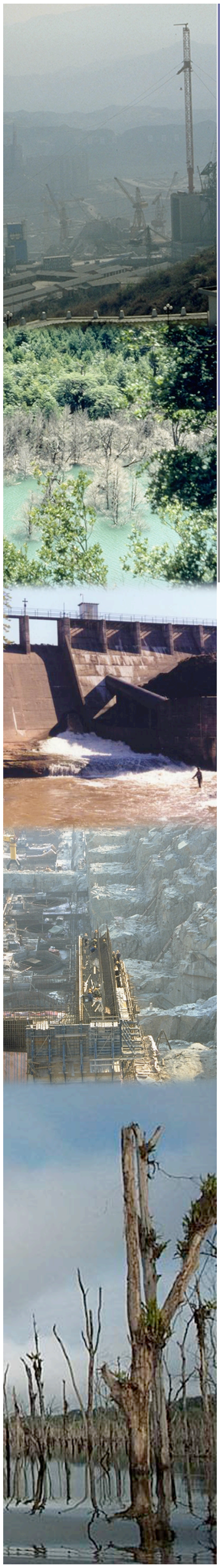

Tropical Hydropower is a Significant Source of Greenhouse Gas Emissions:

A response to the International Hydropower Association

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The International Hydropower Association released a four-page document entitled "Greenhouse Gas Emissions from Reservoirs" at the UN climate convention negotiations in Milan in December 2003. The IHA concludes that hydropower contributes very little to climate change when compared to fossil fuel generating options.

The IHA's assertions are variously irrelevant, incomplete or simply wrong. Although much more research is needed for a complete understanding of this issue, on current evidence the climate impact of reservoir-based hydropower schemes in the tropics is frequently worse than fossil-based alternatives. In colder regions, reservoir emissions are lower than fossil equivalents – although not as low as the IHA claims. Some of the IHA's spurious claims are addressed below.

IHA Claim:

". . . GHG [greenhouse gas] emissions from natural floodplains are similar to those of reservoirs. Considering the huge areas of natural floodplains, we can conclude that 'net' emissions from tropical hydro, with typically sized hydro reservoirs, are significantly lower than those of the best fossil-fuelled options (per TWh)."

The Reality:

All three tropical hydropower reservoirs for which net emissions have been calculated show a higher climate impact than a natural gas combined-cycle plant. Gross emissions (which appear to commonly be less than net emissions) per unit of power generated have been calculated at nine tropical reservoirs. Only four show a climate impact less than an efficient gas plant.

The Evidence:

Wetlands are a significant global source of methane emissions. Emissions per unit area of reservoirs fall within a similar broad range – spanning several orders of magnitude – to naturally flooded land.[1] But if flooded land is a significant source of greenhouse gases, it follows that creating more flooded land by building hydropower dams will only increase GHG emissions.

The IHA implies that reservoirs flood mainly wetlands (the IHA seems to use "floodplains" as if these were synonymous with wetlands) and so do not increase emissions. Yet in order to optimize power generation, hydropower dams are usually built at former rapids rather than in the middle of large swamps. At Tucuruí dam in Brazilian Amazonia, for example, only 1.3% of the reservoir area had been seasonally flooded wetlands.[2]

The IHA stresses the importance of using "net" rather than "gross" emissions from reservoirs when comparing the global warming impact of hydropower with other power technologies. *Gross* emissions has usually meant only those measured at the reservoir surface. A calculation of *net* emissions requires a comprehensive assessment of the dam's impact upon the total flux of GHGs into and out of sources and sinks throughout the relevant watershed. The IHA implies that those who have found high GHG emissions from hydropower have only looked at gross emissions, and that "net" emissions will always be higher than "gross."

The need to assess net emissions, however, is widely agreed by those working on the climate impacts of dams. Moreover, studies of net emissions from tropical reservoirs show these to be higher than gross emissions.

