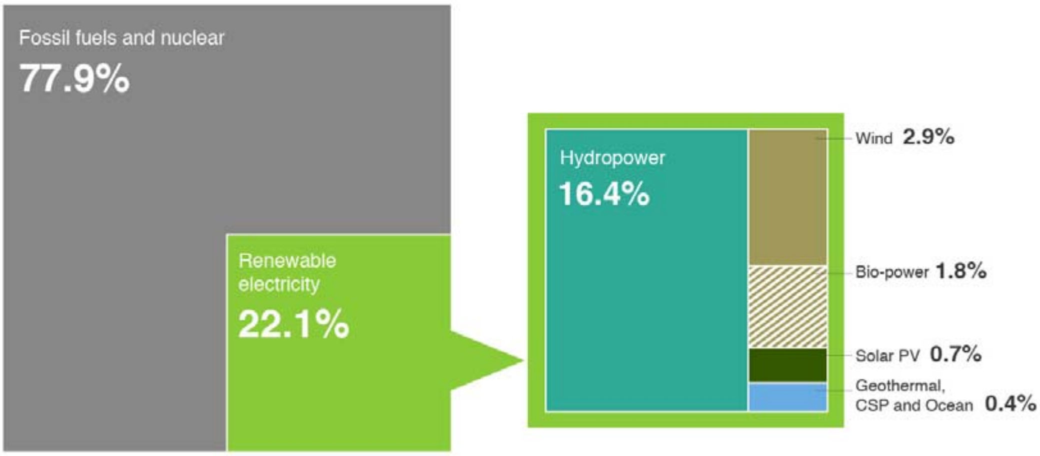
More recently, the traditional roles of hydropower are evolving with the increased penetration of variable renewable energy sources. At an operational level, this means there has been a shift from daily, predictable peaks where generators can plan well in advance, to an increasing proportion of unplanned peaks due to weather patterns impacting wind and solar availability. Consequentially, the timeframes in which supply and demand have to be matched are getting tighter, which is requiring more and more advanced equipment to keep the system reliable.

Energy storage is another important function that hydropower provides. Reservoirs with storage offer a high degree of flexibility, storing potential energy for later use at timescales ranging from seconds, to days, to several months. This service is likely to be called upon more frequently as more renewables are deployed, as there are currently few other commercially viable large-scale energy storage options available.

At present, it is estimated that 99% of the world's electricity storage capacity is in the form of hydropower, including pumped storage[11]. At times of high solar radiation or strong winds, the energy must be used by either the electricity system, stored for later use, or curtailed. In systems with significant deployment of renewable energy, when supply is high, pumped-storage hydropower can absorb excess capacity from the grid to pump water into the upper reservoir, thus avoiding curtailment of those assets. This stored renewable energy can then be used later when it is needed. More specifically, when wind turbines or solar panels are injecting energy into a grid, hydropower units can reduce their own output and store extra water in their reservoirs. This storage 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 ability to compensate for variable renewable energy output, makes hydropower an important asset for enabling the deployment of other renewable energy systems. The figure below shows the position of hydropower compared to other renewable energy in global electricity generation.

Figure 3 – Estimated renewable energy share of global electricity production, 2013

Source: REN21 - Renewables 2014 Global Status Report



In addition, hydropower and especially pumped storage, also provides an array of energy services beyond firm power, including black start capability, frequency regulation, inertial response, spinning and non-spinning reserve and voltage support, among others. These ancillary services are increasingly important to the stability of the energy system and may also offer an alternate revenue stream for hydropower generators. These services are priced differently in various markets around the globe, although it is increasingly recognised that they are often not appropriately or sufficiently rewarded by energy markets. The following table indicates existing and new capacity for pumped storage.

[11] IEA, Technology Roadmap - Energy storage, 2014

Table 2 – Pumped-storage hydropower installed capacity in 2013, by region
Source: U.S. DOE Global Energy Storage Database

	Installed capacity (MW)	Capacity under construction (MW)
Africa	1 580	1 332
Middle East & North Africa	1 505	0
Latin America & The Caribbean	1 025	0
North America	20 557	0
Europe	51 420	8 955
South & Central Asia	5 072	1 700
East Asia	56 315	12 844
Southeast Asia & Pacific	4 642	0
World Total	142 115	24 831

Economic and financial viability

With increasing multi-purpose use of freshwater reservoirs and the growing role of the private sector, it is important to analyse both economic and financial performance of hydropower developments.

Investment in hydropower has traditionally been the realm of the public sector, as hydropower projects are major infrastructure investments. More recently, private players have entered the sector that includes public–private partnerships, where risks are allocated to the party best able to manage it.

With regard to financial performance, hydropower has been subject to some criticism on the basis of cost and schedule overruns. Geological uncertainties associated with project construction, along with legal requirements and political decision-making that are subject to delay, could pose some risks to a project.

Numerous studies have analysed the levelised cost of electricity (LCOE) of hydropower in comparison to other energy technologies. A study of 2155 hydropower projects in the United States found that the LCOE ranged from a low of $0.012/kWh for additional capacity at an existing hydropower project, to a high of $0.19/kWh for a 1 MW small hydro project with a capacity factor of 30%[12]. The weighted average cost

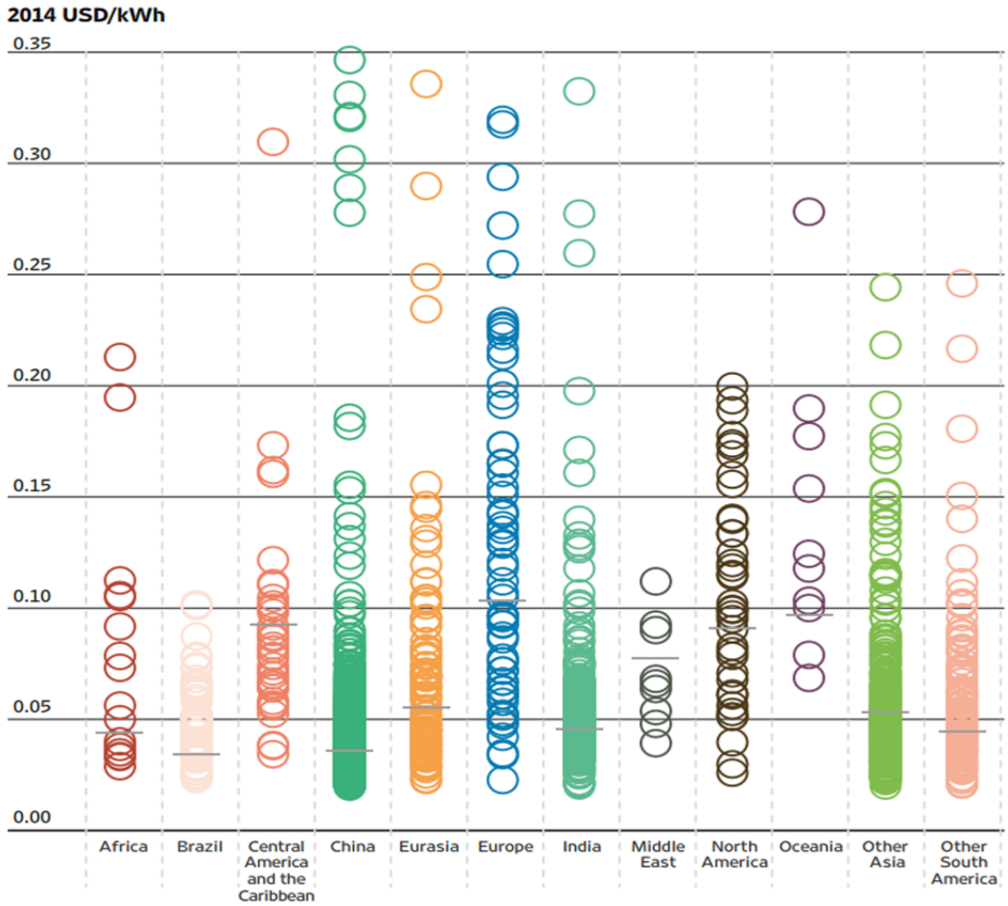
[12] IPCC SRREN, IRENA

of all the sites evaluated was \$0.048/kWh. The LCOE of 80% of the projects was between \$0.018 and \$0.085/kWh.

The share of the electro-mechanical equipment costs in the total LCOE ranged from a low of 17% to a high of 50%, with typical values ranging from 21% to 31%. Civil works costs ranged from zero (for an existing project) to a high of 63%[13]. These costs are indicative and vary from country to country and project to project and are indicated in in Figure 4 below.

Figure 4 – Levelised cost of electricity ranges and weighted averages of small and large hydropower projects by region

Source: IRENA, 2014



While all hydropower projects have the same financial profile of high capital cost, low operation and maintenance cost, no fuel cost and typically steady sustained revenues, the scale of the project plays a major role in the LCOE. Small-scale hydropower (installed capacity of less than 10 MW) may cost between \$2000-4000/MW, while a larger scheme of 300 MW and greater is likely to cost significantly less at approximately \$2000/MW, which considerably enhances the return to the investor[14].

