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Hydropower: the good, the bad and the ugly

Mark Everard examines the benefits and repercussions of harnessing water for power.

People require energy for their daily needs and for development. In a climate-aware world, we know we need low-carbon energy. For decades, hydropower has been promoted as a strategic solution, and it is frequently a favoured resource where rivers are large and other energy-yielding resources are sparse. But is hydropower a panacea, or must we address wider considerations to pursue the goals of sustainability and meet universal human needs?

A SHORT HISTORY OF HYDROPOWER

Harnessing energy from flowing water dates back millennia. Waterwheels for grinding wheat into flour were used in Greece over 2,000 years ago, with widespread global examples of water-powered mills, water pumps, saws and other tools used over the intervening centuries. The invention of the hydropower turbine in the mid-1700s is credited to the French engineer Bernard Forest de Bélidor.[1] Subsequent refinement and implementation of the technology has resulted in hydroelectric power generation across the world, particularly in nations with large rivers of reliable flow and steeper topography, such as widespread installations in China, India and Nepal that are fed by river systems originating in the Himalayas.

As society grapples with development challenges, including achievement of the 17 United Nations Sustainable Development Goals,[2] there remains a growing need for reliable energy in developing nations and increased energy efficiency and transition to renewable sources in the developed world.

THE GOOD

Hydroelectric power comes from the extraction of energy from water-cycle flows that are ultimately driven by solar radiation. Hydropower is classified as green in many parts of the world including the UK, and in the USA hydropower contributes to transition goals of 100 per cent clean electricity by 2035 and net-zero emissions by 2050.[3] Hydropower can provide a base load of power where water flows are reliable; alternatively, energy can be stored in reservoirs or in pumped storage units, providing service flexibility. Hydroelectric power generation also allows states to produce their own energy where suitable water resources are available, without relying on international fuel sources.

Reservoirs for hydropower generation also enable water to be directed to specific uses, including for urban and industrial supply and large-scale irrigation. They also offer recreational and tourism opportunities such as boating, fishing and swimming. Flood control is another commonly described benefit of hydropower installations, as they provide a buffer for flood events by storing surplus water for gradual release during drier periods.

THE BAD

With all these benefits, what could possibly be considered bad about hydropower?

If our worldview is purely utilitarian – creating harvestable water and power with additional recreational benefits – all appears to be good. However, we thought the same about digging up carbon-rich fossil fuels to serve legitimate societal demands for energy. Yet despite global markets and governments still making use of fossil fuels as a cheap default option, we are increasingly aware of the existential threat and disruption posed by such an oversimplistic view of short-term interference with carbon cycles that naturally operate over geological timescales.

The reality, though, is that water is far more than a utility. The global water cycle carries solutes, suspended chemicals, aggregates, biota and energy. It is fundamental to human health, economic activities from food production to heavy industry and contributes to the security and fulfilment of human potential. Interventions in any ecosystem element – tilling a field, removing a keystone species, releasing substances sequestered over geological time back into the biosphere, rearranging atoms into molecular configurations alien to nature – has pervasive, systemic repercussions. Interventions in the water cycle are no different and are either done myopically or with foresight.

Water-cycle interventions have inevitable systemic influence not just on water and energy resources but across a broad swathe of water-vectored ecosystem services. Extensive reviews by the World Commission on Dams[4] and in The Hydropolitics of Dams[5] recognise many of these wider, systemic ramifications. In addition to storing water, dams trap up to 100 per cent of river sediment flows, often contributing to an unanticipated high rate of reservoir infilling and shortened design life. Critically, sediment entrapment also starves downstream river catchments of the nourishing nutrients, minerals and particulate matter necessary to replenish floodplain and delta habitats. Instead, these downstream reaches of catchments tend to erode along with their multiple values, including, for example, those associated with culture, agriculture and the life cycles of fish and other organisms. Common outcomes of simplified hydrology in tropical regions also include proliferation of waterborne diseases such as bilharzia, West Nile and Zika viruses and leptospirosis, as their vectors proliferate in moderated flows.

