Seminário - EPE

S. Carlos, Fevereiro de 2010

Emissões de Gases do Efeito Estufa por Reservatórios de Hidrelétricas e Comparação com Termelétricas

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Introduction

There is a debate not only at academic level but also involving public opinion around the World → GHG fluxes from hydroelectric facilities are higher than those from thermal power plants?

The recent debate on GHG from hydroelectric reservoirs has been concentrated on tropical reservoirs CH_4 emissions.

It has been argued that the tropical reservoirs have low frequency of measurements compared with reservoirs in boreal and temperate regions.

Those affirmatives are not completely true. We will show here that if take into consideration the published data in peer review publications this situation is different.

Survey of hydroelectricity in Brazil and in the World

From: João Lizardo de Araujo (CEPEL), Luiz Pinguelli Rosa and Neilton Fidelis (COPPE) (2009)

Table 1 – Top ten countries with largest water resources

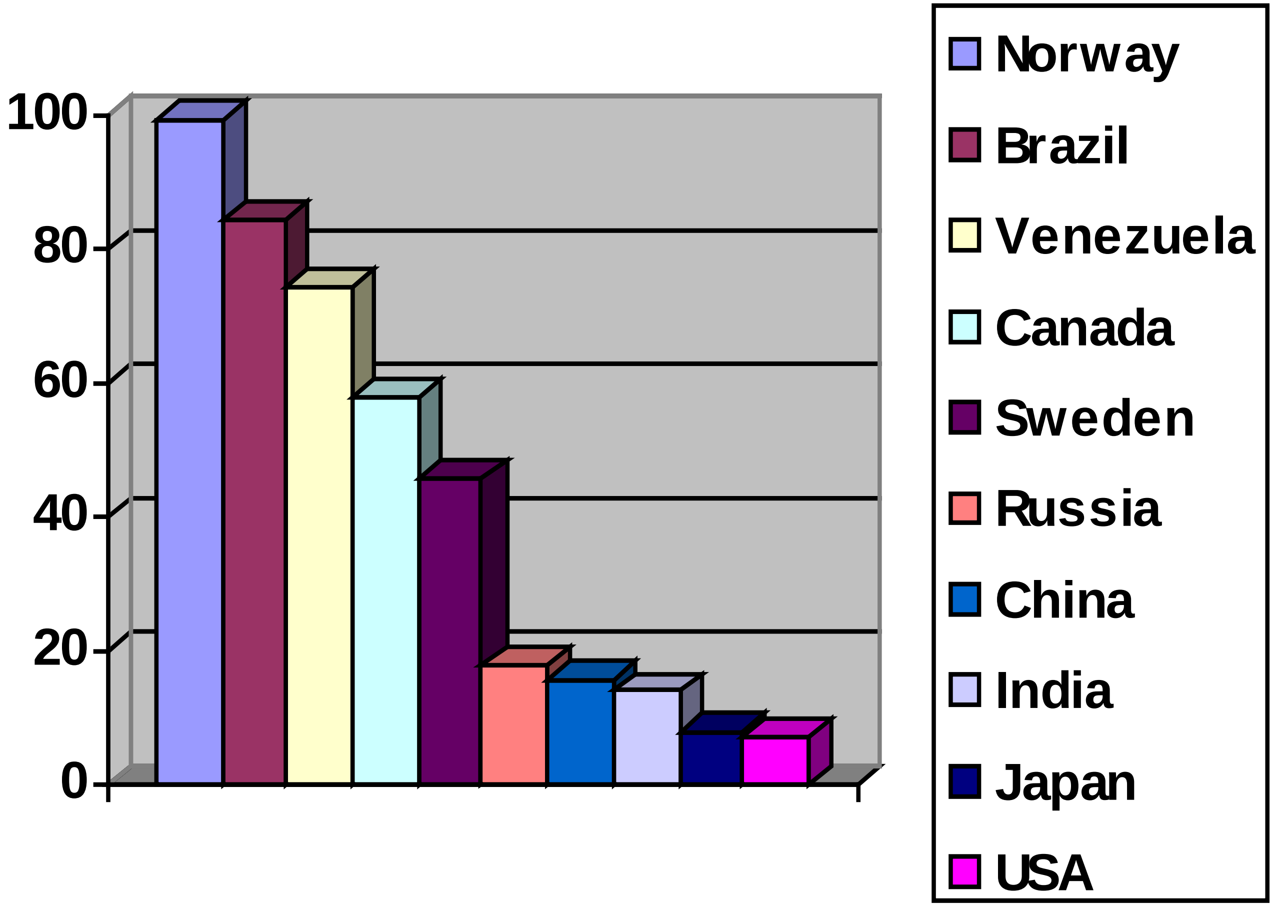
	Thousands Km^3/year	M^3/year/inhabitant*
Brazil	8.2	48.3
Russia	4.5	30.9
Canada	2.9	94.3
Indonesia	2.8	13.3
China	2.8	2.2
USA	2.0	7.4
Peru	1.9	74.5
India	1.9	1.8
Congo	1.3	25.1
Venezuela	1.2	51.0