The most comprehensive study of net emissions yet published is for Tucuruí dam in eastern Amazonia by Philip Fearnside of the Brazilian National Institute for Research in the Amazon. The study concludes that in 1990, net emissions of carbon dioxide and methane from Tucuruí had a climate impact equivalent to **32 million tons of carbon dioxide**.[3] This is more than three times the gross emissions at Tucuruí measured by a team

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[1] See *e.g.*, L.P. Rosa *et al*. (2002) "First Brazilian Inventory of Anthropogenic Greenhouse Gas Emissions. Background Reports. Carbon Dioxide and Methane Emissions from Brazilian Hydroelectric Reservoirs," Ministry of Science and Technology, Brasília, Annex B.

[2] Data from Rosa *et al*. (2002), p.29.

[3] P.M. Fearnside (2002) "Greenhouse gas emissions from a hydroelectric reservoir (Brazil's Tucuruí dam) and the energy policy implications," *Water, Air, and Soil Pollution* 133:1. Fearnside gives a range for emissions from Tucuruí in 1990 of 7.0-10.1 x 10^6 t CO_2-equivalent C with a mid-point of 8.6 t CO_2-equivalent C. (To convert CO_2-equivalent C to CO_2-equivalent, multiply by 3.67). This calculation is based on a Global Warming Potential for methane of 21 (the value used in the Kyoto Protocol). This means that each molecule of CH_4 released to the atmosphere is assumed to have a climate impact 21 times that of a molecule of CO_2. The IPCC's Third Assessment Report raised the methane GWP to 23. Other authors have stressed that the use of GWPs is not well-suited to the form of emissions from reservoirs. Philip Raphals of Helios Institute in Montreal has calculated a hydropower-appropriate methane-multiplier of 39.4 (see Raphals (2001) *Restructured Rivers: Hydropower in the Era of Competitive Markets*, Helios Centre/IRN, Montreal/Berkeley).

from the Federal University of Rio de Janeiro headed by Luiz Pinguelli Rosa.[4] A natural-gas combined cycle (NGCC) plant generating the same quantity of power would have had an impact equivalent to **8.1 million tons of carbon dioxide**.[5]

An as yet unpublished study by Fearnside of another hydro dam in the Brazilian Amazon, Curuá-Una, found net emissions in 1990 7.5 times greater than a comparable NGCC.[6] A preliminary calculation of net emissions at the notoriously poorly planned Balbina dam in central Amazonia made by Fearnside in 1995 found these to be an astonishing *58 times* higher than an NGCC (see Table 1).[7]

Fearnside does not consider CO_2 emitted at the reservoir surface as a net emission. Some of the carbon in this CO_2 will have been removed from the atmosphere by the growth of plankton and plants in the reservoir. Much of the rest will be derived from carbon that entered the reservoir from upstream and may have been converted to CO_2 in the river and floodplain had the dam not existed. Fearnside does include as a net emission CO_2 due to the decomposition of the parts of flooded trees that remain above the reservoir surface.[8]

The major climate impact of reservoirs is due to emissions of methane, a much more powerful greenhouse gas than carbon dioxide. Almost all the methane released by reservoirs should be counted as net emissions. As explained by Fearnside:

> ". . . reservoirs become virtual methane factories, with the rise and fall of the water level in the reservoir alternately flooding and submerging large areas of land around the shore; soft green vegetation quickly grows on the exposed mud, only to decompose under anaerobic conditions at the bottom of the reservoir when the water rises again. This converts atmospheric carbon dioxide into methane, with a much higher impact on global warming than the CO_2 that was removed from the atmosphere when the plants grew."[9]

The main pathway for the release of methane in Fearnside's net emission calculations from Tucuruí and Curuá-Una is from water discharged at turbines and spillways. The solubility of a gas increases proportionately to rising pressure – the chemical principle known as Henry's law. Water entering dam turbines and, depending on their design,

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[4] Rosa *et al*. (2002).

[5] Based on generation of 18 TWh and life cycle emission factor of a combined-cycle natural gas plant of 0.45 tCO_2eq/MWh (mid-range of estimates in International Energy Agency Implementing Agreement For Hydropower Technologies And Programmes (2000) "Hydropower and the Environment: Present Context and Guidelines for Future Action, Volume 1: Summary and Recommendations." Tucuruí generation in 1990 was actually lower than 18 TWh which was the generation in 1991. Fearnside (2002) uses the 1991 figure to correlate with data for CH_4 concentrations in the reservoir that are only available from 1991.