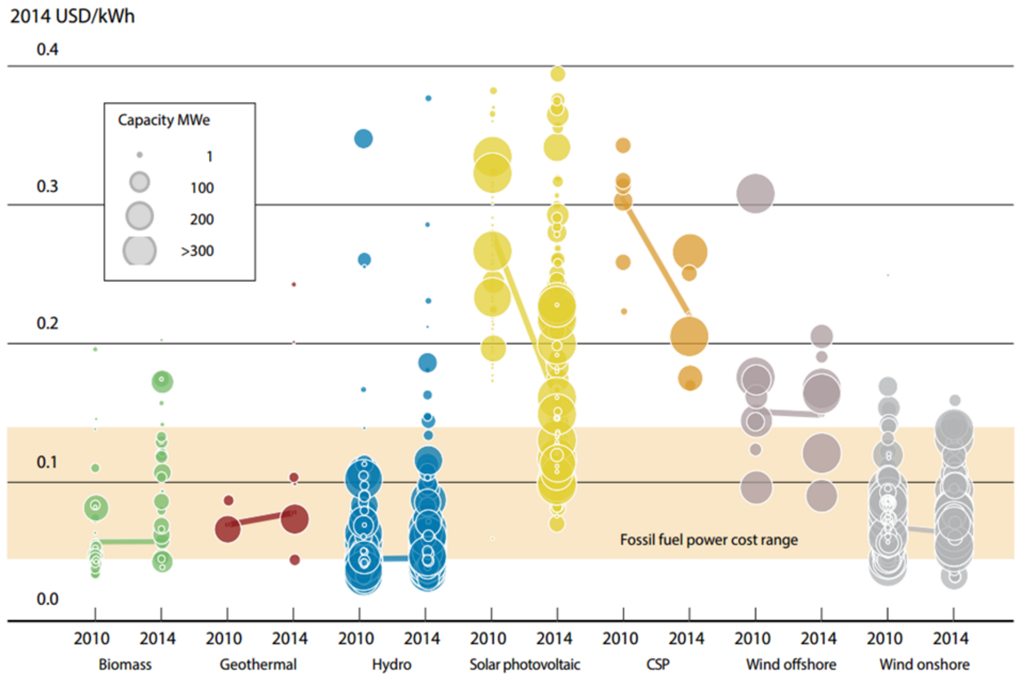
It is important to note that hydropower's revenue stream is steady only when long-term power purchase agreements (PPA) or feed-in tariffs exist. There is a substantial price risk in liberalised power markets, when no such mechanisms are in place, although

[13] IRENA, 2014, http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-HYDROPOWER.pdf
[14] IEA ibid

this is the case for all energy technologies and is not specific to hydropower. In such cases, hydropower operators will make generation decisions on the basis of shorter-term electricity prices, which can in many cases, bring higher returns relative to long-term PPAs. However, spot markets also bring an element of risk to the hydropower operator which must be considered.

Figure 5 – Levelised cost of electricity from renewable power generation technologies, 2010 and 2014*

Source: IRENA, 2014.



**Size of the circle represents the size of the project. The centre of each circle is the value for the cost of each project on the Y-axis*

As shown in Figure 5 above, the LCOE of hydropower is favourable in comparison to other energy sources, high upfront investment costs can be a deterrent or a source of project delays. The decision for investment in hydropower is often made on an economic basis, rather than purely financial considerations. The non-power services benefits that hydropower can bring to a region often cannot be clearly quantified on a return on investment basis. For example, many hydropower projects offer an element of flood protection for the local region and the economic value lies in the value preservation and avoidance of damages. Although it is a highly valued benefit, there is no specific contribution to return on investment for this service. Other multi-purpose benefits include drought management, drinking water supply, irrigation, navigation and tourism, all which typically do not offer clear and direct revenue streams to reservoir developers.

Economic and financial risk

Reservoirs can extend to hundreds or even thousands of square kilometres, requiring detailed and extensive studies of the hydrology, geology, topography and general environment and social characteristics of the site. These studies, along with detailed proposals for the civil works and other technical impacts incur significant early financial outlay. This increases capital requirements, and therefore risk, as the studies are performed before there is any certainty around project authorisation.

The construction period also brings high risk, although at this stage in the development, there is generally a better indication of what the revenue sources will be when the project is operational. However, with increasing uncertainties in both the climate patterns and economic conditions, this will require a more thorough and individually tailored risk profile.

During the operational phase, low maintenance costs and no fuel requirement mean that most costs have already been incurred and revenues are typically steady. This, combined with the very long operating life of hydropower (up to 200 years), makes it an attractive prospect for those willing to accept longer-term returns and take a long-term perspective. However, while risks decline significantly once operations commence, operational risks can include changing hydrology, changing regulatory environments, and new requirements for multi-purpose reservoirs, all of which could impact electricity generation and, therefore, revenue.

Correlating with the changing risk profile through the planning, construction and operation stages of a project, the risk premium on financing for these projects also declines through each stage. In dynamic markets, risk and consequently reward, is taken on by different players throughout these distinct phases. With greater involvement of the private sector, there tend to be more changes in project ownership over the course of the project's lifecycle. Thus the cost of finance correlates with the risk of the specific lifecycle stage.

New investors

Private investment in the sector has increased over the past decades of high development, where markets have enabled such investment. Investment is also increasingly coming from new international players, both public and private. Chinese entities are investing heavily in Africa, East Asia, and South America. Norway's Statkraft and SN Power have investments in Turkey, Zambia, and Panama. Other notable investments have included South Korean investment in Nepal, Pakistan and the Philippines; Thailand's investment in Myanmar; and Iran's investment in Tajikistan, to provide just a few examples.

Technological developments

Hydropower is a mature technology that is reliable and well understood by planners. Its high efficiency levels of up to 95% can have a major impact on total generation, which in turn impacts the financial performance of a hydropower station. There is, therefore, a significant market for refurbishing existing plants and powering of previously unpowered dams, particularly in more mature markets such as the United States and Western Europe, where greenfield development is uncommon.

Notwithstanding its maturity, hydropower technology continues to evolve to accommodate changing market conditions, as well as to mitigate environmental impacts of new and existing stations. Technological innovation over the past few years has focused on increasing the scale of turbines, improving their durability and flexibility, and reducing environmental impacts. Such advancements continue to increase generating capacity, and mitigate the impact of new and existing stations.

Key recent innovations in the hydropower industry have been:

- Flexible generation: The 20th century saw huge advances in water turbine technology, particularly the invention of adjustable rotor blades and inlet guide vanes, providing greater operating range and efficiency. Variable speed pumps are now in operation at new power stations, enabling flexible generation in both pumping and generating mode. Ongoing work in this field aims to enable retrofitting of existing stations and turbines with similar levels of pumping/generating flexibility, which allows hydropower to deliver more finely tuned ancillary services to the grid. Other advances have included new approaches to reduce friction and low-head turbine technologies, enabling hydropower to operate at less traditional sites.

- Materials: Turbines have benefitted from advances in materials science, which includes new alloys, such as tungsten carbide, which are more resistant to erosion and abrasion from sediments. The effect is that turbine parts can be subjected to higher pressure flows, thus generating more power. These materials also enable operation in harsher environments where sediments make up a greater percentage of the flowing water.

- Environmentally conscious designs: Although hydropower is a low-carbon renewable energy, the construction of a dam inevitably alters the river regime, possibly affecting fish passage, dissolved oxygen concentration, sediment transport and more. New measures are being implemented to counter these impacts, such as: fish-friendly turbines; fish lifts and more effective fish ladders specifically adapted to local species; the selection of turbines with limited impacts on dissolved oxygen; oil-free turbines and bio-degradable lubricants; and the addition of bottom outlet sluices and other sediment management techniques to flush sediment and more.

- Water management optimisation: From the generation perspective, stored water is a fuel to be utilised when its value is high and stored when it is low. Yet, unlike fossil fuels, its supply depends on climate conditions and storage is a function of a variety of constraints such as operating regimes, minimum and maximum water levels and required environmental flows. The optimisation of reservoir management is crucial to maximizing revenues for power producers. Advances in mathematical modelling have led to the development of highly sophisticated optimization software and decision-support tools which help inform operational decision making.

Ongoing work on faster reacting times, broader operating range, improved material resilience, and larger machines will continue to progress hydropower technology over the next several years.

Table 3 – Largest hydropower plants under construction, by capacity

Source: Power Technology, International Rivers

	Country	River	Expected Capacity (MW)	Year of Completion
Baihetan	China	Jinsha	13 050	2019
Belo Monte	Brazil	Xingu	11 230	2019
Wudongde	China	Jinsha	8 700	2020
TaSang	Myanmar	Salween	7 110	2022
Grand Renaissance	Ethiopia	Blue Nile	6 000	2017
Myitsone*	Myanmar	Irrawaddy	6 000	2019
Diamer-Bhasha	Pakistan	Indus	4 500	2020
Dasu	Pakistan	Indus	4 320	2019
Jirau	Brazil	Madeira	3 750	2015
Rogun	Tajikistan	Vakhsh	3 600	N/A

* Construction halted

3. Role of governments

Regulations and incentives

Water, energy and climate policies have the potential to influence decisions on hydropower developments strongly. This has led to various tariff structures, regulations and frameworks, which have incentivised some types of hydropower, while deterring the development of others.