Dam schemes also have significant implications for the life cycles of fish and other migratory riverine organisms of diverse inherent, subsistence, functional, recreational and spiritual value. Inundation of irreplaceable cultural assets also occurs, such as sacred Hindu temples, many over 1,000 years old, behind dams unwisely conceived as 'temples of modern India' – a term coined in 1954 by India's first prime minister, Jawaharlal Nehru.[6] Dams and reservoirs can be massive in scale. Three Gorges Dam on the Yangtze River in China, with a total capacity of 39.3 km^3 (a theoretical mass of 3.93 billion tonnes), is the world's largest dam scheme that in 2012 also became the world's largest hydropower generation plant with an installed capacity of 22,500 MW. However, filling of the Three Gorges Dam measurably shifted the Earth's tilt and also increased seismic activity in the region by seven to eight times, including triggering a 5.1-magnitude earthquake near the dam site in 2013.[7] Displacement of hundreds of people was driven by rockfalls and landslides around the dam, adding to the displacement of at least 1.3 million people along the river during construction and filling.[8] Many large dams constructed or conceived in the Indian Himalayas are in highly geologically active zones, with potential dam failure posing considerable implications for deluges of released water. Many nations also ban the photographing of dams to prevent them from becoming terrorist targets.

Likely but overlooked implications for all systemically interconnected ecosystem services were assessed in a study of the proposed Pancheshwar Dam, potentially the world's second tallest, intended to harness hydroelectric power and water and planned to impound the Mahakali River that divides India and Nepal in the Middle Himalayas.[9] Dam proposals reached an advanced state in 2010 but have not progressed since, in part informed by wider dissemination of the distributional outcomes of that ecosystem services assessment, but also due to other factors such a political change in Nepal. The assessment concluded that ecosystem services would be affected across substantial areas both upstream and downstream with significant impacts and some complete losses of ecological, cultural, spiritual and tourism importance, and that these would have ramifications over substantial distances lower in the catchment. Most people directly or indirectly dependent on the river's ecosystem services were not considered or engaged in the planning process. Consideration of environmental and social consequences only came later, seemingly too late to influence scheme design and decisions locked in by sunk costs. The net value of the proposed Pancheshwar Dam to Nepal, India and beyond was considered at best highly questionable, with potential positive outcomes overstated and negative consequences substantially overlooked.[9] No consideration was given to how people use water and energy, or to other potentially more sustainable and less disruptive options to the catchment ecosystem.

These discussions bring into question not only the winners and losers from the impoundment of flowing water for energy and water harvesting but also the net value of these interventions once the costs of compromised or lost ecosystem services are weighed against the intended benefits. Undoubtedly, the winners include politically and economically influential and often remote beneficiaries of piped water and wired power. But what about the potentially millions of graziers and other rural farmers whose livelihoods depend upon depleted catchments, potentially for hundreds of kilometres downstream of dams, those afflicted across this range by the possible proliferation of waterborne diseases, and the diverse people dependent upon natural ecosystems and cultural resources, many of which are irreplaceable?

Dam building for hydroelectric power and large-scale water transfers often primarily serves already economically and politically advantaged and frequently remote beneficiaries, but with inevitable negative outcomes for people local to dam sites and those dependent upon multi-beneficial flows at catchment scale. This form of technological appropriation of water and energy is analogous to the enclosure of terrestrial commons, formerly supporting countless livelihoods but annexed as private or municipal property and often converted for short-term profit.