[6] Fearnside (forthcoming) "Do Hydroelectric Dams Mitigate Global Warming? The Case of Brazil's Curuá-Una Dam."

[7] P.M. Fearnside (1995) "Hydroelectric Dams in the Brazilian Amazon as Sources of 'Greenhouse' Gases," *Environmental Conservation* 22:1. This calculation did not include degassing emissions at Balbina's spillway and turbines.

[8] Fearnside (2002).

[9] P.M. Fearnside (2004) "Greenhouse gas emissions from hydroelectric dams: Controversies provide a springboard for rethinking a supposedly 'clean' energy source," *Climatic Change* 66.

spillways is under high pressure from the water above and can contain large amounts of dissolved methane. When this water is discharged the pressure instantly drops to atmospheric pressure and the dissolved methane is suddenly released – an effect similar to that of the fizz of carbon dioxide bubbles when a bottle of Coke is opened.[10]

Fearnside's estimates for degassing at Tucuruí's turbines and spillways have been heavily criticized by Luiz Pinguelli Rosa, a former president of Brazilian hydropower utility holding company Eletrobrás. Rosa believes that downstream emissions at Tucuruí are negligible. Rosa criticizes Fearnside in the journal *Climatic Change* for not having directly measured the degassing emissions but rather modeling them from measurements of methane concentrations in the reservoir seasonally adjusted from data on degassing emissions at Petit Saut dam in French Guyana. Fearnside responds that Rosa has misinterpreted the data and points out that Rosa has done no measurements at Turucuí to prove that the degassing is negligible.[11]

Rosa's *Climatic Change* paper is largely based on a "background paper" produced by his research institute in 2002 for the first Brazilian inventory of greenhouse gas emissions as required under the UN climate convention. This inventory background paper is also cited in the IHA's recent paper. It is the most comprehensive study yet done to measure and compare emissions between a number of different tropical hydro plants.

The Executive Summary of the inventory background paper states that "the hydroelectric plants studied in general had lower emissions than equivalent thermoelectric plants." A similar conclusion is made in Rosa *et al.*'s *Climatic Change* paper: "the hydro-power plants studied generally posted lower emissions than their thermo-based counterparts."

A close look at the inventory background report reveals that these conclusions are misleading. The studies by Rosa's team of gross emissions at the surfaces of nine Brazilian reservoirs in a variety of different ecoregions in fact reveal four with emissions higher than equivalent natural gas combined-cycle plants, four with lower emissions than NGCCs and one (Tucuruí) with a similar contribution to global warming (see Table 2, p.6). One Amazonian project, Samuel, has gross emissions more than twice as high as an equivalent coal plant.[12] Had the inventory followed Fearnside's net emissions approach, carbon dioxide emissions would likely be lower, but methane emissions – and overall

[10] Fearnside (2004).
[11] L.P. Rosa *et al*. (2004) "Greenhouse gas emissions from hydroelectric reservoirs in tropical regions," *Climatic Change* 66; Fearnside (2004). Rosa *et al*. recognize a need for future studies to include emissions due to degassing at dam outlets. The IHA has ignored the issue of emissions from turbines and spillways.
[12] Rosa *et al*. (2002), p.70. The text in Rosa *et al*. (2002) is vague about their actual findings on the comparison between the hydropower projects studied and thermal alternatives. Data showing the comparison are given only in one table (Table 48, p.70), and in this table the rows of data on five of the hydro projects are all but blacked out by dark shading making it very difficult to read the numbers. This is the only table in the report to use this dark shading. Rosa *et al*. refer in *Climatic Change* to calculations they published in the mid-1990s which showed that Tucuruí "emitted far less than an equivalent thermo-power plant, even when fueled by natural gas and combined cycle" (p.8). But they fail to state that their 2002 publication concludes that Tucuruí's emissions are roughly equal to a combined-cycle plant.

climate impact – would likely be much higher due to the inclusion of degassing at dam outlets.[13]

This analysis of the work by Rosa's team shows there is no basis for the IHA statement that "net emissions from tropical hydro, with *typically sized* hydro reservoirs, are significantly lower than those of the best fossil-fuelled options" (emphasis added). The four reservoirs for which Rosa *et al*. found higher emissions than gas plants range in size from 312 to 2,430 square kilometers – sizes typical of tropical reservoirs.

