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Please cite as:


ISSN: 1541–1443.

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The original publication is available at:

http://revista.drclas.harvard.edu/files/revista/files/water_0.pdf?m=1442956331

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 (CH₄) rather than carbon dioxide (CO₂), since the layer lacks oxygen to form CO₂.

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.
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 captur­
ing 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 prac­
tical way to avoid underestimating the
turbine emissions is to calculate them by
the difference in the methane concentra­
tion 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 concentra­
tion measurements there is a prob­
lem with traditional sampling devices
(Ruttner bottles) that leads to underesti­
mating 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 prob­
lem, 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 Balhina 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 reli­
able estimates of emissions: each dam is
different, and simple extrapolations based
on such factors as area or installed capac­
ity 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 rais­
ing and lowering of the water level each
year. When the water is drawn down to
power generation 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 bot­
tom of the reservoir where the water is
without oxygen. The carbon in the weeds
has been removed from the atmosphere
in the form of CO₂ by photosynthesis, but
it is returned in the form of CH₄, 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 CO₂ 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
warning impact. Unfortunately, we do
not have that much time to begin doing
something about global warming. Bra­
zil's massive dam-building plans would
be emitting peak emissions exactly in the
time window when global warming needs
be brought under control to avoid grave
consequences, including those that threat­
en the Amazon forest. Brazil's 2011-2020
Energy Expansion Plan calls for building
30 large dams in the country's Legal Ama­
zon region, or one dam every four months.

In addition to emitting gases, tropic­
al 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 finan­
cial bonus from the CDM. The global
total is staggering: 288 million tons of
CO₂-equivalent carbon per year for the
dams in the CDM's "pipeline" as of Janu­
ary 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 sig­
nificant part of the money that the world
has for fighting global warming—money
that could be spent on forms of mitiga­
tion 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 mul­
tiple impacts on global warming. These
impacts are not being properly quanti­
fied and incorporated into decision-mak­
ing in places like Brazilian Amazonia.

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500 award, the Conrad Wessel, Chico
Mendes and Benchimol prizes, the
Scopus prize (from Elsevier & CAPES)
and membership in the Brazilian
Academy of Sciences. In 2006 he was
identified by Thompson- ISI as the
world's second most-cited scientist on
the subject of global warming.