For example, as a renewable energy, in some markets, hydropower is eligible for price premiums such as feed-in-tariffs and for quota systems such as renewables obligations. Such government-funded incentive programmes have been shown to be positive drivers of deployment, as well as indirectly inducing hydropower development to help manage the variable output of large quantities of wind and solar coming online as a result of the same programmes. This is the case in Spain and Portugal, where a feed-in-tariff has spurred significant investment in wind and solar technologies, which in turn have led to increased development of pumped-storage hydropower to help balance the system.

It is important to note that hydropower is highly subject to regulatory environments, related not just to energy, but also to water and environment. These policy spheres are often managed quite separately across various governments, leading to disjointed decision-making and conflicting signals. For example, in Europe, the EU's 20-20-20 legislation directs European countries to achieve a 20% share of renewables in the total final energy consumption by 2020. At the same time, the EU Water Framework Directive mandates actions that have in some cases been shown to deter consideration of hydropower. While targeted policies can be a factor in promoting hydropower, complementarity of policies across the suite of issues relevant to hydropower, will also influence how it can be developed.

In either case, policy certainty can be as crucial as the policy itself. As price premiums form an important component of the revenue stream for projects in some markets, lack of confidence in the certainty of receiving payment for the expected period can deter investment. Australia is a prime example of a jurisdiction where investor certainty in hydro and other renewable energy investment has been severely dented by recent policy changes. In this case, it is estimated that investment in renewable energy projects declined by about 70% in the last year, following the decision to repeal the 2011 Clean Energy Act, which established the carbon pricing mechanism[15].

While several factors are increasing the demand for hydropower, which include a push for low-carbon technologies to help mitigate climate change, a desire for independence from price fluctuations associated with imported fossil fuels, and a drive for economic development; market structure may indeed be hindering development.

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[15] "Lagging behind: Australia and the global response to climate change", Climate Council of Australia, 2014, http://www.climatecouncil.org.au/uploads/211ea746451b3038edfb70b49aee9b6f.pdf

This is illustrated by the fact that, despite the clear need for increased storage and other balancing services, most market systems do not appropriately reward these services. For example, in Germany, existing pumped-storage projects have to pay transmission fees as final consumers during pumping operations (but not for generation). Policymakers are partly addressing this for new pumped-storage projects, which are exempted for 20 years. Additionally, any pumped-storage project, which was or is extended after 4 August 2011, by at least 7.5% of installed capacity or 5% of generation, is exempt for 10 years[16].

National and regional issues

Hydropower projects, especially large-scale types, usually tend to be the focus of national policy and public debate. Reasons for this include the high capital investments required, the potential impacts such developments would have on the local environments, the possible displacement of communities from hydropower project sites, and the competing demands between energy, water and food. While governments generally view hydropower in a favourable light, as they are a means of reducing national emissions, boosting energy security and fostering economic development, hydropower projects can be met with popular resistance on both local and national levels.

An example of this can be seen in India, where there have been numerous instances of local conflict over hydropower development in the country in recent years. Plans to fully exploit the heavily drained north-east of the country press ahead – there are more than 150 planned hydro projects for the region, particularly in Arunachal Pradesh state[17], as illustrated by the map in Figure 6. However, there have been continuous protests of the perceived lack of consideration from government and involved private sector stakeholders on the changes to river regimes, and the ecosystems they support, that hydropower development would bring. The region is also the most seismically active in India, which is argued would make dam building challenging and dangerous. Local, tribal indigenes to the region who depend on the rivers and forests for their livelihoods are greatly opposed to hydropower development, and have continuously run demonstrations and hunger strikes. Also of concern is the view held by many in India on these hydropower projects – the projects are being undertaken simply to produce and export power for the sake of profit, and not to contribute to the development of the exploited region.

[16] Section 118 of German energy act (Energiewirtschaftgesetz), 2014
[17] International Rivers – North East India

Figure 6 – Hydropower projects in various stages in Arunachal Pradesh state, north-east India

Source: International Rivers

In some cases public pressure can have a profound effect on the outcome of not only planned projects, but the entire governing policy on hydropower. The following case study in Chile gives an illustration of this.

Chile's uncertain hydropower future

Though a major source of electricity for the country, Chile is rethinking hydropower as a future primary energy supply. The growing unpopularity of large-scale power projects in the country led the national government to halt development of the controversial 2,750MW HidroAysen hydropower project in the country's Patagonia region in 2014.

The cancellation of the $8 billion joint venture between Endesa Chile and Colbun S.A., is seen as a victory for environmentalists and the wider Chilean population. There were growing concerns that HidroAysen, which comprises of 5 separate hydroelectric dams on the Baker and Pascua rivers, would cause significant damage to the environment and wildlife of Chile's rural south. The project also made insufficient provisions for local communities who would be displaced by the project, according to the Ministry of Environment. In response, Endesa Chile admitted the project is no longer in its immediate portfolio, but defended the sustainability of the project, believing the region's water resources are important for Chile's energy development[18].

With its hydropower future uncertain, Chile may need to look to other sources such as LNG and renewables in meeting its growing energy demands.

[18] Endesa Chile, 2015

The role of governments on hydropower development is to ensure that projects meet acceptable sustainability requirements – economic, social and environmental – and that all negative impacts that may be incurred from the projects are mitigated to the bare minimum. This is of prime importance to developing and emerging economies considering hydropower development. This is to ensure that the benefits from hydro projects are enjoyed across the country, and especially in areas where the water resources are being exploited.

In some instances, issues with hydropower exist at a supra-national level. 260 of the world's rivers cross at least one national boundary[19]. Countries which share the same water resources may be forced to compete for resource capacity in order to meet its individual needs, typically the upstream parts of the river is exploited for hydropower and the downstream parts for irrigation. In addition, planned developments by one country to dam parts of a river may have negative implications for countries further downstream of the river, such as flooding and irregular water availability.

Such issues are complicated when individual nations take actions on the matters, without consulting other affected parties. In recent cases, regional powers have taken unilateral decisions to advance with (such as China on the Mekong River) or derail (like Egypt on Ethiopia's project on the Nile) hydropower projects solely to suit their national interests. This may lead to "water wars" between neighbouring countries, and can damage diplomatic relations between them. An example of cross-border issues which may arise is highlighted in the following case study.

Cross-border conflict and co-operation – Damming the Nile in Ethiopia

The under-construction $4.2 billion Grand Renaissance Dam (GERD) on the Nile River, close to Ethiopia's border with Sudan, has been a source of contention in North-East Africa since construction began in 2011. The 6,000MW hydroelectric project, hoped to bring energy self-sufficiency to Ethiopia and alleviate poverty in the country, is of grave concern to Egypt, the most downstream nation on the Nile, which depends greatly on the world's longest river for its agriculture and power. So much so, that Egypt has previously threatened military action on Ethiopia in order to halt construction.

The Nile has long been a focal point for tensions between the nations it flows through. A colonial-era agreement attributes use of most of the river's capacity to Egypt and Sudan, an agreement the ten upstream nations on the Nile do not recognise. In addition, Sudan, naturally Egypt's ally on these matters, appears to have switched allegiances and is now in favour of GERD, upon realising the potential benefits of its operation, including increased irrigation capacity and import of excess generated electricity from the dam.

There have been efforts to ease tensions over the issue recently, and in March 2015, leaders from Egypt, Ethiopia and Sudan signed a "declaration of principles" in the hope of fostering diplomatic co-operation on GERD. The

[19] IHA – Cross-border projects

agreed principles include giving priority to downstream countries for electricity generated by the dam, a mechanism for resolving conflicts, and the provision of compensation for any damages incurred[20].

The dam is expected to be in operation by 2017.

Regional co-operation between the involved parties is crucial to ensure that the available water resource is utilised equitably and its potential maximised. Thorough assessments must be undertaken during the pre-project phase of the development, and revisited throughout the lifecycle of the project. This is to analyse the benefits and costs, financial, social and otherwise, of the hydropower project to each of the involved countries. Compensation and other concessions may have to be made to countries that bear sizable costs compared to any perceived benefits.

Multilateral development banks (MDBs), such as the World Bank, have been identified as key players in the reduction of conflict between parties, in terms of project initiation and financing. The 80MW Rusumo Falls hydropower project in the Nile Basin region (Rwanda, Burundi and Tanzania) is proof of how multilateral interactions between nations in the region facilitate the relatively smooth progress of a large-scale hydropower project. In this case, the entirety of the project is being developed under the aegis of the African Development Bank (AfDB).The region has a history of conflict in addition to low electrification rates and high levels of poverty. The successful implementation of the Rusumo Falls project is expected to contribute greatly towards economic development and political stability[21].

