2014

Hydropower

Mary Finley-Brook
University of Richmond, mbrook@richmond.edu

Recommended Citation

Finley-Brook, Mary. "Hydropower." In *Achieving Sustainability: Visions, Principles, and Practices*, edited by Debra Rowe, 464-69. Vol. 1. Gale, 2014.

Hydropower

Hydropower dates back to the use of waterwheels to grind grain in Greece over two thousand years ago. Modern hydropower is a mature industry that has been used to generate electricity since the 1880s by capturing flowing water with a dam or other diversion structure and channeling it through a waterwheel or turbine. According to a 2012 report by the International Energy Agency, internationally dams are responsible for the largest amount of power generation from a renewable source; yet they have come under scrutiny as a result of environmental and social impacts perceived to be unsustainable (McCully 2001). Specific impacts, and their severity, vary from project to project and are related to social, political, economic, historical, regulatory, and environmental conditions, which also influence benefits such as job creation or watershed management.

After reviewing international practices, in 2000 the World Commission on Dams published critical findings that led to some industry changes. Because social and ecological safeguards are applied unevenly, sustainability concerns remain at the forefront. Repercussions of unsustainable practices that are acceptable to investors or developers may be unacceptable to environmental organizations, human rights groups, or affected populations. Nevertheless, major development banks have begun to prioritize funding for large dams after a decade of slowdown from 2000 to 2010 (Vittorio 2013). Sources of electricity are increasingly judged by their ability to mitigate climate change, and hydropower is often viewed favorably in spite of the fact that large dams with impoundments often require deforestation of vast areas for the creation of a reservoir. In places where trees are not cleared, flooded vegetation releases methane, a potent greenhouse gas (GHG), as it decays underwater. Partially in response to concerns over the social and ecological impacts of industrial dams, there has been momentum toward micro-scale hydro projects, which produce less than 100 kilowatts of electricity. Micro-hydropower generally does not require human resettlement, one of the most devastating consequences of large dams, but overall efficiency is lower and the cost of electricity per kilowatt hour is more expensive.

There are expanding opportunities for the development and expansion of new forms of renewable hydropower from tides, waves, currents, temperature gradient (ocean thermal energy conversion and submarine geothermal energy), and salinity gradient. Modern use of these technologies, known as marine and hydrokinetic industries, is at an early stage of development, although simple tidal and wave power was generated in times past. New hydropower technologies hold promise for low-carbon and ecologically friendly

Sustainability Topics Linked to Hydropower

Crosscutting			
Climate change	Human rights	Gender	Livelihoods
Environmental			
Downstream flow regimes	Erosion and sedimentation	Water quality	Biodiversity and invasive species
Social			
Resettlement	Indigenous peoples	Public health	Cultural heritage
Economic/financial			
Financial viability	Economic viability	Project benefits	Procurement

Figure 1. The breadth of sustainability concerns in hydropower development. *(Reproduced by permission of Gale, a part of Cengage Learning.)*

energy production, but when compared to more proven sources they can be relatively expensive and unlikely to instill investor confidence.

Hydropower and Sustainability

Careful site selection is essential to minimize negative costs from hydropower (Ledec and Quintero 2003). Dam projects influence hydrological regimes, sediment transport, water quality, biological diversity, and land-use change (REN21 2013). They can cause the resettlement of people as well as have effects on downstream water users, public health, and cultural heritage. In a historic pattern of unequal distribution of costs and benefits, the high costs of ecological degradation, resettlement, and loss of resource access are felt in source landscapes, while benefits, such as electricity and profit, are frequently exported. With effective planning and investment, dam reservoirs can bring complementary income opportunities through tourism or aquaculture, although both can lead to additional social and environmental costs without implementation of best practices. The development of complementary economies frequently involves paternalistic treatment of groups made vulnerable after dam projects, rather than prior involvement in planning and decision making (Finley-Brook and Thomas 2010). In the case of resettlement, it is necessary to obtain free, prior, and informed consent, particularly in indigenous peoples' territories. A tendency to rush or limit consultation can lead to confrontations with local populations and may result in resistance.

With the input from a multi-stakeholder forum involving state and industry representatives, development banks, and social and environmental nongovernmental organizations (NGOs), the nonprofit International Hydropower Association (IHA) established an International Sustainability Assessment Protocol to improve planning, implementation, and operation of dams (IHA 2010). The protocol has brought important sustainability issues to the forefront and has helped firms improve their practices. Nonetheless, the protocol contains areas of nonconsensus, with some forum members disagreeing with the majority opinion, demonstrating broader divergence in policy circles and in public opinion. In addition, the best practices outlined in the protocol are hard to achieve. Perfect scores are generally not assumed across all areas, and multiple scores exist for projects that demonstrate gaps in best practices, meaning that some unsustainability may occur even in projects using the protocol.

