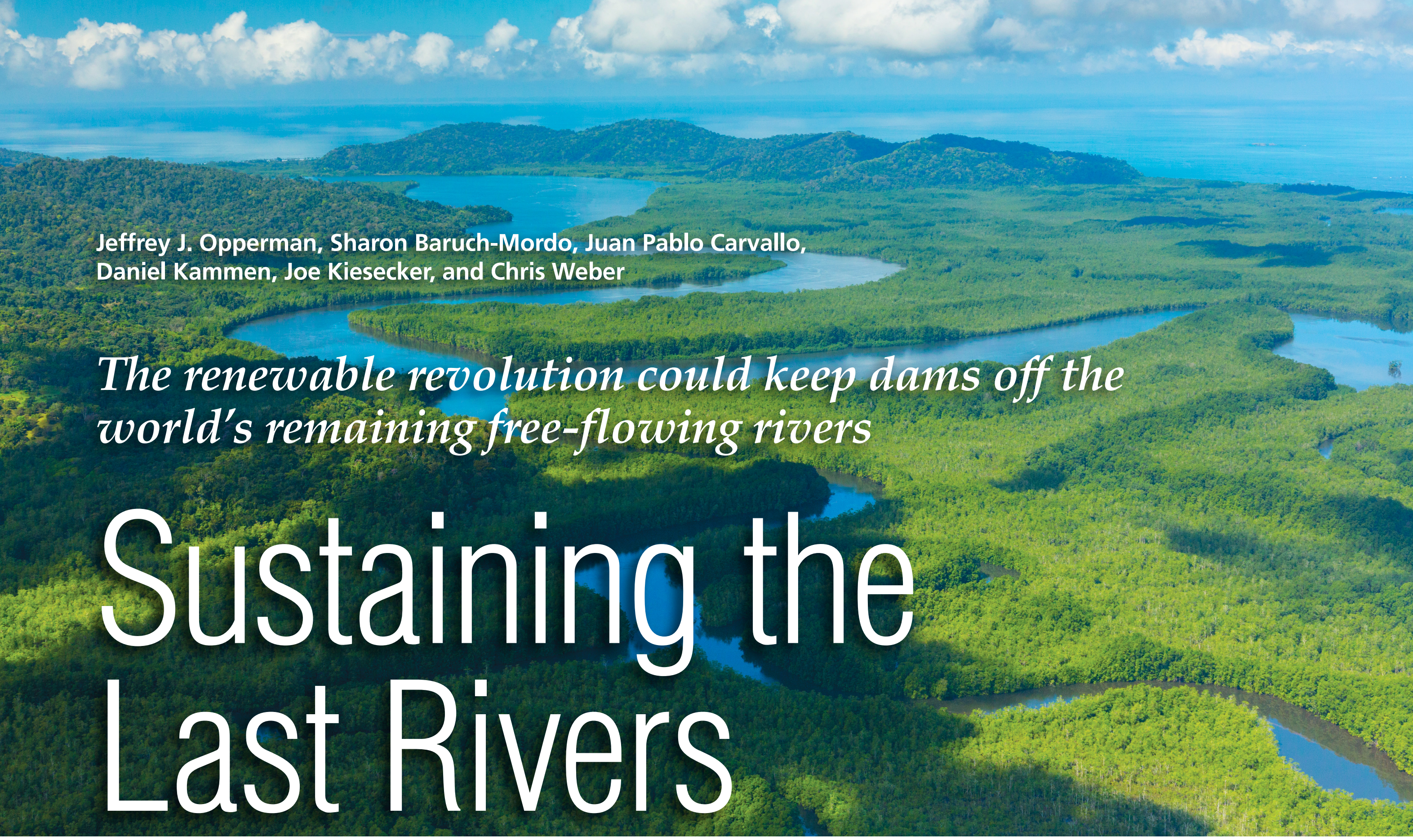

Jeffrey J. Opperman, Sharon Baruch-Mordo, Juan Pablo Carvallo, Daniel Kammen, Joe Kiesecker, and Chris Weber

The renewable revolution could keep dams off the world's remaining free-flowing rivers

Sustaining the Last Rivers

For millennia, the Térraba was essentially one thing: a free-flowing river that coursed through the mountains of southern Costa Rica before spreading across productive floodplains and flowing into one of the largest mangrove forests in Central America, providing food and livelihoods to people all along its meandering path. Then, in the span of a few decades, the Térraba became several things. It was a proposed site for a hydropower dam, potentially the largest in Central America and the cornerstone of Costa Rica's future power system. It became a flashpoint of intense conflict between the government and indigenous Teribe people mobilized by plans to inundate part of their land and several communities. And on the broadest scale, it became a case study of the daunting challenges of balancing economic growth with sustainable energy development.

