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PERSPECTIVE

Greenhouse gas emissions from Brazil's Amazonian hydroelectric dams

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Abstract

Tropical dams are often falsely portrayed as 'clean' emissions-free energy sources. The letter by de Faria *et al* (2015 *Environ. Res. Lett.* **10** 124019) adds to evidence questioning this myth. Calculations are made for 18 dams that are planned or under construction in Brazilian Amazonia and show that emissions from storage hydroelectric dams would exceed those from electricity generation based on fossil fuels. Fossil fuels need not be the alternative, because Brazil has vast potential for wind and solar power as well as opportunities for energy conservation. Because dam-building is rapidly shifting to humid tropical areas, where emissions are higher than in other climatic zones, the impact of these emissions needs to be given proper weight in energy-policy decisions.

Tropical hydroelectric dams have significant greenhouse gas emissions. Although this has now been known for over two decades, it has yet to have any perceptible effect on dam-building decisions. In Brazil, incorporation of discussion of greenhouse gases into environmental impact assessments for dam projects has not changed this (e.g., Fearnside 2011). Public perception of hydropower continues to be that this is 'clean energy'.

The paper by de Faria *et al* (2015) provides emissions calculations for 18 dams that are proposed or under construction in Brazilian Amazonia and makes a significant advance towards generalized procedures that can be applied to other tropical dams. The study confirms high emissions from tropical hydropower, showing that they can often exceed the global warming impact of generation from fossil fuels.

Tropical dams emit substantially more than dams in the temperate and boreal zones (e.g., Barros *et al* 2011). The study by de Faria *et al* (2015) restricts its data and conclusions to tropical dams, thus avoiding the all-to-common practice of mixing results from different biomes. Because most existing dams and measurements are in locations outside of the humid tropics, information from these regions tends to make dams look better than they are likely to be in the tropical areas such as Amazonia where major dam-building plans are concentrated today.

Dams emit carbon dioxide (CO_2), but only part of this emission is a net contribution to global warming because part of the CO_2 emitted is removed from the atmosphere through photosynthesis by plants in the reservoir and its drawdown zone and is merely being returned to the atmosphere in the same form. However, part of the CO_2 comes from nonrenewable sources, such as the trees flooded when the reservoir is initially flooded and from soil carbon—this portion representing a contribution to global warming.

Tropical dams also emit methane (CH_4), which has much more impact on global warming per ton of gas emitted than CO_2. Each ton of methane has a very large effect on global warming relative to CO_2 while it remains in the atmosphere: 595 times more per ton of each gas present in today's atmosphere, including feedbacks (Hartmann *et al* 2013, supplementary material, appendix 2, p 2SM-4; Myhre *et al* 2013, supplementary material, appendix 8, p 8SM-13). However, each ton of CH_4 remains in the atmosphere for only 12.4 years on average (Myhre *et al* 2013, p. 714), or roughly ten times less than an average ton of CO_2. This makes the time horizon (and any valuation given to time through discounting or other means) critical in comparison of dams with fossil fuels (e.g., Fearnside 2012a). Because fossil fuels emit virtually all of their carbon as CO_2, the shorter the time horizon the greater the relative impact attributed to dams. The fact that dams have a large peak of emissions in the initial years after a reservoir is filled, in contrast with the constant emission of CO_2 each year as fossil fuels are burned in a thermoelectric plant, also makes time critical in comparing these energy sources (Fearnside 1997). The International Hydropower Association, an industry group, has long pressed for all calculations being done on a 100-year basis (e.g., Goldenfum 2012).

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) calculates an impact of CH_4 34 times that of CO_2 per ton of gas considering a 100-year time horizon, and 86 times when considering a 20-year time horizon (Myhre *et al* 2013, p. 714). It is the 20-year horizon that is relevant to global efforts to prevent mean global temperature from exceeding either the limit of 2 °C above the pre-industrial average, agreed in Copenhagen in 2009 as the definition of 'dangerous' interference with the climate system or the aspiration for limiting warming to 1.5 °C endorsed in the 2015 Paris agreement (Fearnside 2015a). The de Faria *et al* letter's main conclusions are based on the 100-year time horizon, but, as the authors point out, the impact of dams relative to fossil fuels is much greater if a 20-year horizon is considered. Values calculated for a 20-year horizon show this clearly (table S-23 and figure S-14).

Tropical dams produce methane because the water column in reservoirs is often stratified by temperature, with a thermocline separating cold water at the bottom (the hypolimnion) from the warmer surface water (the epilimnion). Oxygen in the bottom water is quickly exhausted, and decomposition of organic matter must therefore end with formation of CH_4 rather than CO_2. In the case of run-of-river dams where reservoir volume is small and river streamflow is large, the water moves through the main channel of the reservoir at sufficient speed to prevent stratification. However, bays and flooded tributaries can stratify, producing methane (Fearnside 2015b). The de Faria *et al* paper confirms lower emissions in run-of-river dams than in storage dams. While most of the dams in the study are run-of-river, both Brazil's president and the country's top electrical officials have publically defended a shift of priority to storage dams in Amazonia (Borges 2013).

The de Faria *et al* study shows that even the minimum estimated emissions are substantial. They also show that the real total emissions are much higher than these minimum values, but that data are still lacking for reliable quantification of components omitted from the minimum calculations. The authors produce a 'bottom-up' and a 'top-down' calculation for each dam. The bottom-up calculation is based on amounts of carbon calculated to be initially present in the reservoir and subsequently oxidized through different pathways, while the top-down calculation is based on data from existing dams: flux measurements in the reservoirs and downstream emissions calculated from the difference in methane concentration above and below the dams. Use of difference in concentrations to infer degassing from water emerging from the turbines is an important distinction from a series of studies in Brazil financed by hydropower companies, which used floating chambers at a distance downstream of the dams to estimate degassing (e.g., Ometto *et al* 2011), a technique that misses most of these emissions (Fearnside and Pueyo 2012). The top-down 100-year calculation produces a mean result 2.7 times higher than the bottom-up calculation in the case of 'low' residence-time reservoirs such as run-of-river dams and 6.1 times higher in the case of 'high' residence-time reservoirs such as traditional storage dams (based on table S-22). These large differences show the magnitude of the factors that the authors judged to be too poorly quantified to incorporate into their process-based bottom-up calculation.

The bottom-up calculation assumes zero carbon inputs from the sources that are poorly quantified, these factors representing 84% of the emission in the case of reservoirs with high residence times. As the authors point out, the large discrepancy between the results of the bottom-up and top-down calculations means that more research is needed in both data collection and modeling. Of course, omitting uncertain components that are believed to be important in the real-world system makes modeled results less realistic rather than making them more reliable (e.g., Watt 1966). In this case, carbon sources omitted from the bottom-up calculation include methane from renewable sources from organic matter washed into watercourses in the catchment area and the annual flooding of herbaceous vegetation that grows in the reservoir's drawdown zone (e.g., Fearnside 2009). The authors recognize the effect of omissions in making the bottom-up calculations underestimates, and therefore representations of a minimum level of impact from tropical dams. Their finding of significant emissions even at these minimum levels should serve as a warning to decision makers. Brazil is not forced to choose between hydropower and fossil fuel because the country has vast untapped potential for solar and wind generation, in addition to opportunities for energy conservation (Moreira 2012).

The perception of dams as clean is still actively promoted by the hydropower industry and by government energy authorities in countries such as Brazil (e.g., Fearnside 2012b). The letter by de Faria *et al* should help to change this perception.

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