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[20] Al-Jazeera - Egypt, Ethiopia and Sudan Sign Nile Dam Accord, http://america.aljazeera.com/articles/2015/3/23/Egypt-Ethiopia-Sudan-sign-Nile-dam-accord.html
[21] AfDB – Rusumo Hydro Power Plant

4. Sustainability

The subject of sustainability of development has been debated extensively over the last few decades. Hydropower projects can make a significant contribution to sustainable development when they are developed and operated in an economically viable, environmentally sound and socially responsible manner. Hydropower has a special role to play in economic development, social justice and environment caution which represent the basic pillars of sustainable development. It is at the crossroads of two basic human needs, energy and water supply. However, the history of hydropower includes periods of intense controversy over the need for large dams, the practices involved in developing hydropower and the impact of development on local communities and the environment.

Hydropower development, as with any large infrastructure project, requires a change to the existing environment. This has consequences that impact the local environment, as well as the people living in communities near to the development site. These impacts are well identified, and although not all negative impacts can be eliminated, much can be done to mitigate them.

Hydropower projects are strongly site specific and as such each project will differ in its impacts, positive and negative, depending on issues such as size, geography, surrounding land use and environment. While size is not a direct determinant on impact, a number of the impacts that arise from the development of hydropower projects are related to the impoundment of a reservoir in storage projects; although in these cases the positive impacts tend to also be greater due to the multiple purposes for which a storage reservoir can be used, and the greater operating flexibility offered by such projects.

Some of the possible key issues that can arise from the development of hydropower projects include environmental impacts, largely resulting from changes to its hydrologic characteristics brought about through the introduction of structures, and social impacts effecting local and regional communities.

Environmental impacts can include interruptions to movement of aquatic species and changes to flow regimes, with impacts on sediment transport in some regions. Further issues might include impacts on water quality and biodiversity in the reservoir area.

Social issues generally revolve around project affected communities, which might include people resettled to accommodate the impoundment of project, and host communities who will be required to take in the resettlees; in some instances indigenous peoples impacted by the project, or communities downstream of the project. Other social impacts might include issues around public health, access to resources and livelihoods and cultural heritage.

At the same time, project impacts can be positive: road works and infrastructure associated with the project for example often enable or improve access for local communities, with positive implications for issues such as public health and education, amongst others. As with many large infrastructure projects, costs are generally local while many of the benefits are experienced at regional or national levels.

While some impacts are unavoidable, most can be minimised or mitigated and compensated for. Generally, experience has shown that most negative impacts can be substantively addressed, although it is also true that challenges still remain around implementing these solutions. Tools such as the Hydropower Sustainability Assessment Protocol[22] are working to address this implementation challenge at the project level.

The establishment in 1998 of the World Commission on Dams commenced a detailed review of sustainability and dams, and while its values and strategic priorities were accepted by most, there was considerable concern with the applicability of the recommended guidelines. This concern notwithstanding, international financing for the development of hydropower stalled through the late 1990's and early 2000's. Responding to this, the sector developed various initiatives to address the social and environmental project impacts, provide guidance on project development and develop frameworks to assess performance.

These tools range from guidelines and criteria developed by international financial institutions and expert credit agencies (for example, the World Bank Safeguards and the Equator Principles) which while applicable to dams and hydropower reference all infrastructure projects, to sector-specific initiatives such as the UNEP Dams and Development Project and IEA's Hydropower Good Practice.

This work in turn laid the foundation for further methodologies that focus specifically on assessing sustainability in hydropower. One such initiative, the Hydropower Sustainability Assessment Protocol was developed by a multi-stakeholder forum made up of representatives from governments of developing and developed nations, international financial institutions, and social and environmental civil society. The Protocol and a further tool coordinated by IEA, the Sustainable Development of Hydropower Initiative are considered in more detail below.

Hydropower Sustainability Assessment Protocol[23]

A major initiative related to defining and assessing the sustainability of hydropower is the Hydropower Sustainability Assessment Protocol (the Protocol), which is a sustainability assessment framework for hydropower development and operation, coordinated by International Hydropower Association. The Protocol addresses an integrated set of considerations including environmental, social, technical and economic/financial perspectives along the project development lifecycle. As a tool, its aim is to measure and guide improved performance in the hydropower sector. It enables the production of a sustainability profile for a project through the assessment of performance on important topics before, during and after construction of a hydropower project. This profile, as illustrated below, can then form the basis for dialogue among project stakeholders, and for continued improvement in project design and implementation, as well as for decision-making.

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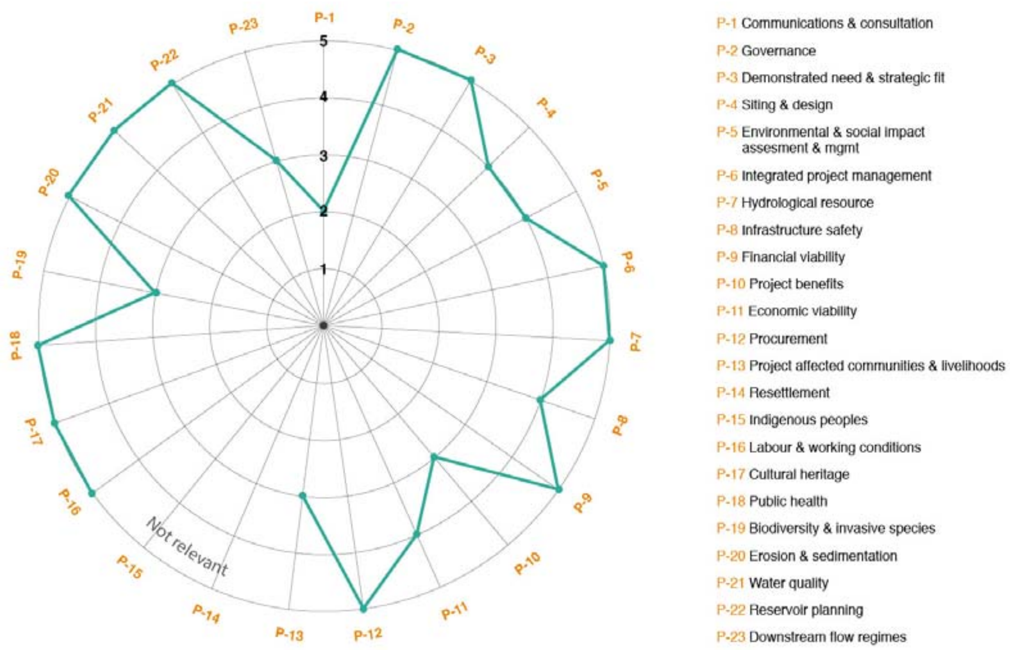
[22] www.hydrosustainability.org
[23] Ibid, where assessment results, supporting information, governance details and the tool itself can be accessed.

Figure 7 – Range of sustainability topics reviewed during an assessment using the Hydropower Sustainability Assessment Protocol

TECHNICAL	ENVIRON-MENTAL	SOCIAL	ECONOMIC AND FINANCIAL	INTEGRATED
Siting and design	Downstream flows	Project affected communities and livelihoods	Economic viability	Demonstrated need and strategic fit
Hydrological resource	Erosion and sedimentation	Resettlement	Financial viability	Communications and consultation
Reservoir planning, filling and management	Water quality	Indigenous peoples	Project benefits	Governance
Infrastructure safety	Biodiversity and invasive species	Cultural heritage	Procurement	Integrated project management
Asset reliability and efficiency	Waste, noise and air quality	Public health		Environmental and social issues management

Use of the Protocol has created the possibility for more informed and efficient decision-making on hydropower. The results, captured in a 'spider diagram', provide a synthesis of issues in any project allowing for directed improvements of identified weaknesses. As can be seen from the example below, it provides a good holistic overview of the project performance on the various topics. Feedback from the more than twenty projects assessed to date has shown benefits including better management of sustainability issues, the value of independent review of sustainability issues, the ability to compare with international best practice, increased communication with stakeholders and facilitation of access to finance.

Figure 8 – Protocol results 'spider diagram'



The following is a case study of where the Protocol was used.

Sustainability Assessment of Kabeli-A, Nepal

In September 2014, a team of assessors visited the 37.6 MW Kabeli-A hydropower project in Nepal, to apply the Hydropower Sustainability Assessment Protocol (Protocol) as part of an International Hydropower Association project in partnership with the Norwegian Agency for Development (NORAD), to support sustainable hydropower in developing countries. The project, developed by Kabeli Energy Ltd. (KEL), was in the preparation stage when the Protocol assessment took place, and construction is set to begin in the spring of 2015.

Prior to the assessment, the assessors supported KEL through a two-month planning period, which included a training course on the Protocol and a preparation visit.

Accredited assessors carried out the sustainability assessment over a one-week period, during which time they visited the project site, conducted 54 interviews with project stakeholders and reviewed project documentation. The project scored basic good practice or better on all 22 topics assessed. Emphasis was placed on ensuring good stakeholder relationships, transparent communication and areas for improvement. Further management plans are under development and if these are completed in time for construction; and their conformance, monitoring and follow-up is implemented in a satisfactory manner, the project will likely meet basic good practice in future assessments through the construction and operation phases.