As hydropower sustainability measures continue to evolve and improve, there is increasing recognition that planning is generally most effective when it takes into consideration dynamic climate and environmental impacts, using models for optimizing water flow, as well as local cultural norms and possible changes in social conditions, such as can occur with population growth. Technological developments that may improve hydropower's sustainability include fish passages, "fish-friendly" turbines that reduce downstream passage mortality, and design changes to minimize or avoid discharges of lubricating oil (REN21 2013). Some projects implement upstream land-use management or reforestation to reduce sedimentation. Other practices include no-access or conservation areas, or the use of "river offsets" outside of the dam concession area, to compensate for negative project impacts such as biodiversity loss.

Status of Hydropower

The top five countries in terms of industrial hydroelectric power—China, Brazil, the United States, Canada, and Russia—account for 52 percent of the world's total capacity (REN21 2013). China maintains nearly a quarter of the world's capacity and in 2012 contributed 52 percent of the net global additions. Other countries with significant additions in 2012 were Turkey, Vietnam, Brazil, and Russia. Construction of new large-scale hydroelectric dams in the United States and Western Europe has slowed, but additions of pumped-storage capacity continue to increase because of its ability to provide ancillary services in terms of grid reliability, network frequency control, and reserve generation. Pumped storage projects store and generate energy by moving water between two reservoirs at different elevations. At times of low electricity demand, water is pumped to an upper reservoir, and during high demand this stored water is released.

MICRO-HYDRO INSTALLATION

Micro-hydropower is deployed in a wide range of environments. Small dams can provide a relatively affordable option for electrification in locations without access to the electrical grid. Capital costs for building small dams can be prohibitive for low-income populations, but maintenance expenses are generally low if micro-hydropower projects are built (Okot 2013). Hydro projects can be scaled to fit the needs of local populations, with *pico-hydropower* being the term used for the smallest and least expensive projects producing fewer than five kilowatts. Pico-hydropower is utilized in areas without need for large amounts of electricity. These installations can be very simple as long as there is a gradient to maintain moving water and pipes so as to divert water to produce electricity.

Installation of a micro-hydropower system is site-specific with many possible configurations, but at a basic level generally involves the construction of the intake canal; the installation and alignment of the penstock (enclosed pipe), turbine, and generator; the construction of a powerhouse; and the connection of a transmission line. Small dams are generally "run-of-river," with diverted water redirected back into the same watercourse. Figure 2 shows a typical micro-hydro layout. Hydropower systems may generate electricity directly or charge batteries; in many systems an inverter and generator are used. The desilting tank and forebay (settling chamber) are important, as this is where sediments and particulate matter will settle out (Okot 2013). Installations generally have a valve at the top of the penstock that can be closed when the turbine is to be shut down and emptied of water for maintenance. When the valve is closed, a spillway is used to divert water back to the river.