Source: D'Áraujo 2008; FAO 2003; *per capita data is for 2001

Countries with higher hydro capacity 2005 data

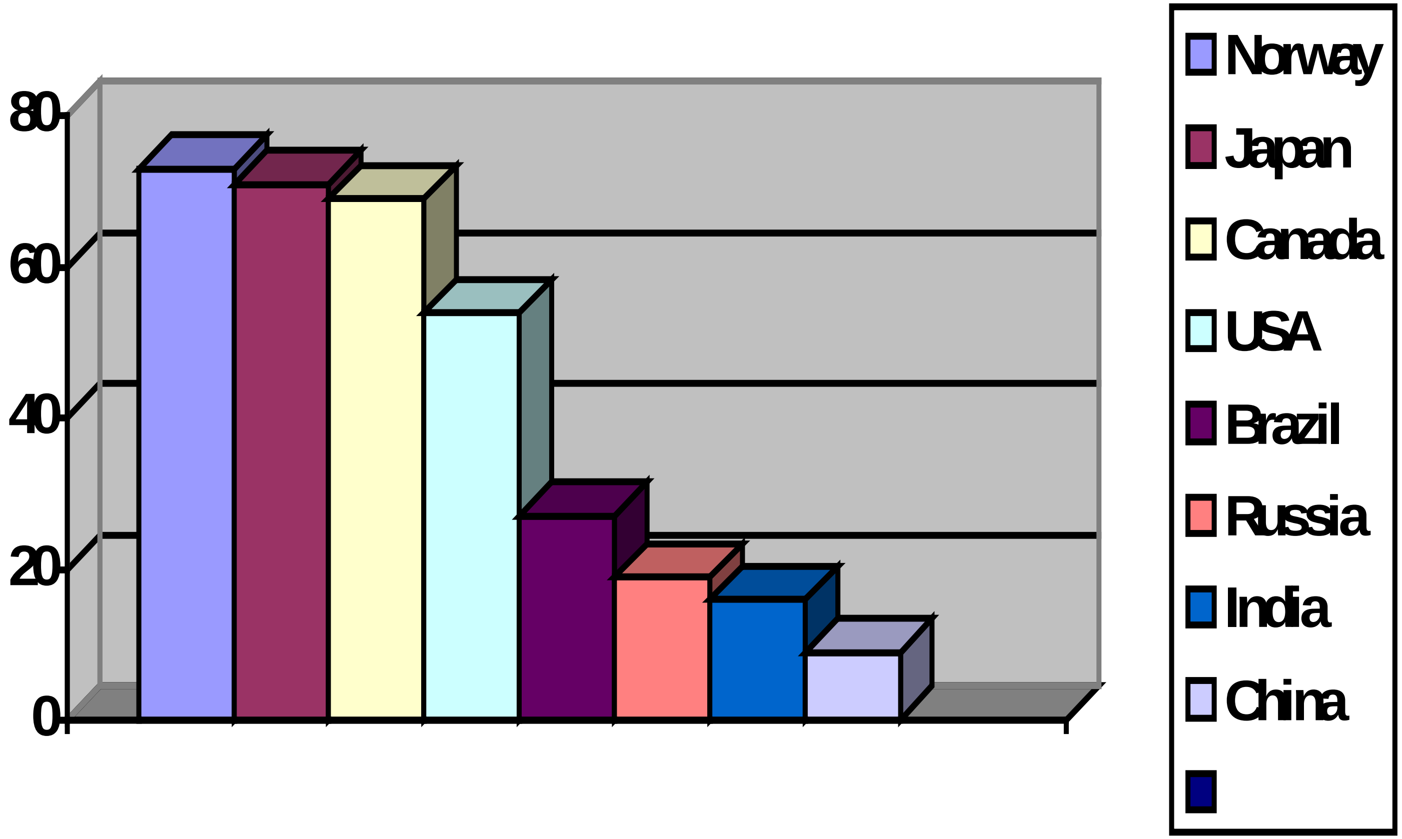
	Installed Capacity (MW)
China	100.000
USA	77.354
Canada	71.978
Brazil	71.060

countries with the highest percentage of hydropower in their electricity generation (%)