The use of the Protocol as an assessment and training tool demonstrates its value from developing to developed countries. Pratik Man Singh Pradhan, Vice President Business Development of Butwal Power Company, KEL's parent company reflected on the assessment, saying:

'It was very good that we could assess this project and make sure we are accommodating international standards. Having gone through this process, this project is now a reference for us and means we are well prepared to deliver future projects sustainably from an environmental and social perspective.'

A growing body of support for the Protocol

As the Hydropower Sustainability Assessment Protocol is used around the world and results are made available, a growing body of support is recognising the value of its objective, quality driven approach to improving project sustainability

Referencing the Protocol World Bank: The Protocol for use by World Bank clients: lessons learned and recommendations. OECD: Common Approaches IIED: A review of social and environmental safeguards for large dam projects WWF: Everything you need to know about the UN Watercourses Convention Citi: Hydropower sector brief ICPDR: Sustainable Hydropower Development in the Danube Basin: Guiding Principles. EON: The Hydropower Sustainability Assessment Protocol in practice – a utility's perspective	*"This review concludes that the most practical and effective tool currently available for measuring and communicating good practice, and the degree of respect for WCD guidelines and general good practice of individual projects, is the Hydropower Sustainability Assessment Protocol."* -IIED *"The application of the Protocol followed by a management plan to address identified gaps is likely the most powerful existing tools to improve the sustainability performance of hydropower schemes."* -World Bank

The Sustainable Development of Hydropower Initiative

This initiative, proposed by Brazil during the Major Economies Forum (MEF) Clean Energy Ministerial in 2010 and coordinated by IEA, seeks to share expertise, best practice, and methodologies related to the sustainability and financing of hydropower, as well as motivate multilateral developing and financing agencies to consider sustainable hydropower in their portfolios of possible energy solutions for developing countries. Focus areas include resettlement, dam safety, navigation and irrigation and fresh water. Examples of best practices in assisting people affected by resettlements include financial compensation, free education and job training, free electricity and provision of goods such as food parcels, fertiliser and livestock. In addition, infrastructure such as roads, schools, clinics, community housing and recreational facilities further assist communities to adapt, derive economic benefit and put them on a sustainable development path.

Dam safety practices have evolved to pay particular attention to the management of underground water levels in order to get as close as possible to the original and natural state of the river. Practices include maintaining fish stock levels and migration patterns. The Initiative identified that small hydro projects could contribute to sustainability in some African countries. Such schemes would provide new and more manageable transport routes within the waterways thus enhancing economic opportunities for the aquaculture sector of the area.

With the development of tools and initiatives to improve and assess hydropower's sustainability performance, there has been a sea change in the well-being of the hydropower sector and the rate of deployment. There is now continuous improvement in sustainability practices and work is ongoing to build consensus around good practices on remaining issues to move the sector towards continued improved performance. These include connectivity for aquatic species, reconciling urgent development needs with a need for sustainability, boundaries related to resettlement of local and indigenous communities, and conservation of sensitive areas.

Both initiatives emphasise sustainability practices that are possible and benefits that stand to be gained by following a holistic and inclusive process in all stages of project development. The following case study and its success, are testament to adopting this thorough approach.

The Kokish River Hydroelectric Project, Vancouver Island, Canada

As social and environmental acceptability becomes increasingly important for the development of greenfield hydropower projects, the partnership between a private energy producer and a Canadian First Nation is a prime example of sustainable development. The Kokish River Hydroelectric Project[24], located

[24] Namgis First Nation, Kokish Run of River Power Project, 201124, retrieved December 2014, http://www.namgis.bc.ca/Kokish/Pages/default.aspx, Brookfield Renewable Energy Partners, Kokish Hydro Facility, 2014

on north-eastern Vancouver Island, Canada, is a 45 MW run-of-river power plant owned and operated by Brookfield Renewable in partnership with the ‘Namgis First Nation (‘Namgis).

The Kokish River contains valuable fish resources which are afforded a high level of protection, particularly as healthy fisheries are crucial to the ‘Namgis traditional way of life. Fish and fish habitat protection measures extended into every facet of the project, from design and construction, to operations and long term monitoring. The partners developed fish passage systems (instream flow releases, fish ladder, coanda screen) for the Kokish facility, which greatly contributed to the success of this project.

Throughout the project, great emphasis was placed on respecting the riverine environment and providing economic diversification through job creation and signing of a power purchase agreement with the provincial utility, which in return led to providing economic strengthening to the ‘Namgis. The ‘Namgis participated in project environmental assessment work, including setting the terms of reference for studies, sitting in technical meetings and fields studies, organization of public meetings, and review of all environmental impact assessment reports. An independent technical advisor was hired by the ‘Namgis to assist with the environmental work.

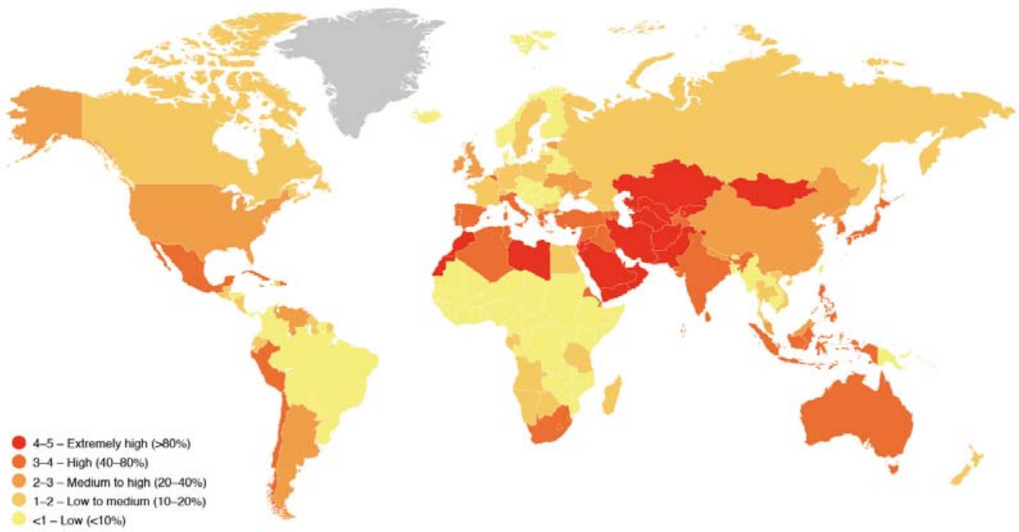
Brookfield Renewable and the ‘Namgis are proud of their partnership in completing a project that provides financial benefits for the community while respecting the environment and protecting fish habitat.

Energy-water nexus

Water and energy are closely tied together. An increase in energy demand will lead to an increase in water demand, and vice-versa. Water is required for energy in power generation, heating/cooling, extraction and refining of natural resources and fuel production. On the other hand, water requires energy for its extraction, treatment and transmission for supply. While demand for fresh, potable water is rising, it is important to note that water is a renewable, but fixed, resource to be shared. As such, access to potable water worldwide is becoming increasingly strained, with regions such as the Middle East and North Africa already suffering from high water stress (the ratio of total annual water withdrawals to total available annual renewable supply). A global shortage in freshwater supply, equal to 40% of global demand, is predicted by 2030[25] and the following map indicates the level of water stress experienced by the various regions in the world.

[25] Water Resources Group - Background, Impact and the Way Forward

Figure 7 – World baseline water stress by country
Source: WRI Aqueduct



There however remains a lack of a clear and universally accepted methodology in quantifying water usage for different purposes, including energy. The IEA measured global withdrawal of water for energy production in 2010 was 583 billion cubic metres, about 15% of total global water withdrawal. Of which, only 66 billion cubic metres (12%) of withdrawn water was consumed (i.e. not returned to the point of withdrawal)[26] On the other hand, some studies claim that the global consumptive water footprint (amount of water used and polluted in the entire production chain of a product) or energy is estimated at 378 billion cubic metres per year[27]. In addition, almost 90% of freshwater used to produce primary energy is for the production of biomass, even though less than 10% of primary energy comes from biomass[28]

Power plants powered by fossil fuels and nuclear energy are the largest users of water for electricity generation, as they require water for cooling purposes. The vast majority of the water withdrawn by thermal power plants is returned to reservoirs from which it was taken. However, the quality of water discharged from these plants can be a concern. Water from “once-through” cooled power plants is of a higher temperature than the reservoir water, and may contain pollutants which are harmful to fish and plants. The dynamic between growing thermal power generation and dwindling water availability is illustrated in China, where as of 2012 over 50% of total proposed power generation capacity was located in areas with high or extremely high baseline water stress[29]. It is also worthy of note that some emerging, clean energy technologies such as carbon capture, utilisation and storage (CCUS) and concentrated solar power (with wet cooling) may exacerbate the energy-water nexus problem further, due to their high water demands.

