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# Climate Change and the Amazon

## Tropical Dams Emit Greenhouse Gases

BY PHILIP M. FEARNSIDE

**MOST HAVE HEARD SO MANY TIMES THAT** hydropower is "clean" or "green" energy that they are surprised to learn otherwise. Unfortunately, the reality is much more complicated. Dams, especially those in the tropics, emit significant amounts of greenhouse gases, and to categorically call them "clean" is a mistake.

I was not the first to discover that dams emit greenhouse gases—a group from Canada published a paper in 1993 showing emissions from dams in that country. But two years later, I showed that some Amazonian dams such as Balbina emit even more greenhouse gases than would be emitted from generating the same power from fossil fuels. That 1995 paper was the one that enraged the hydroelectric industry. The U.S. Hydropower Association spokesperson labeled the idea that dams produce greenhouse gases as "baloney." The debate was only beginning. Both sides of the long argument with the hydroelectric industry, especially the ex-president of ELETROBRÁS, can be found at http://philip.inpa.gov.br. The hydroelectric industry subsequently shifted its position from total rejection to admitting that dams emit some greenhouse gases, but only an insignificant amount.

Unfortunately, the amounts are not insignificant, especially if they are quantified without omitting important sources of emission. First, the trees left standing in the reservoirs project out of the water, where they decay in the open air and release their carbon as carbon dioxide—half of the dry weight of wood is carbon. The wood that is underwater decays very slowly, but this is not the case for soft vegetation such as leaves and for the carbon in the soil. The water in a reservoir divides into layers, with a warmer, less dense surface layer in the top 2-10 m that is in contact with the air and contains oxygen. A division (the thermocline) separates this layer from a colder, denser layer that extends to the bottom. The water in the two layers does not mix, and the oxygen in the bottom layer is quickly exhausted, leaving this layer with almost no oxygen. All decay at the bottom of the reservoir therefore must end in methane ($CH_4$) rather than carbon dioxide ($CO_2$), since the layer lacks oxygen to form $CO_2$. Though it is present in much smaller concentrations in the atmosphere, methane is a much more potent greenhouse gas than carbon dioxide.

Some of the methane is released through the surface of the reservoir as bubbles or through diffusion, as would take place in a naturally formed lake. What makes hydropower emissions different from those of natural lakes is that water is drawn from near the bottom of the reservoir for the turbines, and it is also drawn from well below the thermocline for the spillways. The water released below the dam is therefore loaded with methane. Since the solubility of gases in water is proportional to the pressure (Henry's Law in chemistry), the methane will form bubbles and escape when the pressure is suddenly released as the water emerges from the turbines. This is the same phenomenon that is apparent when one opens a bottle of Coca Cola: the gases form bubbles

**The spillway at the Tucuruí releases methane from the water it draws from 20 m below the surface.**



PHOTO BY PHILIP M. FEARNSIDE

when the pressure is released by removing the cap. The pressure under the weight of water at the bottom of a reservoir is much greater than that inside a soft drink bottle, and, consequently, the release of gas is greater when the pressure is released.

As shown in a paper I published in June 2012 in *Nature Climate Change* (together with Salvador Pueyo), many of the estimates of hydro emissions that have been used to claim that emissions are small have underestimated or ignored key sources of emissions. Emissions from turbines and spillways have often been ignored completely. When included, they have sometimes been measured by capturing bubbles with chambers floating on the water surface in the river well below the dam outlet. Most of the methane has already been emitted as the water emerges from the turbines (and some is released even inside the turbines). The only practical way to avoid underestimating the turbine emissions is to calculate them by the difference in the methane concentration in the water above the dam, at the level of the turbines, and below the dam. This approximately doubles the emission figure as compared to estimates based on downstream chambers. For concentration measurements there is a problem with traditional sampling devices (Ruttner bottles) that leads to underestimating the emissions. When one of these devices takes a sample of water from near the bottom and raises it to the surface, a significant amount of the gas comes out of solution and escapes on the way to the surface. A new type of sampler designed by Alexandre Kemenes avoids this problem, resulting in concentration values that approximately double the emission again. Different groups have made direct estimates at two dams (the Petit Saut Dam in French Guiana and the Balbina Dam in Brazil), confirming that emissions are substantial and exceed those of fossil fuel for years. I have calculated emissions for a number of Amazonian dams, indicating emissions that are varied but often high. A considerable amount of information is needed about each dam to make reliable estimates of emissions: each dam is different, and simple extrapolations based on such factors as area or installed capacity are problematic.

A huge peak of emissions occurs in the first few years after a reservoir is flooded, because the leaves from the trees that are killed decay; soil carbon is also released in this period. Emissions then decline to lower levels, but they do not disappear. One feature that can supply carbon for forming methane indefinitely is the raising and lowering of the water level each year. When the water is drawn down to generate power in the dry season, a large mudflat is exposed around the edge of the reservoir. Weeds quickly grow on this land, and when the water rises again, this soft vegetation decomposes at the bottom of the reservoir where the water is without oxygen. The carbon in the weeds has been removed from the atmosphere in the form of $CO_2$ by photosynthesis, but it is returned in the form of $CH_4$, a much more potent greenhouse gas. Because this is an ongoing process, the reservoir acts as a "methane factory."

The sustained emission from this "methane factory" may be less than the global warming impact of the $CO_2$ that would be emitted in generating the same amount of electricity from fossil fuel. However, it may take many years to pay off the greenhouse "debt" from the very high emission in the first few years. My calculation for the planned Belo Monte and Babaquara (Altamira) complex in the Amazon region is that it would take 41 years to break even in terms of global-warming impact. Unfortunately, we do not have that much time to begin doing something about global warming. Brazil's massive dam-building plans would be emitting peak emissions exactly in the time window when global warming needs to be brought under control to avoid grave consequences, including those that threaten the Amazon forest. Brazil's 2011-2020 Energy Expansion Plan calls for building 30 large dams in the country's Legal Amazon region, or one dam every four months.

In addition to emitting gases, tropical dams are now having an impact on global warming through another route. This is by their serving to justify carbon credit under the Kyoto Protocol's Clean Development Mechanism (CDM). Aside from underestimating or ignoring the emissions from dams themselves, the greater impact is because the dams are not "additional," that is, they would be built anyway without any subsidy from the CDM. For example, the two dams under construction on Brazil's Madeira River are nearing completion, and only now are applications being made for the CDM subsidy. Obviously, the companies that are building the dams expect to make money independent of any financial bonus from the CDM. The global total is staggering: 288 million tons of $CO_2$-equivalent carbon per year for the dams in the CDM's "pipeline" as of January 2012. In addition to authorizing the emission of this amount of carbon by the countries that buy the credit, awarding carbon credit to dams also wastes a significant part of the money that the world has for fighting global warming—money that could be spent on forms of mitigation with a real benefit for climate. The CDM loophole needs to be closed by not giving carbon credit for dams.

In summary, tropical dams have multiple impacts on global warming. These impacts are not being properly quantified and incorporated into decision-making in places like Brazilian Amazonia.

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