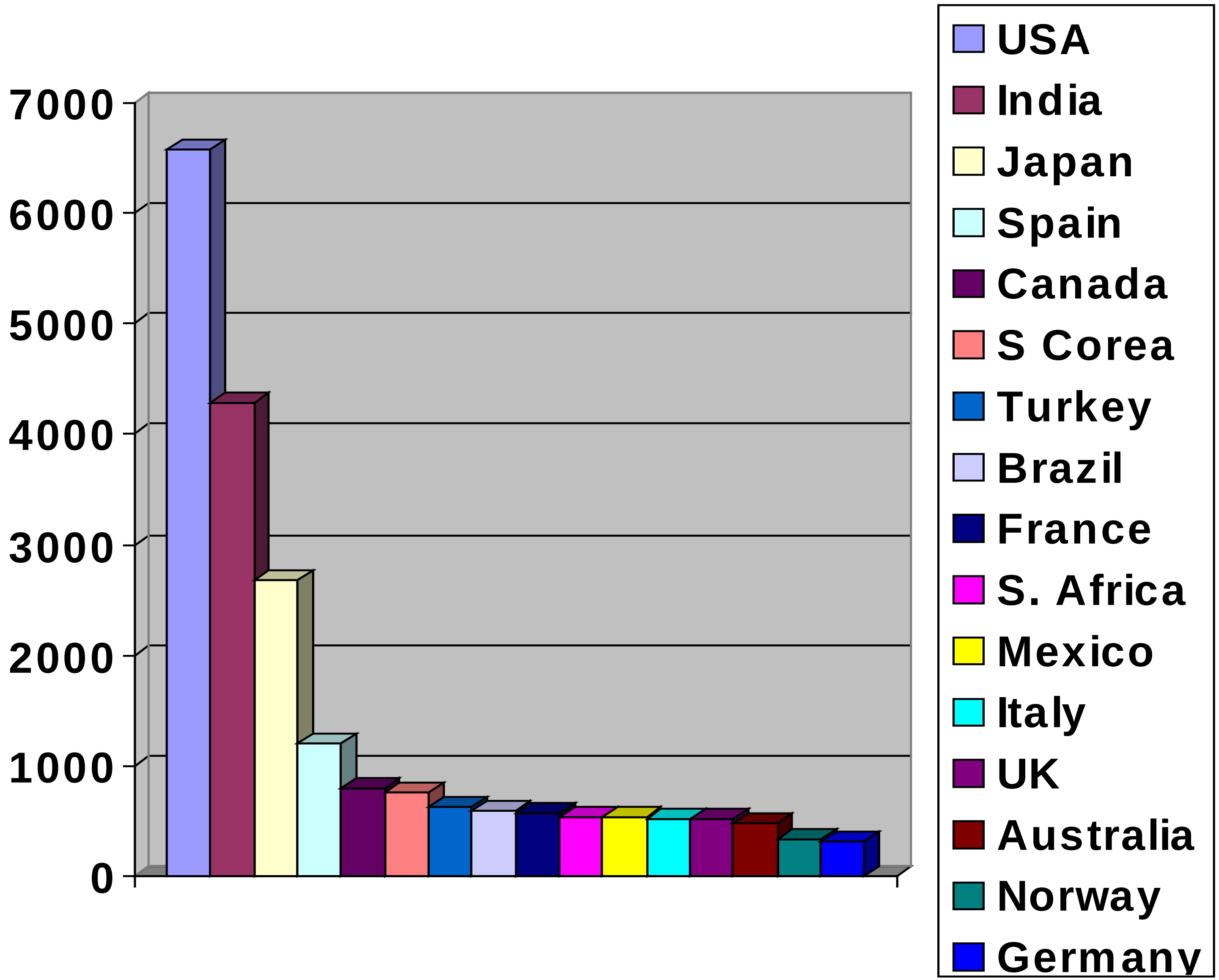
Source: IEA, 2006

Percentage of economic hydropower potential that is currently utilized in selected countries



Source: WEC 2007; BEN 2007 for Brazil estimate

Countries with large number of big dams



Source: WCD 2000, excluding China, which has over 22,000 dams nearly 47,600 large dams have been constructed globally, roughly half of them primarily or exclusively for irrigation purposes

- Number of large dams, average areas and volumes of reservoirs

	World	Europe	Asia	North America	South America	Africa	Austral Asia
Number	47655	5480	31340	8010	979	1269	577
Area (km^2)	23	7	44	13	30	43	17
Vol. (km^3)	269	70	268	998	101	883	205

Source:

Former Studies on Tropical Reservoirs by COPPE:

Focus on CH4 emission from decomposition of already existing biomass in flooded area

Data on CH4 concentration in the reservoirs of Balbina and Samuel

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Former Conclusions on Emissions from Tropical Reservoir

- Correlation with reservoir age is not enough to explain emissions
- Not all biomass already existing in the flooded area is decomposed
- Not all emissions come from decomposition of biomass already existing in the flooded area