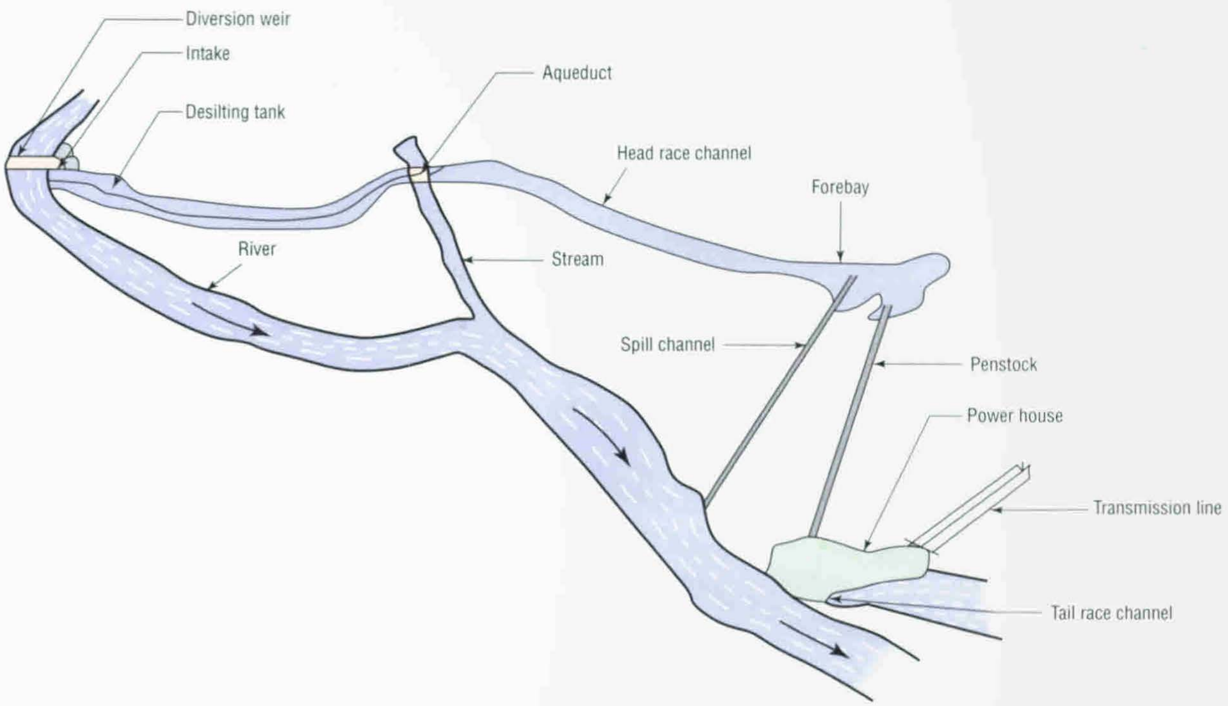
Micro-hydropower is popular among industrialized and developing countries alike. In India there are approximately 700 small hydro projects producing about 2,500 megawatts of energy and several hundred more plants are under construction (Singal, Saini, and Raghuvanshi 2010). In community-based micro-hydropower projects, such as in those funded by the Global Environmental Facility's Small Grants Program (SGP) in the Dominican Republic, local involvement includes volunteer labor during installation, when villagers are trained to repair and maintain the projects. Successful applications for SGP sponsorship in the Dominican Republic have come from organizations ranging in size and scope, including agricultural federations or cooperatives, local water or environmental commissions, and community councils. Ideally, user groups such as these develop their own watershed and energy management guidelines and agree on the rules.

In Asia and Latin America new installations using conventional technologies are common. The Clean Development Mechanism (CDM) under the United Nations Framework Convention on Climate Change supported the construction of many new projects, but the value of the CDM's Certified Emission Reductions fell in 2011 and 2012, thus providing less incentive to build projects like industrial dams that require significant infrastructure and time to develop. CDM projects remain rare in Africa. Owing to economic, political, and social constraints, Africa has experienced relatively slow growth in hydropower in spite of the potential for increased use in many countries (International Energy Agency 2012).

In Australia, Europe, North America, and India, there are efforts to decommission older dams. Decommissioning provides opportunities to restore rivers and surrounding biodiversity as well as to remove long-standing infrastructure that holds in place massive amounts of sedimentation and quite often pollution. Because removal methods are site-specific, knowledge and technology for decommissioning dams is still nascent. Scientific procedures to monitor changes over time are also still evolving. River restoration and management agreements in post-dam situations involve long-term planning and investment commitments.

Tidal and Wave Energy

The production of tidal energy, though very old, has never been widely put to use. Pilot projects are testing increasingly efficient technologies that are expected to boost tidal energy, which requires relatively high capital costs for construction and as much as ten years for project development. The ability to produce energy depends on the facilities developed (length and height) as well as the difference between high and low tide. Although not utilized on all coasts, projects exist in many countries, including Australia, Canada, France, Indonesia, Ireland, Norway, the United Kingdom, and the United States (US Department of Energy, National Renewable Energy Laboratory 2013). Tidal currents are variable, but they are predictable. Nevertheless, the twelve-hour cycles generally do not match consumption cycles, meaning that tidal projects often complement other energy sources. At 21 to 28 US cents per kilowatt hour, tidal power is much more expensive



SOURCE: Singal, S.K., R.P. Saini, and C.S. Raghuvanshi. 2010. "Analysis for cost estimation of low head run of river small hydropower regimes." *Energy for Sustainable Development* 14 (2): 117–26.

Figure 2. A typical micro-hydro site. *(Reproduced by permission of S. K. Singal, R. P. Saini, and C. S. Raghuvanshi.)*

than large-scale hydro, but compares favorably with off-grid micro-hydro (REN21 2013).