The four projects with lower gross emissions than fossil-fuel plants had reservoirs between 51 and 1,549 km^2, again, a typical range of sizes. The key factor determining emissions per unit of power produced is not just reservoir size, however, but the ratio of reservoir size to power production. The Brazilian dams with a better emissions performance than a gas plant tend to have deep, narrow reservoirs that are relatively small in area compared to their generating capacity.[14]

In the first years after reservoir filling, a huge pulse of carbon dioxide and methane is emitted due to the decomposition of flooded vegetation and soils. Once this initial pulse has subsided, emissions seem to vary from year to year with no clearly established pattern of decline over time.[15] Fearnside estimated emissions for 1990 as this is the baseline year for national GHG inventories under the UN climate convention. Tucuruí's reservoir began to fill in September 1984, so much of this initial pulse of net emissions is not included in Fearnside's calculation.

Hydropower's emissions compare especially unfavorably with those from fossil-fuel plants in the early years of dam operation. This is due to the initial pulse of emissions as well as those from construction and related deforestation (*e.g*., from power lines, access roads and reservoir evictees). Fearnside suggests that dam emissions should be subject to a discount rate to account for societal preference for emissions to be delayed into the future. Any weighting of emissions for time preference would strongly favor fossil fuels over hydropower.[16]

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[13] Rosa *et al*. (2004) imply that Fearnside (and IRN) have fallen to "the lures of the thermo-power and nuclear-power lobbies that are trying to blame higher emissions on power dams." This ill-considered accusation only calls into question Rosa's own biases. Rosa's team is funded by and works with a number of Brazilian hydropower interests (See *e.g*., Rosa *et al*. (2002), p.17; Rosa *et al*. (2004). To this author's knowledge the fossil-fuel and nuclear lobbies have not supported or published any research on hydropower emissions.
[14] Rosa *et al*. (2004).
[15] See *e.g*., Rosa *et al*. (2004); E. Duchemin *et al*. (2002) "Hydroelectric reservoirs as an anthropogenic source of greenhouse gases," *World Resource Review* 14:3.
[16] P.M. Fearnside (1995); Fearnside (2002) "Time preference in global warming calculations; A proposal for a unified index," *Ecological Economics* 41:1, pp.21-31.

Table 1. Net emissions from Brazilian Reservoirs compared with Combined Cycle Natural Gas

Dam	Reservoir Area (km^2)	Generating Capacity (MW)	Generation (TWh/yr)	Emissions: Hydro (MtC-CO_2eq./yr)	Emissions: Gas Combined Cycle (MtC-CO_2eq./yr)[4]	Emissions Ratio Hydro/Gas
Tucuruí[1]	2430	4240	18.03	8.60	2.22	3.87
Curuá-Una[2]	72	40	0.19	0.15	0.02	7.50
Balbina[3]	3150	250	0.97	6.91	0.12	57.58

1. Fearnside (2002) "Greenhouse gas emissions from a hydroelectric reservoir (Brazil's Tucuruí dam) and the energy policy implications," *Water, Air, and Soil Pollution* 133:1.
2. Fearnside (forthcoming) "Do Hydroelectric Dams Mitigate Global Warming? The Case of Brazil's Curuá-Una Dam."
3. Fearnside (1995) "Hydroelectric Dams in the Brazilian Amazon as Sources of 'Greenhouse' Gases," *Environmental Conservation* 22:1. The emissions figure for Balbina does not include emissions from degassing at turbines and spillways.
4. Using emission factor for gas combined cycle of 0.123 tC-CO_2eq/MWh (equals 0.45 tCO_2eq/MWh). This gives a lower figure for gas emissions than the factor for a NGCC used by Rosa *et al*. (2002).