Experimental measurements of CH_4 and CO_2 emissions from water surface of

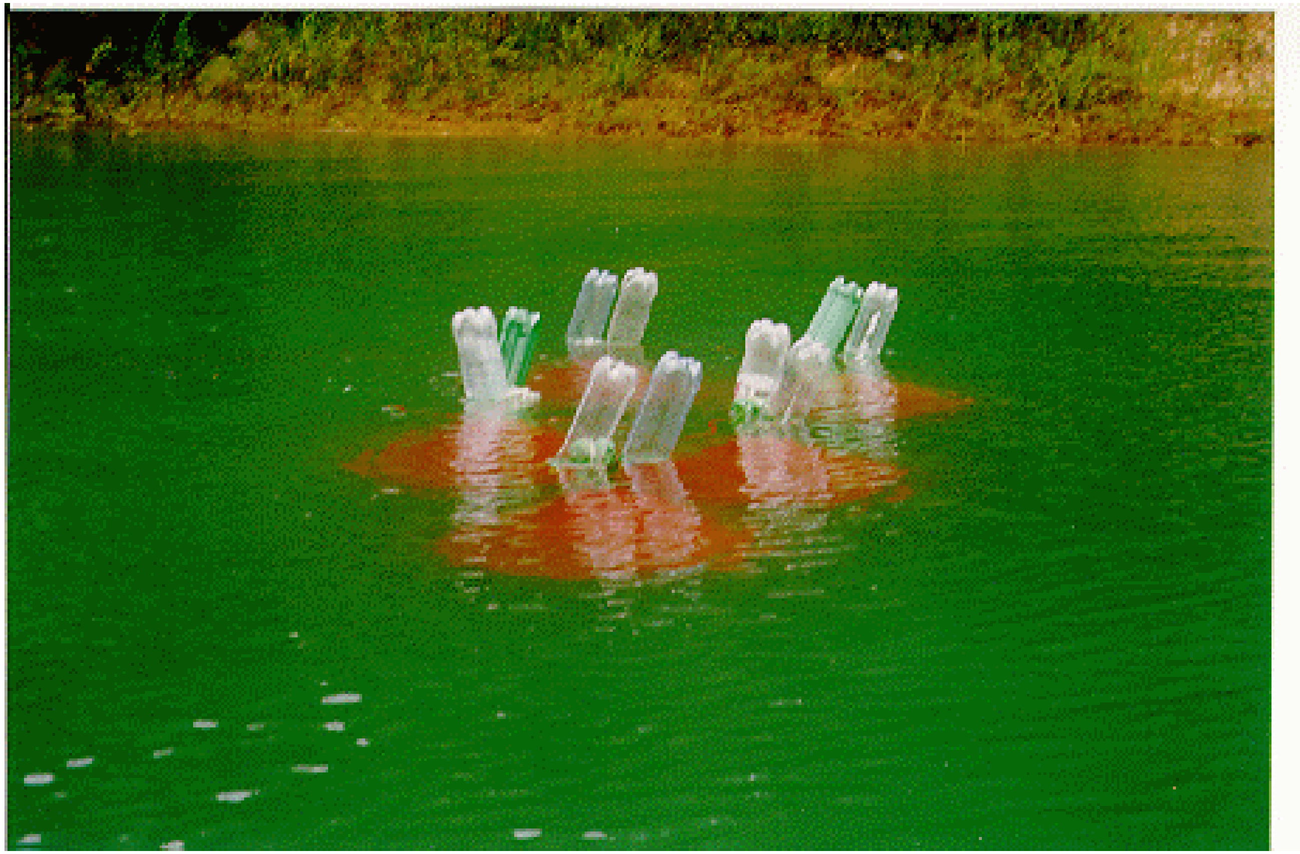
several reservoirs

of

Eletrobrás / Furnas, Eletronorte, Chesf

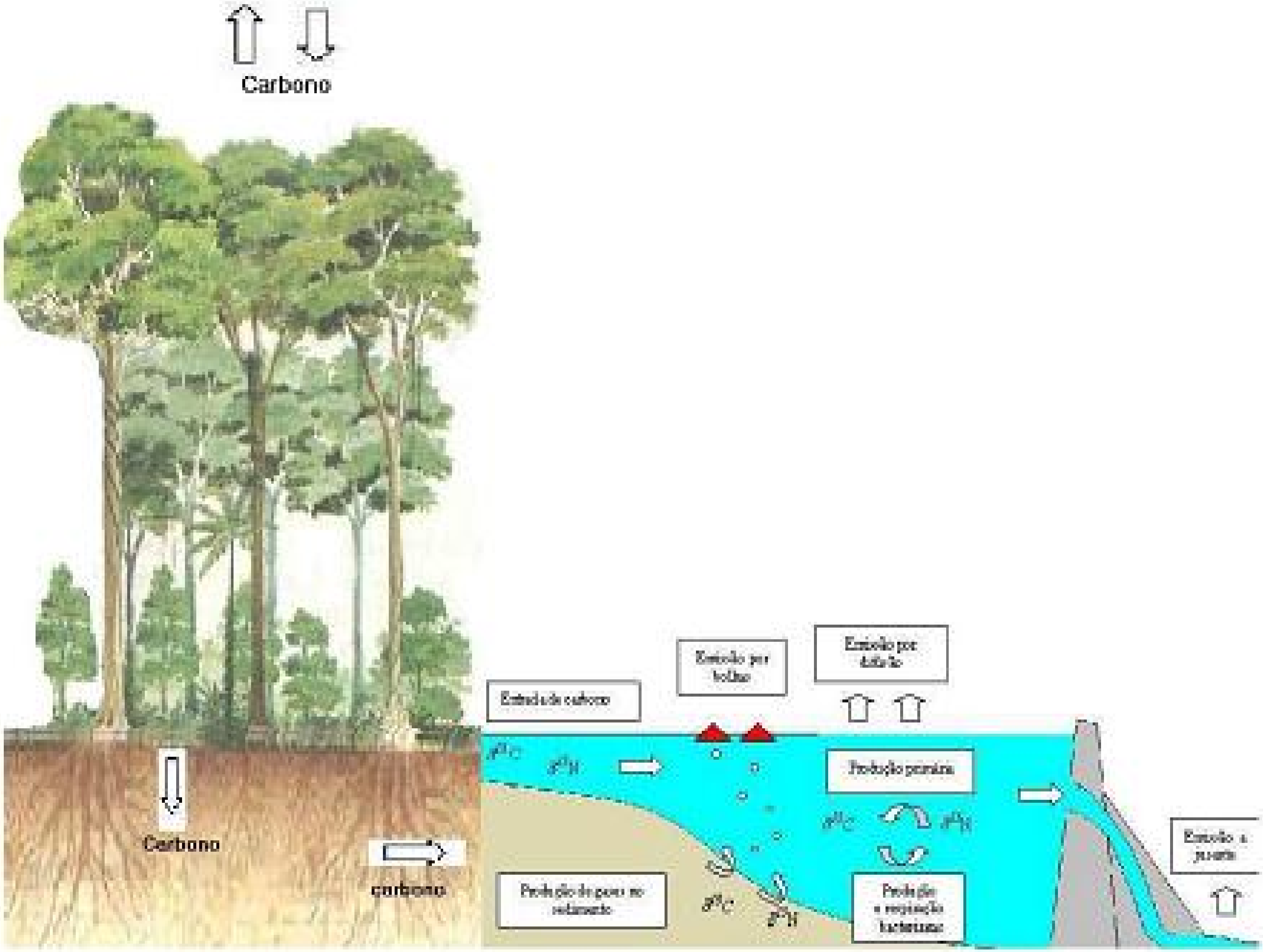
and Itaipu

COPPE / UFRJ



Group of Collecting Funnels Placed in a Shallow Region

Emissions from Reservoirs: Instituto Virtual (IVIG) - COPPE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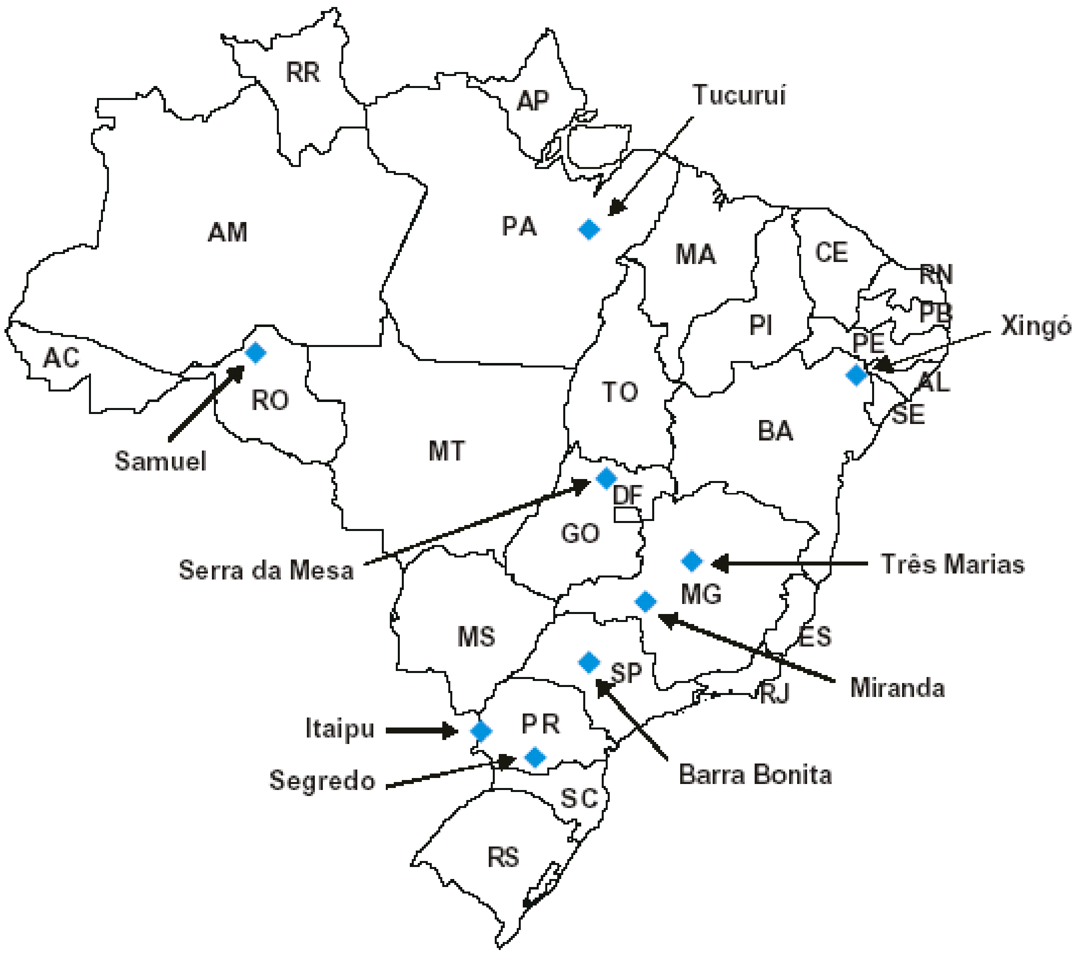
Hidrelétricas Estudadas – COPPE / IVIG – USP/ S. Carlos



Preliminary Conclusions

Very high variability
- in space
- in time

Problems of data extrapolation
- from a point to other in the reservoir
- from a reservoir to other
  - Power law – complex system
  - Correlation with latitude
  - Age of reservoir
  - Biomass in the flooded area
  - Importance of power density (W/m2)
    - Balbina < 0.1 W/m2 ; Itaipu – 10 W/m2

State of the Knowledge

Emission of CH_4 from hydroelectric reservoirs is always unfavorable to reservoirs.

Emissions of CO_2 can be attributed in part to the natural carbon cycle between the atmosphere and the water of the reservoir

.

There are three processes of GHG emissions:

- diffusive emissions,
- bubble emissions
- degassing and down stream emissions.