Nations around the world need energy for economic growth, but they also need to contain rising global temperatures, avoid social conflict and environmental losses, and minimize impacts to rivers and lands that have cultural and economic value. When the hydropower conflict reached full boil in 2010, Costa Rica had achieved two of those three goals. Nearly all citizens had access to power, more than 90 percent of which came from renewable resources. The country's carbon footprint was one-tenth of the United States's on a per-capita basis, and its economy was growing strongly. Yet the majority of that renewable generation came from hydropower, which can have substantial negative effects on environmental and social resources. Many of the country's major rivers had already been dammed, and the Térraba, its last free-flowing long river, was slated to join them.

Costa Rica, along with nearly 200 other nations, has signed on to the United Nations Sustainable Development Goals, which include both "affordable and clean energy" and "climate action," and to the Paris Agreement, which aims to prevent the average global temperature from rising by more than 1.5 degrees Celsius. Achieving this climate target will require electrification of leading greenhouse gas-emitting sectors such as transportation and heating. That transition, along with economic and population growth and the need to bring power to approximately 1 billion people who now lack it, is expected to double the world's demand for electricity by 2050.

Controversial plans to dam Costa Rica's Térraba River illustrate the challenges of balancing economic growth with sustainable energy development.

Because electricity is a leading source of greenhouse gases, simultaneously achieving these energy and climate goals will require a rapid transition to low-carbon energy. Many countries are making progress in expanding access to low-cost electricity; a few, such as Costa Rica, have managed to do so while keeping their carbon emissions low. But overall, they have not yet found energy solutions that are simultaneously low cost, low carbon, and low in conflict with communities, rivers, and other ecosystems—what we call *LowCx3 power systems*.

Juan Carlos Munoz/Nature Picture Library

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Our research suggests the ability to achieve LowCx3 systems might be at hand. This potential arises from the renewable revolution: rapidly falling costs for wind and solar generation and storage technologies, alongside considerable progress in the management of grids, energy efficiency, and demand-side management. Next-generation wind and solar could satisfy the cost and emissions needs while greatly reducing the environmental and social impact of energy generation. Such a comprehensive solution is essential to balanced and sustainable future development.

Rivers Run Through This

Today, global hydropower capacity is roughly 1,200 gigawatts, generating approximately 4,000 terawatt hours per year. This figure represents 70 percent of global renewable generation and around 17 percent of total electricity generation. Most forecasts for achieving the ambitious 1.5 degree climate-warming target would require damming the majority of the world's remaining free-flowing rivers.

Although hydropower projects can provide low-carbon electricity generation, they can also have a range of negative effects—as the Térraba controversy illustrates. Dams can inundate the valleys behind them, converting croplands, freshwater, and terrestrial habitats into reservoirs. The World Commission on Dams estimated that by 2000, between 40 million and 80 million people had been displaced by reservoirs. This number continues to grow because the years since 2000 have seen the largest expansion of hydropower in history.

Reservoirs trap sediment, the building blocks of downstream habitat features, including channel bars, floodplains, and deltas. Naturally flowing river currents serve as conveyer belts to transport sediment from upland to lowland systems. In contrast, the still or slow-moving water in a reservoir can generally move only the smallest sediment while larger materials, including sand and gravels, are deposited within the reservoir. Without these materials, downstream habitats, particularly deltas, can't keep pace with erosion, compaction, and rising sea levels.

Dams are one of the leading causes of shrinking deltas worldwide, affecting hundreds of millions of people and some of the richest farming and fishing locations on the planet. More than 100 dams have been proposed for the Mekong River basin as Laos aims to be "the battery of southeast Asia"; full development of those dams would accelerate the loss of the Mekong delta, which supports a population of 21 million people and half of the rice crop of Vietnam, a top global exporter of rice.

Further, dams disrupt the up- and downstream movement of fish and other aquatic species. Migratory species can be particularly affected by dams that block access to spawning habitats. Because many rivers' fisheries are dominated by migratory fish, their loss can have major negative results for rural communities.

Species Be Dammed

Because of these diverse impacts on rivers' habitat, flow, connectivity, and sediment, scientific studies consistently rank dams among the most destructive contributors to the reduction of freshwater species populations. Freshwater vertebrate populations tracked by the Living Planet Index, a measure of the world's biological diversity, have declined by an average of 83 percent since 1970, nearly double the rate of decline for populations of marine and terrestrial species. (*See "Where the Xingu Bends and Will Soon Break," November–December 2015.*)

These losses of environmental resources are global in scale. Reservoirs trap about one-quarter of the sediment in transport globally, reducing the delivery of sediment to oceans by approximately 1.4 billion tons per year, compared to levels before people began modifying landscapes and rivers. Just this year, an international team led by McGill University's Günther Grill found that only one-third of the world's long rivers—those running more than 1,000 kilometers—can be considered free flowing, mainly because of dams. Today, long free-flowing rivers remain primarily in the Amazon and Congo basins and in basins that drain to the Arctic Ocean. There are no long free-flowing rivers remaining in the United States and Europe and only two in South or Southeast Asia: the Irrawaddy and the Salween. both in Myanmar.