Hydropower also plays a crucial role in the energy-water nexus. While hydropower plants produce electricity by diverting water flowing through them (hence no water withdrawal), water can be lost through its evaporation from the plants’ reservoirs. As a

[26] IEA – Water for Energy
[27] Mekonnen, M.; *The consumptive water footprint of electricity and heat: a global assessment*; Environmental Science: Water Research and Technology
[28] World Energy Council, Water for Energy
[29] WRI Aqueduct

result, there is much debate over how large a water footprint should be attributed to hydropower. Competing demands for water and energy (and food) in some areas can be a source of risk to the development of hydropower projects. On the other hand, the versatility of hydropower plants can be exploited to alleviate local water stresses – diverted water can be made available for other purposes such as irrigation and drinking water supply. Climate change is bound to affect water and energy availability and demand in the future, which would place a higher premium on water storage.

Water availability is a local issue; therefore governments must take a leading role in addressing the vicious cycle of increasing water and energy demand. Co-operation between the energy and water sectors is important, as is driving the operational efficiencies of the major energy and water consumers, particularly electricity generators. Arab nations are investing heavily in the development of Independent Water and Power Plants (IWPPs). These plants use leading technology to generate electricity at high efficiencies, and utilise some of the electricity to desalinate seawater to make it suitable for consumption. The planned Al Khafji IWPP in Saudi Arabia will supply electricity and clean water while running on solar energy, which will almost eliminate the plant's entire water requirements. South African energy giant Eskom runs a fleet of dry-cooled thermal power plants, which consume up to 95% less water as wet-cooled plants.

Moving forward, there is a need to fully understand the linkages between climate change and water availability, through the development of accurate models mapping climate-water interactions. The development of reliable frameworks on the risks of local water availability and quality would better advise governments and the private sector on the undertaking of new developments, as well as foster stakeholder collaboration on such matters. The Water for Energy Framework (W4EF) is a prime example of the tools needed to support addressing the energy-water nexus.

Water for Energy Framework (W4EF)

The Water for Energy Framework (W4EF) is a tool created with the objective to help key stakeholders understand the relationship between energy activities and water. The framework is designed to accurately assess and quantify the water risks faced by a planned or existing energy production site. The initiative for the framework was launched in 2012 at the 6th World Water Forum (WWF6) in Marseille, France. The results from the project research were first presented at the 7th World Water Forum (WWF7) in Daegu, Korea Republic in April 2015. French energy supplier EDF led the three-year project on behalf of the World Water Council (WWC), with the World Energy Council (WEC) involved as an advisor.

The framework uses a range of time-stepped inputs reflecting the conditions and requirements, for energy and otherwise, of the local water site (site water use, local hydrology, local limiting factors) to generate a set of three indicators – Water Use, Water Interaction and Water Situation, which map the risk factors associated with energy activity at the site. Water Use indicators, consider the associated activity's water use, evaluate its efficiency in energy production and provide direct comparison s with other processes. Water Interaction indicators provide an estimate of the margin the activity had before it exhausts local water capacity. Water Situation indicators provide values of the local stress affecting water bodies in the locale, with and without the associated energy activity. The W4EF produces these indicators using an iterative and step-by-step implementation process.

The framework is comprehensive, coherent, consistent and applicable across all energy technologies and can be used anywhere in the world. The aim for the Water for Energy Framework is for its indicators to be used by policymakers, investors, and technical developers for corporate risk water management, corporate reporting, local communication and feasibility studies; and to be endorsed as the energy sector's principal tool for water-energy assessment.

5. Hydropower outlook

Challenges

Looking forward, there are several challenges that the hydropower sector will need to address as it continues the upward trend in development.

Sector knowledge and human resources

With a fresh influx of investors and developers, there are a number of examples of lessons to be re-learned by new players. Capacity building, networking and knowledge transfer among sector actors, are essential for keeping momentum, as well as building and sharing of robust data on good practices in the development and management of hydropower.

As the pace of new development grows and experienced personnel retire, a shortage of technical specialists is expected across a variety of needed skillsets, leaving a high demand for experienced engineers, sustainability specialists, and finance and policy specialists. Opportunities for skills development and training will be needed to manage risks and ensure safe development and operation of hydropower facilities.

The expected rapid pace of hydropower development over the coming decades will only magnify these needs.

Project delays

Hydropower projects are major infrastructure investments that require not only significant public and private sector funding, but also political will, popular support and a social license to operate. Taking a hydropower project from its early feasibility stages through to bankability and construction, requires a significant investment of time and resources from all involved.

However, political timeframes tend to be much shorter than the gestation period of well-planned, strategic development of hydropower resources. This mismatch can lead to stalled projects, impacting both the overall cost and public perceptions of specific developments. An example is the Grand Inga project in the Democratic Republic of Congo, which has been in various stages of planning since 1972. Successive governments have indicated support, although to-date the project has been unable to advance. More recently, in 2014, South Africa has indicated a renewed interest in this project as the major buyer of the electricity that would be generated, potentially providing the revenue certainty needed to move the project forward[30].

Other project delays relate to the complex and multi-sector nature of hydropower. Environmental and social assessments, along with developing associated mitigation

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[30] South African Government – Energy briefs Parliament on treaty of Grand Inga Hydropower Project, http://www.gov.za/energy-briefs-parliament-treaty-grand-inga-hydropower-project

plans and implementing appropriate local population compensation schemes, can also impact the timeframes of a project.

Water consumption

How hydropower uses water is another area for continued research. Water that runs through a turbine as the ‘fuel’ for hydropower is returned to the river basin downstream, thus having negligible impact on water consumption and water quality. However, in some locations, water evaporation from the surface of the reservoir can be high.

In the few studies carried out on this topic, the evaporation rates appear inconsistent, likely due to the variations in site specific conditions for hydropower and an immature methodology for calculating evaporation rates. Identified short-comings in much of the published literature to-date include use of gross evaporation rather than net evaporation rates from reservoirs, where the pre-existing evaporation and evapotranspiration rates are not properly accounted for. A recent study conducted between Hydro-Quebec, in conjunction with McGill University and Environment Canada, on one of its hydropower reservoirs discovered that net evaporation from the reservoir is potentially zero (i.e. evaporation from the host environment before and after creation of the hydropower plant are the same), and in some cases was even negative (less evaporation from the environment after the plant was created). The study boosts hydropower’s credentials as an energy source with a minimal water footprint. It must be noted, however, that hydropower plants’ net evaporation values are expected to vary based on the conditions of the host environment – values are lowest for plants in boreal and temperate regions, and highest for plants in hot and arid regions. More studies need to be conducted around the world in order to confirm this. In addition, there appears to be a lack of clear guidelines on the allocation of water consumption in the case of multi-purpose reservoirs, which may negatively skew water consumption for power generation.

Numerous initiatives have recently been launched in order to develop a more solid, scientific basis for the calculation of water footprint of a wide range of services and products including hydropower production, where the initiatives by World Water Council and the development of an ISO Water Footprint Standard are among the most prominent.

Water storage capacity

While hydropower is recognised for its contribution to energy and water services, global water storage capacity is diminishing. This is due in large part to the more challenging conditions for developing projects with large storage reservoirs. Opposition to large reservoirs can come in the form of both environmental and social concerns.

On the one hand, these concerns must be appropriately addressed in consultation with all stakeholders, especially those most impacted by the development. On the other hand, planners must also consider the broader strategic needs for water storage along with electricity. This is especially true in the context of climate change where water storage infrastructure will be increasingly called upon to help manage the effects of floods and droughts related to extreme weather events.

Strategic planning of hydropower at a national and river basin level can help to address this issue, by ensuring sufficient storage is integrated at the system level, rather than on a project-by-project basis. In markets relying on private sector development, additional services (water management, flood control, tourism etc.) are often considered unfunded obligations placed on the developer, with no recognition of the value they contribute.

Sedimentation

The installation of a dam will impact the rate of sediment transport in a river, in many cases leading to sediments becoming trapped behind the dam rather than flowing downstream. This can have a direct effect on the operating life and the electricity output of hydropower plants, and the distribution of sediments and nutrients downstream. Effects of sedimentation include reduced reservoir and flood management capacity due to the loss of storage, a shortened power generation cycle, and higher maintenance costs. Research undertaken for the World Commission on Dams in 2000 estimated that between 0.5 and 1 per cent of global water storage was lost every year as a result of sedimentation. These challenges become increasingly difficult, the more sediment accumulates over the lifecycle of a reservoir.

While a variety of sediment management techniques are available, work continues on building knowledge in this area and encouraging further action to plan for and mitigate against sedimentation from the early stages of project planning through to operation.

Greenhouse gas (GHG) footprint

The introduction of a reservoir (for hydropower or other purposes), may have the potential to change the greenhouse gas emissions in a river basin. The GHG status of freshwater reservoirs is an area of ongoing scientific research, and policy responses are still evolving as the state of knowledge progresses. There are concerns around the uncertainty in estimates of GHG emissions from reservoir systems, and that these impacts are often attributed to hydropower projects.

The GHG footprint of a reservoir is highly dependent on the local climate conditions, as well as the specific human activity in the catchment area. Assessment of the effect of the creation of the reservoir on the carbon cycle and related emissions should take into account the emissions from the whole catchment area, before the creation of the reservoir; and compare this to the situation after the reservoir has been built. The result would be the net GHG emissions. Emissions due to unrelated anthropogenic sources (e.g. sewage, agricultural run-off, industry, etc.) should be subtracted to allow an accurate estimate of net emissions[31].