Table 2. Gross emissions from Brazilian Reservoirs compared with Combined Cycle Natural Gas

Dam	Reservoir Area (km^2)	Generating Capacity (MW)	Emissions: Hydro (MtC-CO_2eq./yr)	Emissions: Gas Combined Cycle (MtC-CO_2eq./yr)	Emissions Ratio Hydro/Gas
Tucuruí	2430	4240	2.60	2.60	1.00
Samuel	559	216	0.53	0.13	4.04
Xingó	60	3000	0.04	1.84	0.02
Serra da Mesa	1784	1275	0.89	0.78	1.15
Três Marias	1040	396	0.54	0.24	2.23
Miranda	51	390	0.04	0.24	0.16
Barra Bonita	312	141	0.14	0.09	1.59
Itaipú	1549	12600	0.09	7.72	0.01
Segundo	82	1260	0.02	0.77	0.03

All data from Rosa et al. 2002

IHA Claim:

"All reservoirs in all climates sequester large amounts of carbon. They are either "carbon-neutral" or "carbon sinks."

The Reality:

While reservoirs do sequester carbon there is no scientific basis for the claim that reservoirs are either "carbon-neutral" or "carbon sinks" at the watershed level. A quantification of the net impact of reservoirs upon the watershed carbon cycle is much more complex than the IHA suggests and has not yet been attempted.

The Evidence:

The IHA's claim that reservoirs sequester large amount of carbon is based on research by Walter Dean and Eville Gorham of the US Geological Survey. Dean and Gorham estimate that the sediments trapped in reservoirs worldwide each year contain 160 million tons of organic carbon.[17] This equals around 2.5% of annual global emissions from fossil fuels and cement manufacture.

Dean and Gorham's estimate, however, does not mean that reservoirs have a net impact of removing 160 million tons of carbon from the carbon cycle each year. Calculating the net impact would require taking account of numerous factors including:

- The amount of carbon trapped in reservoirs which is converted into CO_2 and CH_4 and released to the atmosphere.

- The impact upon the marine carbon sink of trapping sediments and nutrients in reservoirs, and altering the timing and quantity of freshwater flows into the oceans.

  Oceans play a vital role in slowing down global warming by absorbing almost a quarter of the carbon dioxide released due to industrial activities. While no attempt has yet been made to quantify the impact of dams upon this sink the impact may well be significant when measured against the scale of carbon sequestration in reservoirs.

  A proportion of the carbon buried in reservoirs would otherwise have been buried downstream, especially in deltas and off-shore areas. A global average of almost 20% of land-based carbon flowing to the sea from rivers may be buried off-shore.[18]

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[17] W.E. Dean and E. Gorham (1998) "Magnitude and significance of carbon burial in lakes, reservoirs, and peatlands," *Geology* 26:6.
[18] P. Parekh (2004), "A Preliminary Analysis of the Impact of Dam Reservoirs on Carbon Cycling," prepared for International Rivers Network.

A major pathway for oceanic uptake of atmospheric CO_2 is the "marine biological pump." Through this process, CO_2 is absorbed by plankton through photosynthesis and then transported to deep waters and the ocean floor. Reservoirs trap silicates that would otherwise have reached the ocean and provided an essential nutrient for diatoms, a type of plankton that plays an important role in the biological pump.

Payal Parekh, an oceanologist at the Massachusetts Institute of Technology, estimates that a total shut-off of the biological pump in coastal waters could increase the atmospheric concentration of CO_2 by 40-60 parts per million (by comparison the increase in atmospheric concentration of CO_2 since pre-industrial times is around 87 ppm).[19] While reservoirs do not threaten to close down the coastal biological pump, these figures do indicate the potentially serious climatic impact of a reduction of the pump's effectiveness.

- The impact upon organic carbon in reservoir sediments of dam decommissioning and any measures that may be taken to counter sedimentation such as reservoir dredging or flushing.

It is noteworthy that the IHA is now portraying reservoir sedimentation as a positive consequence of dam-building. Dam promoters usually play down the impact of sedimentation upon reservoirs and criticize those who argue that reservoir sedimentation means that hydropower projects are often non-renewable.

IHA Claim:

For northern reservoirs, "gross emission factors (that overstate true emissions) do not exceed 40 kt CO_2e (carbon dioxide equivalent)/TWh."

The Reality:

A 2002 article in the journal *World Resource Review* by a team led by Éric Duchemin of the University of Quebec shows the upper limit of gross emissions from Churchill Falls hydro scheme in Canada to be 70 kt CO_2e/TWh.[20]

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[19] Parekh (2004).
[20] Duchemin *et al*. (2002).