Wave energy comes from the movement of the ocean and the rise and fall of the swells. The majority of development of this technology is in industrialized countries (see Table 1); in the Canary Islands, however, a wave project may provide a model for future projects and even potentially a local source of income if the Norwegian and Spanish project developers are able to build and export similar platforms as they propose. Some benefits to wave energy projects are the rapid installation, low maintenance costs, and relatively small investment in relation to other renewable sources such as wind power.

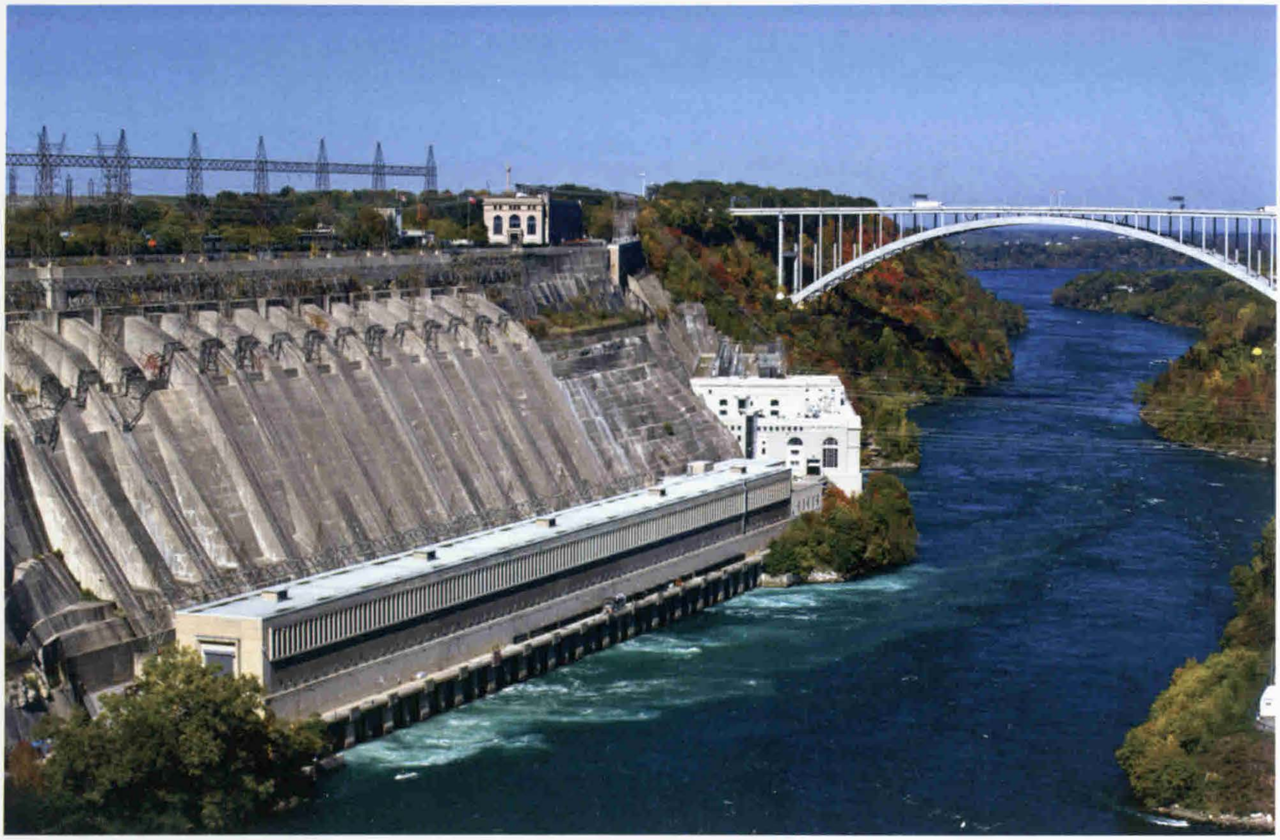
Hydropower Advocacy

There are many advocacy organizations, such as HydroWorld, representing hydropower industries. Journals related to the field include *Hydro Review Worldwide* and *International Journal on Hydropower and Dams*. In 2001 the International Energy Agency created a framework for intergovernmental collaboration through an Ocean Energy Systems Implementing Agreement (OES). Increased activity in the development of ocean wave and tidal current energy by the late 1990s led to recognition of the need for international cooperation under the OES aegis. Since 1995 the International Hydropower Association (IHA) has been circulating information on technology, regulations, and financial support for the sector. The IHA increasingly promotes a strong sustainability