Through the UNESCO/IHA GHG Status of Freshwater Reservoirs project[32], research is underway to build a better understanding of the potential GHG footprint of freshwater reservoirs based on local conditions, including preparation of a screening tool to assess potential emissions, as well as building knowledge on how best to mitigate this impact at specific sites when needed.

The research will also develop a methodology to allocate the GHG footprint of the reservoir to the various services provided by the reservoir. Further work by the IEA will provide detailed modelling guidelines for those sites where potential emissions are deemed to be high, following an initial risk assessment.

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[31] IPCC, 2012; IEA 2014; IEA, 2011; Harby et al., 2012
[32] UNESCO/IHA GHG Status of Freshwater Reservoirs project , http://www.hydropower.org/greenhouse-gas-emissions

Climate change and resilience

Climate change is expected to have wide-ranging impacts on precipitation levels and local hydrology in the future. While these impacts will vary by location, generally speaking there is an expectation of increased precipitation and extreme events, including both flood and drought periods. As water is the fuel for hydropower, this could have profound effects for hydropower projects, both positive and negative. Periods of drought are already impacting hydropower in select locations around the world; for instance in Brazil, as seen in the case study below.

The effect of drought on Brazil's hydropower

Brazil, the world's second largest producer of hydroelectricity, is currently facing its worst drought in 40 years. The lack of rainfall caused hydropower output to fall by 7% in 2013[33]. As 2014 was another dry year for the country, with its largest reservoirs only at 16.1% of capacity on average at the year's end[34]. Brazil's government has been forced to turn to more costly thermoelectric plants in order to avoid blackouts. Industrial customers signing for energy contracts now are facing prices that are more than double the amount customers paid as of January 2014. Though El Nino was expected to increase the amount of rainfall over the winter, changes in weather patterns in Brazil resulted in El Nino not travelling far enough to fill key reservoirs in the north of the country.

Due to uncertainty presented by the changing hydrology, Brazil's hydropower sector may encounter further problems in 2015.

Alternatively, hydropower projects may be called on to provide societies with climate adaptation services, where they could offer flood management and drought protection through the use of the storage component of a reservoir. The case study below illustrates the benefits accrued from "multi-purpose reservoirs". However, plant operators are typically not compensated for these services, and may impact the generation and revenue profile of a particular station. Furthermore, some incentive programs, including climate change offset programmes such as the UNFCCC Clean Development Mechanism, in some cases effectively discourage development of reservoir storage projects, which will limit the sector's ability to provide climate services, despite increased recognition of such needs.

[33] BP
[34] Bloomberg New Energy Finance

Multi-purpose reservoirs –Three Gorges Dam, China

The world's largest hydropower station is, in fact, not simply a hydropower station. China's Three Gorges Dam, well known for its sheer size at 22.5 GW, generates an average 88.2 TWh of electricity per year. In 2014 the station set a new world record of 98.8 TWh of electricity generated in a year[35] , which is roughly equivalent to the energy from 49 Mt of coal.

However, the primary purpose of the dam is to control massive seasonal flooding on the Yangtze River. Each year the river is subject to extreme floods, with major events occurring up to four and five times per year. Before the project's completion in 2007, a single disastrous flood event in 1999 passed through the site, causing economic losses to the region of $26 billion, equivalent to the total investment cost of the entire Three Gorges Dam project. When a similar flooding event took place in 2010, the dam was able to attenuate the peak flood flows, avoiding billions of dollars of economic damage, not to mention protecting the local communities living in the basin.

In addition to flood control services, the navigation lock built around the dam allows the Three Gorges reservoir to be utilized as a shipping lane, bringing valuable goods upstream to the previously inaccessible municipality of Chongqing and others to the south-west. Navigation has increased by more than four times and the overall cost of transportation has decreased by a third.

Project developers and owners will increasingly be expected to demonstrate climate resilience at the financial and regulatory approval stages. This may include provision of improved data analysis on climate change impacts, increased flexibility in project design to accommodate uncertainty, increased storage volumes, and revised operational regimes.

The sector is increasingly aware of the potential impacts climate change may have on its operations, as well as the potential change in services it may provide in a climate-changed world. Current initiatives across the sector include work on decision-making in the face of uncertainty, analysis of multi-purpose benefits of hydropower, and a "no-regrets" design approach that allows for flexibility of projects.

Opportunities

Demand for both water and energy is ever increasing, with estimated 1.2 billion people without access to electricity services globally[36], and 748 million people lacking access to clean water[37].

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[35] **The Yearly Electricity Production of the Three Gorges Hydropower Station Was Over 98.8 TWh Which Hit a World Record, retrieved January 2015,** http://www.ctgpc.com/news/news1.php?NewsId=89748**,** China Three Gorges Corporation, 2015

[36] Global Tracking Framework 2013, UNSE4All

[37] Progress on Drinking Water and Sanitation 2014 Update, World Health Organisation and UNICEF, 2014

On top of this, increasing demands for improved energy quality in service of industrial growth, agricultural production and other economic development purposes serve as conditions for growth in electricity services.

There are many opportunities for hydropower development throughout the world and although there is no clear consensus, estimates indicate approximately 10,000 TWh/year of remaining hydropower potential worldwide. Table 2 gives an overview of the major unutilised remaining potential globally. How much of that will be developed, is a matter of market conditions and government policy. Power pools, increased bilateral trade in electricity, and new customers demanding green energy can enable further growth in hydropower.

Table 4 – Top 20 countries by remaining unutilised hydropower potential*
Source: International Hydropower Association

	Total Potential (GWh/year)	Current Utilisation (%)	Undeveloped (GWh/year)
Russian Federation	1 670 000	10%	1 502 300
China	2 140 000	41%	1 259 325
Canada	1 180 737	32%	798 630
India	660 000	21%	523 245
Brazil	817 600	48%	424 600
Indonesia	401 646	3%	388 809
Peru	395 118	6%	373 339
DR Congo	314 381	2%	306 610
Tajikistan	317 000	5%	301 197
USA	528 923	52%	256 303
Nepal	209 338	2%	206 014
Venezuela	260 720	31%	180 121
Pakistan	204 000	14%	174 658
Norway	300 000	45%	165 296
Turkey	216 000	27%	157 757
Colombia	200 000	22%	155 518
Angola	150 000	3%	146 184
Chile	162 000	12%	142 784
Myanmar	140 000	4%	134 924
Bolivia	126 000	2%	123 704

**Undeveloped hydropower potential is a technical figure based on country reporting and analysis, and does not reflect whether or not development of this potential is economically or sustainably feasible*

Regional hydropower development

In some cases further development relies upon exporting electricity cross-border to other countries, thus making the financial case for developing the hydropower resource. For mountainous countries such as Bhutan, Nepal and Tajikistan, the export of clean electricity to power-hungry neighbours offers a rare opportunity of substantial investment and revenues. Similar opportunities exist across Africa as well as the nations of the Caucasus, with Georgia keen to develop its estimated 80 TWh hydropower resource. Georgia is already exporting electricity to Turkey, where average wholesale tariffs in each country are US$0.043/kWh and US$0.085/kWh[38], respectively. In 2014, 200 GWh was tendered from 1.3 GW Enguri and 200 MW Vardinili hydropower plants[39].

Bilateral trade

In more developed markets, bilateral interconnectors may also be the key to growth. Some Canadian provinces, for example, have abundant hydropower potential, but little room for increased domestic consumption and access to the US market, which shows a growing appetite for green energy. With interconnectors, the challenges are likely to be political and environmental, rather than technical, as extremely long high-voltage DC lines such as the 2071 km, ±800 kV, 6400 MW link connecting the Xiangjiaba Dam to Shanghai have been in operation for some years.

With high-voltage transmission lines, countries with abundant hydropower resources use their reservoirs as 'batteries' to balance the variable generation in neighbouring countries. In the Canadian province of Manitoba, hydropower reservoirs are connected to the grids of the US mid-west, to balance the output of major windfarm developments. Similarly, the Norwegian grid is connected by underwater cables to Denmark, enabling Denmark to use Norwegian hydropower to back up its wind and thermal grid.

Attracting domestic markets

Alternate scenarios for hydropower growth in a particular country may follow the Icelandic model, where attracting energy intensive industries to catalyse domestic demand for hydropower serves as a basis for investing in development. In the case of Iceland, hydropower was developed to attract and build a domestic aluminium industry. Furthermore, hydropower has long been used to support remote mining operations and associated local grids, for example in Katanga, Democratic Republic of Congo. The Malaysian state of Sarawak is pursuing a similar model of domestic economic and industrial growth, underpinned by the development of local hydropower resources to feed power-intensive industries.

Clean energy demand

Demand for clean energy, whether through voluntary and strategic decisions by consumers and business, or whether required by regulation, will also open new markets. For businesses looking to promote their green credentials, hydropower presents an attractive option, not only because it is a renewable energy, but also for its reliability and low operating costs. In 2013, Facebook opened a data centre in Lulea, Sweden, powered by hydro (100MW installed capacity), in part to service its commitment to using clean energy for its operations. Similarly, in 2011, BMW opened a manufacturing facility for its carbon fibre materials for electric vehicles in the US state of Washington, primarily due to the location's abundance of cheap hydroelectricity. Alternatively, regulation encouraging clean energy investment or requiring quotas of clean energy production, will also drive demand.