However, most measured emissions in the World are of diffusive emissions only.

In the case of tropical reservoirs of Brazil there are measurement of bubble emissions and some initial studies on degassing.

Table 1 from IPCC gives the results on CH_4 measured emissions from flooded land in the World through diffusive emission only .

Table 1

CH4 Measured Emissions from Flooded Land

Diffusive Emission - kg CH4 / ha / day

Climate	Median	Minimum	Maximum
Polar/boreal (1)	0.086	0.011	0.3
Cold temperate (2)	0.061	0.001	0.2
Warm temperate moist (3)	0.150	-	1.1
Warm temperate dry (4)	0.044	0.032	0.09
Tropical, wet (5)	0.630	0.067	1.3
Tropical, dry (6)	0.295	0.070	1.1

Source: IPCC, 2006

As it is possible to see in Table 1:

Reservoirs that have lower CH_4 emissions:

- Polar / Boreal (1),
- Cold Temperate (2)
- Warm Temperate dry (4)

Reservoirs have higher CH_4 emissions

- Warm Temperate moist (3),
- Tropical wet (5)
- Tropical dry (6)

The results in Table 1 were taken by IPCC Working Group (IPCC, 2006) from the references:

(1) Blais 2005; Duchemin, 2000 ; Huttunen et al., 2002; Lambert, 2002; Tremblay et al. 2005; Therrien, 2004; Therrien, 2005;

(2) Blais, 2005; Duchemin et al., 1999 ; Lambert, 2002; Tremblay et al., 2005; Therrien, 2004;