Name	Country	Size (MW)	Year Installed
European Pico Pilot Plant	Portugal	0.4	2005
Galway Bay and Atlantic Marine Energy Test Sites	Ireland	1.0	2006
EMEC Wave and Tidal Test Site	UK	10+	2008
Wavestar	Denmark	0.6	2010
Mutriku	Spain	0.3	2011
Wavehub Wave Test Site	UK	50+	2011
Powerbuoy	US	0.1	2012

SOURCE: NREL (National Renewable Energy Laboratory). 2013. *2011 Renewable Energy Data Book*. US Department of Energy.

Table 1. Sample of commercial and pilot wave energy projects. *(Reproduced by permission of Gale, a part of Cengage Learning.)*



One of the Sir Adam Beck Hydroelectric Generating Stations, Niagara Falls, Ontario, with Lewiston-Queenston Bridge over Niagara River. *(Performance Image/Alamy.)*

message and has a network of sustainability partners for capacity building.

One of the best-known bodies advocating for sustainable hydropower was the World Commission on Dams (WCD), which the World Bank and the International Union for Conservation of Nature (IUCN) helped form in 1997. Extensive research processes with hearings around the world led to the publication of recommendations for improvement. The WCD's 2000 report was respected because the commission included scientists, water and dam experts, donors and private-sector representatives, state agencies, and NGOs. Even after the WCD disbanded, significant international attention revisited the progress made toward implementing its recommendations at the ten-year anniversary in 2010. International Rivers, an NGO, along with regional and local groups on every continent continues to pressure industry to uphold ethical and legal standards with dam construction and use.

See also Appropriate Technology; Cost-Benefit Analysis; Energy Conservation; Green Jobs; Local Economy.

Resources

Finley-Brook, Mary, and Curtis Thomas. 2010. "Treatment of Displaced Indigenous Populations in Two Large Hydro Projects in Panama." *Water Alternatives* 3 (2): 269–290.

GEF-SGP (Global Environmental Facility Small Grants Program). "Dominican Republic." Accessed April 25, 2013. Available from http://sgp.undp.org/index.php?option=com_countrypages&view=testimonials&country=43&Itemid=204

International Energy Agency (IEA). 2012. *World Energy Outlook*. OECD/IEA.

International Hydropower Association. 2010. *Hydropower Sustainability Assessment Protocol*. Accessed July 8, 2013. Available from http://www.hydrosustainability.org/IHAHydro4Life/media/PDFs/Protocol/hydropower-sustainability-assessment-protocol_web.pdf

Ledec, George, and Juan David Quintero. 2003. "Good Dams and Bad Dams: Environmental Criteria for Site Selection of Hydroelectric Projects." World Bank, Latin American and Caribbean Region, Sustainable Development Working Paper 16. Available from http://siteresources.worldbank.org/LACEXT/Resources/258553-1123250606139/Good_and_Bad_Dams_WP16.pdf

McCully, Patrick. 2001. *Silenced Rivers: The Ecology and Politics of Large Dams*. Enl. ed. London and New York: Zed Books.

Okot, David Kilama. 2013. "Review of Small Hydropower Technology." *Renewable and Sustainable Energy Review* 26: 515–520.

REN21 (Renewable Energy Policy Network for the 21st Century). 2013. *Renewables 2013: Global Status Report*. UN Environmental Program. Available from http://www.ren21.net/REN21Activities/GlobalStatusReport.aspx

Singal, S. K.; R. P. Saini; and C. S. Raghuvanshi. 2010. "Analysis for Cost Estimation of Low Head Run-of-River Small Hydropower Schemes." *Energy for Sustainable Development* 14 (2): 117–126.

US Department of Energy, National Renewable Energy Laboratory (NREL). 2013. *2011 Renewable Energy Data Book*. Available from http://www.nrel.gov/docs/fy13osti/54909.pdf

Vittorio, Andrea. 2013. "Development Banks Step Up Lending for Hydropower, Sustainability Still Focus." *Bloomburg BNA*. Accessed July 9, 2013. Available from http://www.bna.com/development-banks-step-n17179874891/

World Commission on Dams (WCD). 2000. *Dams and Development: A New Framework for Decision-Making*. London: Earthscan.

Mary Finley-Brook
Associate Professor,
Department of Geography and the Environment
University of Richmond, VA