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Most projections in the Intergovernmental Panel on Climate Change (IPCC) *Special Report on Global Warming of 1.5° C* anticipate that, to meet that climate target, global capacity of hydropower will need to reach between 1,700 and 2,400 gigawatts by 2050. The upper end is twice the amount of hydropower we have today. Even a level of development near the lower end of that range would result in fragmentation of an additional 190,000 kilometers of river channels globally. Dams are planned or proposed on most of the remaining tropical free-flowing rivers, including the Irrawaddy, the Salween, the Congo and its major tributaries, and major tributaries of the Amazon.

In other words, many of the projected scenarios to safely maintain the planet's climate require a major tradeoff: the loss of most of the planet's remaining free-flowing rivers to hydropower development.

Shifting Possibilities

That tradeoff may not be inevitable. The realm of what is possible for future power systems is shifting rapidly. Costs for wind and solar photovoltaic generation, which directly converts the Sun's radiation to electricity, have been declining far more rapidly than anticipated and both are now in the neighborhood of five cents per kilowatt hour. That's comparable to the low end of fossil fuel costs and the average costs of hydropower.

With their costs dropping so rapidly, and projected to decline even further,

Facilities like Costa Rica's Cachi Dam provide power, flood control, and recreation, but can also carry high social and environmental costs.

Juan Carlos Ulate/Reuters

wind and solar projects are driving the growth of power generation capacity. Renewables—primarily wind and solar photovoltaic—represented two-thirds of new electricity capacity added in 2018. However, this rate is still behind the pace of investment necessary to meet climate objectives.

Meanwhile, new hydropower capacity additions have been declining since 2013. Beyond the falling costs of other renewable-energy technologies, hydropower faces a broad set of other challenges: Growing hydrological risks, increasing social resistance, and cost and schedule overruns have led to a number of high-profile project cancellations.

Although these trends in cost and investment suggest that wind and solar will eventually become the planet's primary forms of energy generation, on their own they do not mean that these technologies will substitute for hydropower—and thus avoid the damming of the remaining free-flowing rivers. The IPCC pathways referenced above anticipate the 500 gigawatts to 1,000 gigawatts of additional hydropower capacity even though they also foresee a 60-fold increase in solar photovoltaic energy. Further, wind and solar are variable sources, so they need to be combined with a mix of energy storage and on-demand "dispatchable" generation.

Hydropower can be both stored, in the form of water behind a dam, and dispatched, by increasing flow through turbines. The extent to which the renewable revolution can allow countries to avoid dams that have significant conflicts with communities and ecosystems will hinge on solutions at the scale of grids; solutions that find the right mix of generation and storage to substitute for high-conflict dams.

Many of the scenarios proposed to maintain the planet's climate require the loss of most of the planet's remaining free-flowing rivers to hydropower.

Broader Options

A range of recent modeling studies, including several that we have conducted, have demonstrated that energy systems can indeed be LowCx3. Studies for Sarawak (Malaysia), Uganda, Chile, and countries in the Mekong Basin region of Southeast Asia have all shown expansion options that meet the forecasted demand, are low carbon, and avoid high-conflict hydropower projects—largely by shifting toward more wind and solar along with investments in battery storage and drawing on existing hydropower to provide storage. These options also have costs comparable to business-as-usual options that include coal or higher levels of hydropower.

We simulated a power system expansion for Uganda and showed that substituting solar photovoltaic and battery storage for two dams proposed in a national park had no impacts on projected power system costs. A similar simulation we did for Chile avoids new dams on free-flowing rivers, reduces carbon emissions by 75 percent, and delivers electricity that costs only 1.5 to 2 percent more than that from a business-as-usual scenario, which included hydro and coal.

To be sure, poorly planned wind and solar development can also harm ecosystems and trigger public resistance. Thus, achieving low-conflict grids requires the widespread availability of wind and solar power in areas with few or no impacts on social and environmental resources. The global technical potential for generation from low-conflict utility-scale wind and solar—on already converted lands such as degraded fields, rooftops for solar, and agriculture for wind—is 17 times the renewable energy targets that countries have committed to under the Paris Agreement. Further, it's more than 40 times greater than the additional hydropower generation forecast in IPCC scenarios.