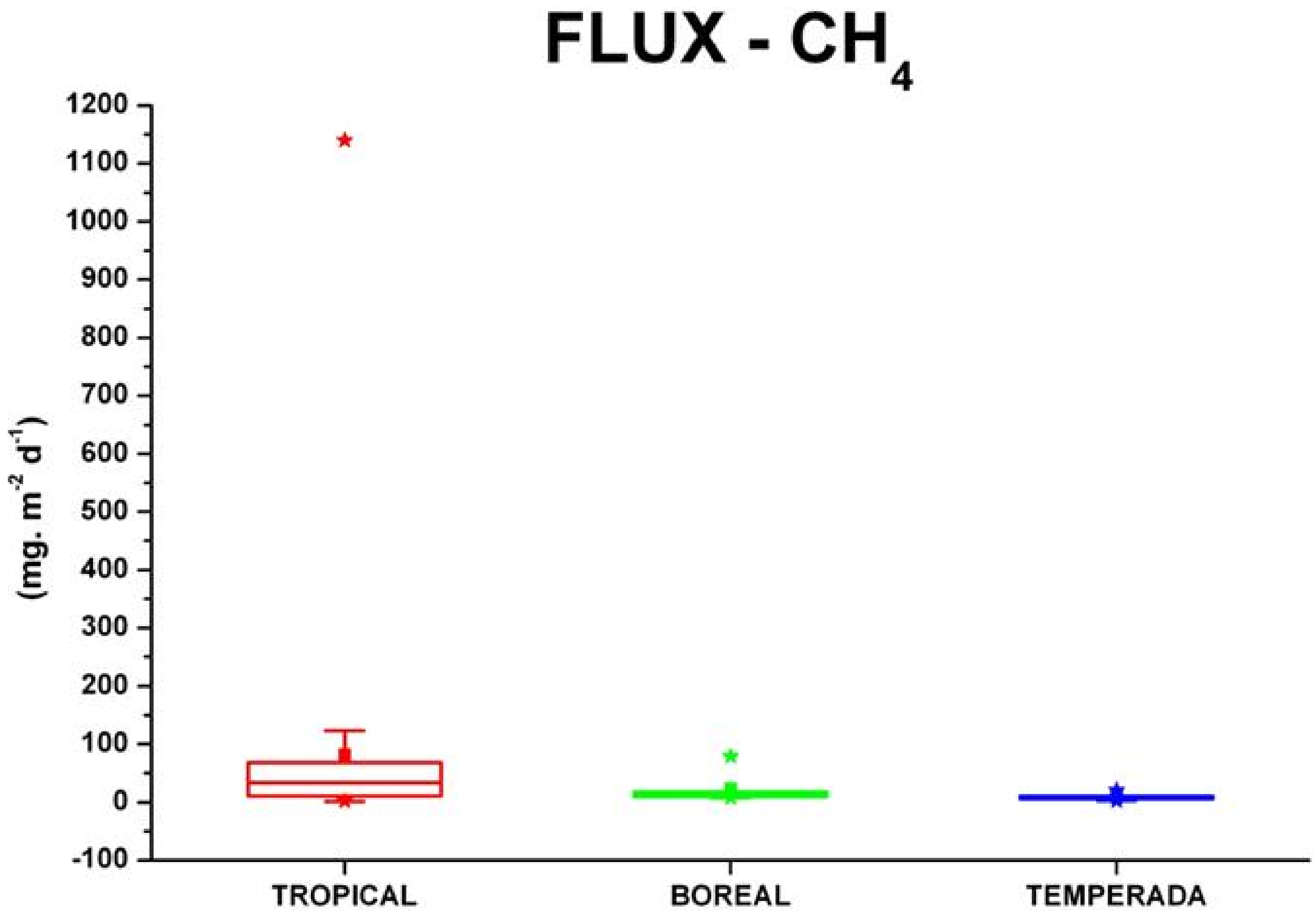
(3) Duchemin, 2000; Soumis et al., 2004; Smith and Lewis, 1992; Tremblay et al., 2005 ;

(4) Soumis et al., 2004 ; Therrien et al., 2005; Therrien, 2004;

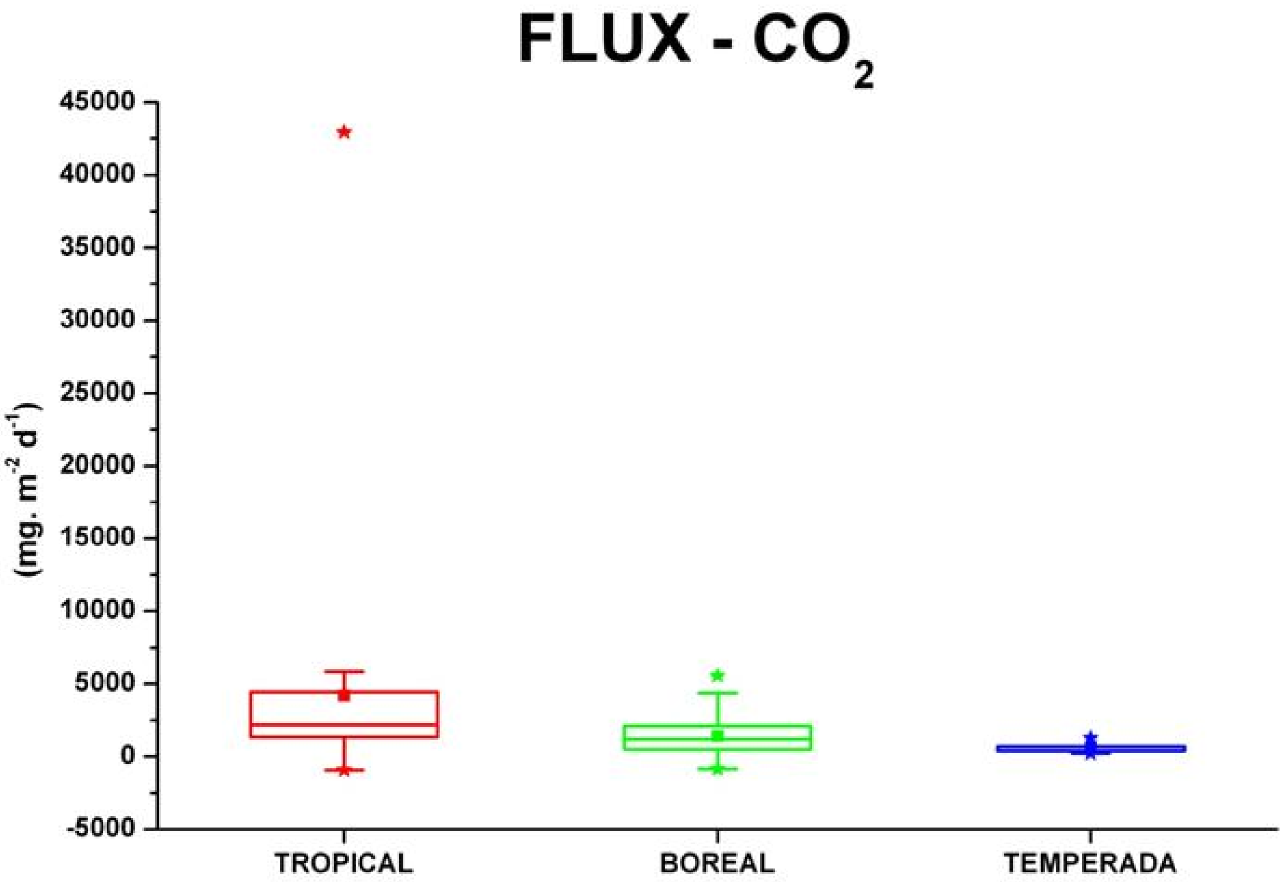
(5) Abril et al., 2005; Duchemin et al., 2000; Galy-Lacaux , 1997; Galy- Lacaux, 1996; Keller, 994 ; Rosa et al., 2002; Therrien, 2004; Lima et al., 2002;

(6) Rosa et al., 2002; Santos, 2000.