THE UGLY

Annexation of power and water from transboundary rivers by a country that deprives its downstream neighbours can be a source of conflict and civil unrest. It can even be so between states within large nations, such as Tamil Nadu and Karnataka in southern India that share the Kaveri River. While sharing transboundary rivers has been found to be more of a lever for collaboration than a source of conflict,[10] there remain many global instances of inter-state tensions, such as the sharing of Indus River resources between India and Pakistan. Looking beyond utilitarian access to resources, wider distributional implications become apparent when all ecosystem services are considered. These systemic implications are still largely overlooked yet have geographical and inter-generational ramifications. There are also many instances of large dams featuring more as a facet of empire building than a population benefit. One such example was the Aswan High Dam, one of the world's largest embankment dams built across the Nile between 1960 and 1970, with the promise of year-round irrigation and the lifting of the Egyptian people out of poverty. Yet this scheme, creating the vast Lake Nasser, bearing the then-President's name, overlooked numerous consequences and hardships resulting from the impoundment of the River Nile. The once-productive floodplains of the Nile Valley – formerly naturally replenished by high seasonal flows of sediment-laden water – have been progressively eroded, starved of nutrients and deprived of crucial salt-flushing processes, leading to widespread salinisation from evaporation during year-round irrigation. Additionally, the reservoir experiences substantial rates of evaporation from its 5,250 km^2 surface area under a tropical sun as well as rapid infilling from trapped sediment. A further downstream consequence is the systematic degradation of the structure and associated cultural, agricultural and ecological resources of the Nile delta.

Even where international aid flows into developing nations for dam construction, ostensibly to benefit the people, key beneficiaries often include consultants from the developed world with vested interests in narrowly framed technical solutions of more immediate payback than ecosystem-informed alternatives. And that is before we get into any implications of corruption and the distributional outcomes of dam operation.

POWER TO THE PEOPLE

Yet we need energy for development. We need renewable energy too, helping us make a transition away from dependence on fossil fuels and nuclear resources. However, it would be foolhardy to conflate renewable with sustainable energy if all ecosystem service ramifications are overlooked.

The World Commission on Dams (WCD) report recognises that 'dams have made an important and significant contribution to human development'.[4] However, the report recognises the need to think, plan and operate on a far more systemic basis taking account of the implications and distributional benefits of dam design and operation, including prior consideration of alternative approaches to resource security and enhancement. The WCD proposed seven strategic priorities: public acceptance; comprehensive options assessment; addressing existing dams; sustaining rivers and livelihoods; recognising entitlements and sharing benefits; ensuring compliance; and sharing rivers for peace, development and security. These priorities are backed up by 26 guidelines for good practice to shape more sustainable and equitable water resource development.[11]

The extent to which the WCD's priorities and guidelines have been applied is, at best, moot.[5] However, practical, rapid and, above all, fully systemic approaches to ecosystem service assessment have since been developed to analyse the likely outcomes of different development options. This includes the Rapid Assessment of Wetland Ecosystem Services, adopted at intergovernmental level at the 2018 Ramsar Convention on Wetlands, which provides a pragmatic approach suitable for testing and comparing alternative solutions and revising designs and operations for benefit optimisation.

TIME FOR FORESIGHT

Consideration of energy in terms of the ecosystem services from which it can be harvested leads to an interesting observation about three different timescales:

1. The first and longest relates to fossil fuel energy captured from solar input during the Carboniferous (or coal-bearing) period between 358.9 and 298.9 million years ago. However, releasing energy from the molecular bonds of fossilised organic matter also remobilises sequestered carbon with damaging implications.

2. Next in terms of time lag from input to exploitation is harvesting from flows of water, extracted from the response of the water cycle to solar energy (and in some cases lunar gravity) but with wider impacts across a broad spectrum of water-vectored ecosystem services. (Biomass-based generation shares similar features.)

3. Finally, the near-instantaneous harvesting of direct solar and wind energy has far more localised and fewer systemic complications.

Energy generation from solar and wind sources now exceeds price parity with fossil fuels; along with novel energy carriers such as hydrogen and together with battery technology they are important renewable sources forming the backbone of an energy transition towards net-zero carbon.[12] There is therefore no reason to hold back from rethinking energy development along this energy-source hierarchy: closer to the arrival of solar input, with fewer wider damaging repercussions for the atmosphere and water cycle, and with fewer and more localised impacts to mitigate.

Hydropower has a role to play as an inherently renewable energy source, although it should always be contextualised by wider thinking about the right solution, right place and optimising systemic benefits. The energy-source hierarchy can be integrated into national strategies and priorities for development aid as a framework against which to consider all energy-harvesting options in the context of their distributional outcomes, and to prioritise unlocking restrictive patents to accelerate progress towards sustainability.

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