The grid studies described previously suggest that many power systems can expand with a greater emphasis on wind and solar photovoltaic while avoiding high-conflict hydropower. And there is a huge pool of low-conflict wind and solar available for power systems to draw on: In the countries with the most proposed hydropower, the potential generation from low-conflict wind and solar photovoltaic is generally tens, hundreds, or even thousands of times greater than the generation of new hydropower in inventories of potential dams.

Substituting greater investment in wind and solar to avoid high-conflict dams could bring profound benefits to rivers. In our recent study, *Connected and Flowing*, we found that this substi-

Wind turbines like these turbines near Tilaran in Costa Rica can contribute to energy systems that are what the authors call *LowCx3*—low cost, low carbon, and low conflict.

tution could dramatically reduce the extent of rivers affected by fragmentation relative to status quo hydropower expansion. We saw that a strategic combination of reduced hydropower expansion, along with best practices such as siting new projects in basins that already have dams, could reduce future river impacts by 90 percent.

LowCx3 Is Here

Many countries and companies are building the LowCx3 future right now. In Chile, several proposed dams that had stirred considerable conflict were suspended in 2015, and solar photovoltaic has dominated subsequent grid capacity expansion. Thailand has signaled uncertainty about whether it will sign a power purchase agreement that would underwrite a new hydropower dam on the Mekong in Laos. Instead, it is emphasizing domestic renewable energy, including pursuing floating solar photovoltaic projects on existing reservoirs.

Thailand isn't the only country where reservoirs could offer significant potential for low-conflict siting of solar projects: A recent report by the World Bank, *Where Sun Meets Water*, reported that, even with conservative assumptions, the global potential of solar projects on reservoirs is 400 gigawatts, comparable to the lower end of the IPCC projections of that additional hydropower needed by 2050.

These examples reach the same conclusions as our studies: By seizing the opportunity offered by the renewable revolution, countries can achieve low carbon power systems without damming free-flowing rivers. However, plans or preparation for dams are moving forward on the Mekong and other important rivers. The trends in technology and investment that underpin the renewable revolution create the opportunity for LowCx3 solutions, but, on their own, these trends aren't sufficient to ensure these solutions emerge in time for the Mekong and other rivers. That will require the political will to pursue these opportunities.

In November 2018, the Costa Rican government decided to suspend indefinitely the El Diquís hydropower project in the Térraba River basin. The government concluded that the dam was no longer part of its least-cost expansion plans, citing the declining costs of other technologies and slowing demands because of energy efficiency. Costa Rica's future power expansion will now feature solar, wind, and geothermal sources, with the expansion of variable renewables facilitated by the country's significant existing fleet of hydropower plants.

Costa Rica has pledged to become carbon neutral by 2021. The Teribe have maintained autonomy over their land. And the Térraba remains free flowing.

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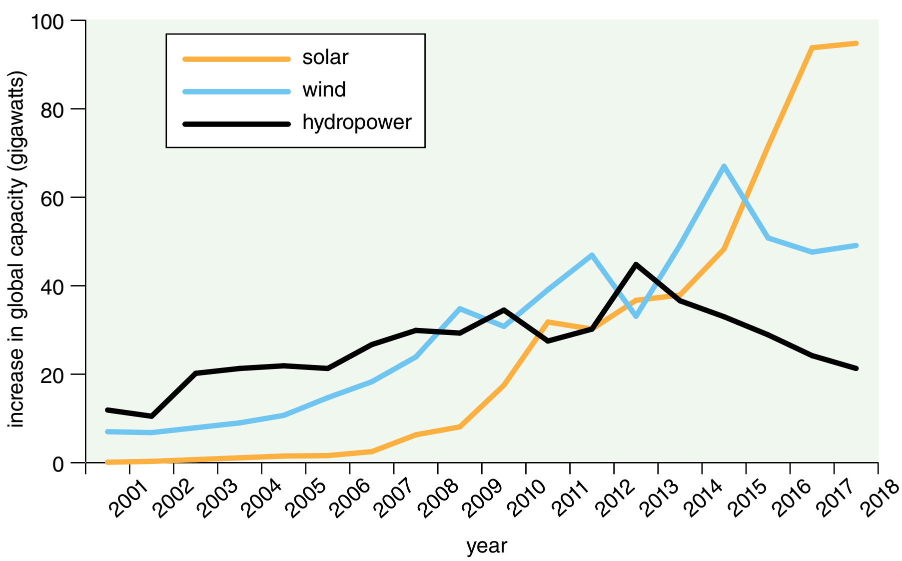

Rapidly falling costs for wind and solar generation are creating a renewable revolution that could rely less on hydropower and carbon-emitting sources.

For relevant Web links, consult this issue of *American Scientist Online:*

www.amsci.org/magazine/issues/2019/september-october

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