- Mean Values of CH_4 Fluxes of Hydro for Different Biomes Around the World (gross emissions without degassing figures)



- Mean Values of CO2 Fluxes of Hydro for Different Biomes Around the World (gross emissions)



Discussion of Data from Tropical Reservoir

- Tropical reservoirs emissions are considered in the case of Brazil

- There are significant data on diffusive and bubble emissions and some preliminary results on degassing.

- Besides the results shown in next table there are new ones from Eletronorte and Furnas (which will be shown by André Cimbleris in another presentation today)

Table 2 – CO2 and CH4 Emissions of 9 reservoirs in Brazil - Diffusive plus bubble emissions

Reservoir	Latitude South	Kind of Biomass	CO2 Kg/km2/d	CH4 Kg/km2/d
Tucuruı´	03˚45’	Rain Forest	8,475	109.4
Samuel	08˚45’	Rain Forest	7,448	104.0
Xingo´	09˚37’	Savanna	6,138	40.1
S.Mesa	13˚50’	Savanna	3,973	51.1
T.Marias	18˚13’	Savanna	1,117	196.3
Miranda	18˚55’	Savanna	4,388	154.2
B.Bonita	22˚31’	Atlantic forest	3,985	20.9
Itaipu	25˚26’	Atlantic forest	171	20.8
Segredo	25˚47’	Atlantic forest	2,695	8.8

Source: Dos Santos et al, 2006

Not included in above results:

Degassing of CH_4 + downstream emission

Net CO_2 emission + carbon balance

Degassing + downstram emission

Observed in measurements by **Galy-Lacaux in Petit Saut - French Guyana**

Now under study in Brazil

The new result is the downstream methane emission below the dam, after the water passes through the turbines.

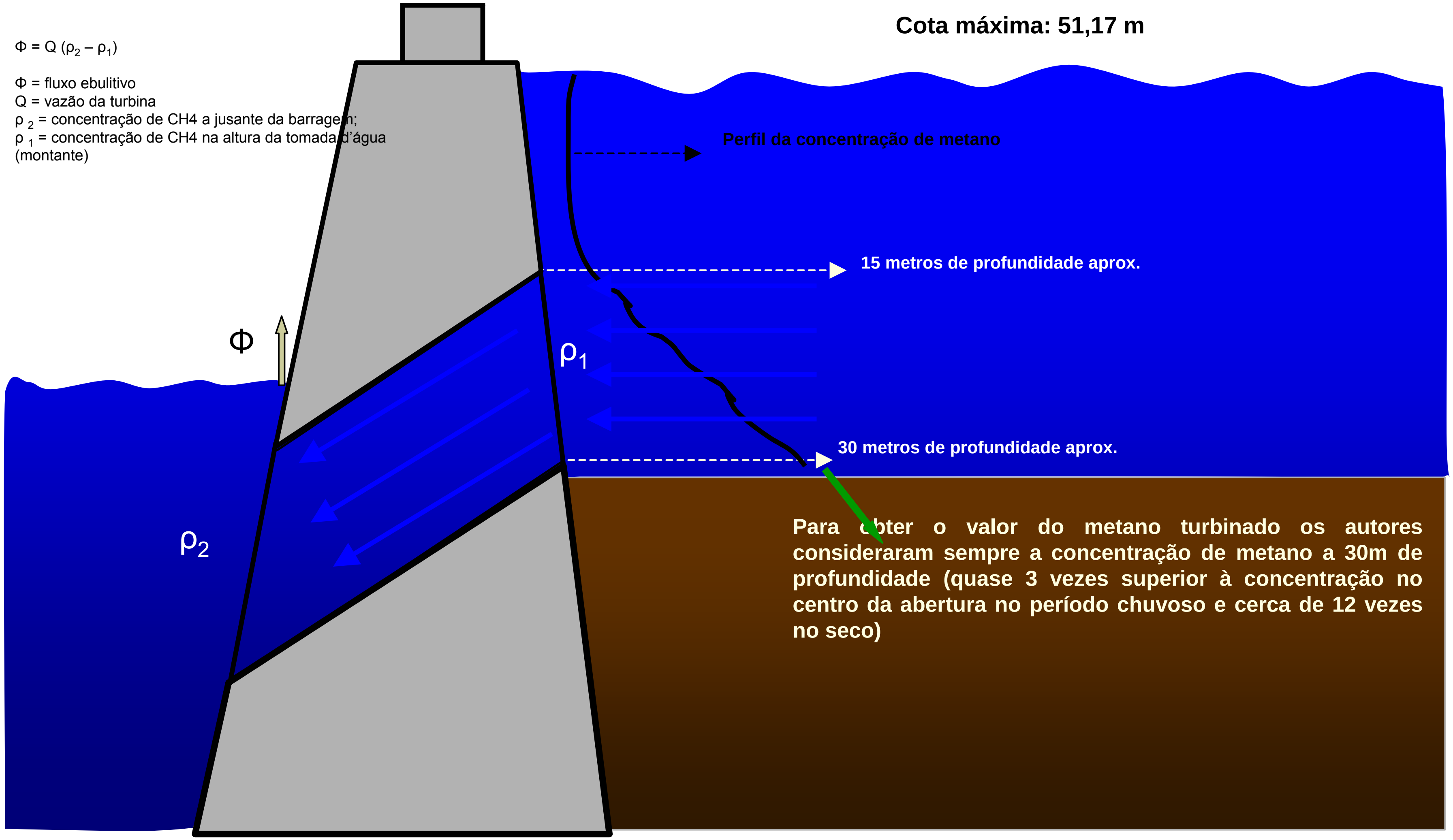
Kemenes et al (2007) estimate the downstream methane emissions after the dam (flux from the turbines and from the river after the dam) of Balbina reservoir, as D=39,000t/y of carbon a year (34,000t/y and 5,000t/y respectively).