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[38] http://www.hydroworld.com/articles/print/volume-21/issue-01/articles/russia---central-asia/georgian-hydropower-turns-river.html
[39] http://www.icis.com/resources/news/2014/07/21/9803129/georgian-electricity-exports-to-turkey-to-fall-in-august-teias/

New demand for electricity

In addition to an overall increase in demand for electricity in emerging and developing countries as they grow economically, electricity is increasingly central to power, heat and transport, which will in turn drive further demand for hydropower as a clean, reliable, and flexible power source. This is illustrated by the expectation that electric vehicles will significantly increase their market share of the road transport sector, as it has done for railways. Globally, the total number of cars, including plug-in hybrids and battery electric vehicles, is expected to increase by 2.2 times to 2.6 times by 2050. The total market share of internal combustion engines is expected to shrink by between 22% and 76% in 2050[40]. Electricity is also increasingly used to manage the temperature in homes and workplaces. These new demands for electricity may drive further adjustments to hydropower's role in the energy mix in all markets.

Evolving energy mix and market dynamics

As the energy mix continues to evolve, the system will continue to need more energy storage and dynamic capacity to balance grids. As hydropower has good synergies with all generation technologies, its role is expected to increase in importance in the electricity systems of the future. However, markets and policy will need to evolve to appropriately incentivise investors, particularly where the private sector is expected to engage.

[40] Global Transport Scenarios 2050, World Energy Council, 2011

6. Global tables

Table 5 – Hydropower installed capacity and production in 2013, by country

Source: REN21, World Energy Council, EIA, Enerdata, Global Transmission Report, EUROSTAT, NREL, Russian System Operator, Bhutan Department of Hydropower & Power Systems, Afghan Central Statistics Organisation, Statistics Estonia, Askja Energy, SEAI, Jamaica Public Service Co., Jordan Electric Power Company, Kenya National Bureau of Statistics, Kazakhstan Statistics Agency, Luxembourg Statistics, Moldova Bureau of Statistics, Mongolia National Statistics Office, Mauritania National Statistics Office, Slovenia Statistical Office, Nepal Electricity Authority, Swaziland Electricity Company, Sri Lanka Public Utilities Commission, PEEGT, Taiwan Power Company, Tajikistan Ministry of Foreign Affairs, Tanzania National Bureau of Statistics, Uruguay Secretary of Energy, Zimbabwe National Statistics Agency

	Installed capacity (MW)	Actual generation in 2013[a] (GWh)	Share of total electricity generation in 2013[b] (%)
Afghanistan	374	883	84%
Albania	1 446	5 175	89%
Algeria	269	310	1%
Angola	994	3 817	68%
Argentina	9 100	29 633	21%
Australia	6 400	13 547	6%
Austria	9 500	41 000	61%
Azerbaijan	995	2 621	11%
Bangladesh	230	1 300	3%
Belarus	13	44	0%
Belgium	120	300	0%
Bhutan	1 510	7 550	100%
Bolivia	485	2 515	34%
Bosnia and Herzegovina	2 156	7 358	45%
Brazil	85 700	375 000	67%
Bulgaria	2 324	3 947	9%

	Installed capacity (MW)	Actual generation in 2013[a] (GWh)	Share of total electricity generation in 2013[b] (%)
Cameroon	719	4 285	70%
Canada	76 100	388 000	62%
Central African Republic	25	142	78%
Chile	6 000	19 400	27%
China	260 000	905 000	17%
Colombia	9 300	41 800	67%
Congo (Democratic Republic)	2 472	7 772	99%
Congo (Republic of)	119	605	60%
Costa Rica	1 750	7 127	76%
Cote d'Ivoire	604	1 636	40%
Croatia	1 849	6 289	63%
Cuba	64	97	1%
Cyprus	1	0	0%
Czech Republic	1 055	2 276	3%
Denmark	9	18	0%
Ecuador	2 200	10 562	45%
Egypt (Arab Republic)	2 800	13 121	9%
El Salvador	472	1 976	32%
Equatorial Guinea[c]	124	7	7%
Estonia	9	26	0%
Ethiopia[c]	1 886	6 549	99%
Finland	3 140	13 917	20%
France	20 500	75 700	13%
Gabon[c]	170	899	43%

	Installed capacity (MW)	Actual generation in 2013[a] (GWh)	Share of total electricity generation in 2013[b] (%)
Georgia[c]	2 676	7 151	75%
Germany	4 784	20 500	3%
Ghana	1 580	7 206	56%
Greece	2 426	6 000	10%
Guinea[c]	128	550	57%
Hungary	55	206	1%
Iceland	1 884	12 354	68%
India	39 600	143 000	13%
Indonesia	5 078	13 010	6%
Iran	9 500	12 400	5%
Iraq	2 513	4 409	7%
Ireland	237	696	1%
Israel	7	28	0%
Italy	16 185	54 672	19%
Jamaica	23	115	3%
Japan	22 217	80 234	7%
Jordan	12	58	0%
Kazakhstan	2 230	7 889	9%
Kenya	810	4 435	50%
Korea (DPR)[c]	5 000	13 365	71%
Korea (Republic of)	1 718	4 099	1%
Kyrgyzstan	2 948	13 017	14%
Laos[c]	3 263	11 140	92%
Latvia	1 576	3 172	49%

	Installed capacity (MW)	Actual generation in 2013[a] (GWh)	Share of total electricity generation in 2013[b] (%)
Lebanon[c]	275	997	7%
Lesotho[c]	80	486	100%
Lithuania	116	509	11%
Luxembourg	30	1 145	40%
Macedonia[c]	555	1 031	17%
Madagascar[c]	132	697	66%
Malawi[c]	300	1 900	87%
Malaysia	3 917	7 546	6%
Mali[c]	155	724	76%
Mauritania	97	123	18%
Mexico	11 500	34 730	12%
Moldova	76	374	41%
Mongolia	30	99	2%
Montenegro	658	1 958	65%
Morocco[c]	1 306	1 615	6%
Mozambique[c]	2 180	14 994	100%
Myanmar (Burma)[c]	2 900	7 688	73%
Namibia[c]	341	1 591	89%
Nepal	709	3 299	93%
Netherlands	37	88	0%
New Zealand	5 500	23 953	56%
Nicaragua[c]	105	413	10%
Nigeria[c]	1 270	5 602	21%
Norway	29 400	129 000	96%

	Installed capacity (MW)	Actual generation in 2013[a] (GWh)	Share of total electricity generation in 2013[b] (%)
Pakistan	6 826	30 032	32%
Paraguay	8 810	72 695	100%
Peru	3 604	21 733	55%
Philippines	3 521	9 251	12%
Poland	940	2 405	1%
Portugal	4 700	14 600	28%
Puerto Rico	156	150	1%
Romania	6 391	15 457	26%
Russian Federation	47 300	174 800	16%
Rwanda[c]	66	135	44%
Senegal	60	287	9%
Serbia	2 891	11 053	30%
Sierra Leone[c]	54	100	69%
Slovakia	1 607	4 346	15%
Slovenia	1 142	3 907	32%
Somalia	5	0	0%
South Africa	2000	4860	2%
Spain	13 800	34 000	12%
Sri Lanka	1 628	6 009	50%
Sudan and South Sudan[c]	2 250	6 553	67%
Suriname[c]	189	600	34%
Swaziland	61	240	100%
Sweden	16 300	61 000	38%
Switzerland	13 800	41 000	56%

	Installed capacity (MW)	Actual generation in 2013[a] (GWh)	Share of total electricity generation in 2013[b] (%)
Syria (Arab Republic)	1 611	2 908	10%
Taiwan, China	2 041	4 056	2%
Tajikistan	4 628	15 641	98%
Tanzania	562	2 569	29%
Thailand	2 435	7 391	4%
Togo[c]	65	88	81%
Tunisia	66	51	2%
Turkey	22 500	59 200	25%
Turkmenistan	1	3	0%
Uganda[c]	685	2 425	80%
Ukraine	5 470	11 567	6%
United Kingdom	1 676	4 700	1%
United States of America	79 020	269 000	6%
Uruguay	1 538	7 497	70%
Uzbekistan	1 731	10 564	19%
Venezuela	16 000	80 011	61%
Vietnam	14 250	40 423	31%
Zambia	1 836	11 230	99%
Zimbabwe	746	5 408	58%

[a] Hydropower generation, including pumped storage
[b] Total net electricity generation produced domestically
[c] Figures from 2012 data

7. List of figures and tables

Figures

Tables

Appendix A: Project participation

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Côte d'Ivoire
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Ethiopia
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Ghana
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Hungary
Iceland
India
Indonesia
Iran (Islamic Republic)
Iraq
Ireland
Israel
Italy
Japan
Jordan
Kazakhstan
Kenya
Korea (Republic)
Kuwait
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Lithuania
Luxembourg
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Nigeria
Pakistan
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