This result has the same order of magnitude of the emission from the water surface of the reservoir (S=34,000t/y).

Degassing

$\Phi = Q\,(\rho_2 - \rho_1)$

Φ = fluxo ebulitivo
Q = vazão da turbina
ρ_2 = concentração de CH_4 a jusante da barragem;
ρ_1 = concentração de CH_4 na altura da tomada d'água (montante)



The degassing measured in Balbina has the same order of magnitude of the emission from the water surface of the reservoir (S=34,000t/y).

So, including downstream methane emission D total emission T is two times the emission from water surface S, that is:

$$T = S + D = 2S \text{ approximately.}$$

So, for comparison with thermal power emissions we consider a lower limit (S) and an upper limit 2S, to include degassing in tropical reservoirs located in rain forest and savanna regions in Brasil, as we show in next slides.

S (measured) < Total Emission < 2S (surface flux + degassing)

Comparison with Thermal Power Plants

REFERENCES ON THE PROBLEM OF GWP

LUIZ PINGUELLLI ROSA AND ROBERTO SCHAEFFER **Global Warming Potentials. The Case of Emissions from Dams;**
Energy Policy, Vol. 23, nº 2, p. 149-158, 1995.

JAN FUGLESTVEDT, TERJE BERNTSEN, ODD GODAL, ROBERT SAUSEN, KEITH SHINE and TORA SKODVIN, **Metrics of climate change: assessing radiative forcing and emission indices;**
Climatic Change 58**:** 267–331, 2003

KEITH SHINE, JAN S. FUGLESTVEDT, KINFE HAILEMARIAM and NICOLA STUBER, **Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases;** Climatic Change 68: 281–302, 2005

IPCC, Forth Assessment Report, 2007
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HOWEVER WE HAVE USED CONVENTIONAL GWP IN OUR CALCULATIONS!

Relationship between Thermal Power Emissions (β) and Hydro Power Emissions (χ) → Next Table

INDEX → *IH* $= \beta / \chi$

- IH > 1 → emissions per MWh from thermal power is higher than those from the hydroelectric reservoir.
- IH < 1 → emissions per MWh from thermal power is lower than those from the hydroelectric reservoir.

Table 3 – Comparison with GHG Emissions from Thermoelectric Plants
Emissions from Natural Gas Power Plant / Emissions from Hydro Plant

Dam	Hydro plant characteristics: Power (1) MW	Área (2) Km2	Power Density (3) W/m2	CH4 Emission from reservoir surface: C-CH4 (4) t/ year	C- CO2 Equival. (5) t / MWh	Index of Emission Thermo divided by Hydro: Natural Gas Simple Cycle (6)	Nat. Gas Combined Cycle (7)
Balbina	250	2824	0.09	25500	0.1769	0.6 – 1.2	0.3 – 0.7
Tucuruı´	8000	2430	1.74	72774	0.0158	7.4 – 14.8	4.5 – 8.9
Samuel	216	559	0.39	15914	0.1278	0.9 – 1.8	0.5 – 1.0
Xingo´	3000	60	50.0	659	0.0004	287.5 –572.1	160.0- 319.5
S. Mesa	1275	1784	0.70	24906	0.0338	3.4 –6.8	1.9 – 3.8
T. Marias	396	1040	0.38	55886	0.2448	0.5 – 1.0	0.3 - 0.6
Miranda	390	50	7.71	2136	0.0095	12.9 – 25.7	7.7 – 15.4
B. Bonita	140	312	0.45	1785	0.0100	27.0	16.2
Itaipu	14000	1549	8.13	8820	0.0019	142.0	84.0
Segredo	1260	82	15.37	197	0.0003	899.0	592.0
Total of 10 plants	28537	10690	2.66	208 687	0.0127	9.2 - 18.3	5.5 – 11.0

(5) = (4) multiplied by GWP of C in CH4 divided by {power (1) x capacity factor x 8760 h}

(6) and (7) upper limits → only reservoir surface emissions

lower limits include downstream emissions

Conclusion 1

Among the 10 reservoirs studied,

Table 3 indicates that 7 of them, (97% of total installed capacity in the Table), have GHG emissions per MWh lower than those from natural gas power plants (IH > 1).

Conclusion 2

The best results are of Segredo, Xingó and Itaipu - whose emissions per MWh can be more than 100 times lower (IH > 100) than that from natural gas power plant; the three hydro-plants have high power density (more than 8 W/m2).

Conclusion 3

Three hydro-power plants (Balbina, Samuel and Três Marias) can have emissions per MWh higher than those of natural gas fuelled power plants (IH < 1); the three have very low power density (less than 0.4 W/m2) and they totalize only 3% of total installed capacity.

Conclusion 4

Two reservoirs located in rain forest region (Balbina and Samuel) have high emissions, but Tucurui emission per MWh is at least 4.5 lower than a natural gas fuelled power plant (IH > 4.5) even including downstream emission in our approximation), Its density power is 1.74 W/m2.

New Data

1 - Furnas reservoirs

Including Carbon balance in reservoirs

2 - Balbina and Tucurui reservoirs

Including degassing → measurement inside the water intake