SCIENTIFIC ERRORS IN THE FEARNSIDE COMMENTS ON GREENHOUSE GAS EMISSIONS (GHG) FROM HYDROELECTRIC DAMS AND RESPONSE TO HIS POLITICAL CLAIMING

LUIZ PINGUELLI ROSA[1], MARCO AURÉLIO DOS SANTOS[2], BOHDAN MATVIENKO[3], ELIZABETH SIKAR[4] and EDNALDO OLIVEIRA DOS SANTOS[5]

[1]*Tenured Professor, Energy Planning Program, Graduate Engineering Programs Coordination Unit, Rio de Janeiro Federal University (PPE/COPPE/UFRJ)*
E-mail: lpr@adc.coppe.ufrj.br

[2]*Contributing Professor, Energy Planning Program, Graduate Engineering Programs Coordination Unit, Rio de Janeiro Federal University (PPE/COPPE/UFRJ)*
E-mail: aurélio@ppe.ufrj.br

[3]*Assistant Professor, Water Resources and Applied Ecology Center, São Paulo University (CRHEA/USP/SC)*
E-mail: bohdan@linkway.com.br

[4]*Construmaq São Carlos*
E-mail: elizabeth@linkway.com.br

[5]*Doctoral Student, Atmospheric Sciences, Graduate Engineering Programs Coordination Unit, Rio de Janeiro Federal University (COPPE/UFRJ)*
E-mail: eos@ivig.coppe.ufrj.br

In the September 2004 edition of Climatic Change (N°66), an editorial comment was published by Philip Fearnside, jointly with an article written by ourselves (Rosa et al., 2004) reporting on a broad-ranging project through which we measured CO_2 and CH_4 emissions at eleven Brazilian hydroelectric dams, from Itaipu, with the largest installed capacity in Southern Brazil, northwards to Tucuruí in Amazonia.

This comment reflects a long-standing controversy over the estimates presented by Fearnside and the experimental results that we have obtained so far on greenhouse gases emissions by hydroelectric dams in Brazil (Rosa et al., 1996; Fearnside, 1996).

The key issue in this latest comment by Fearnside is based on the fact that the water intake for the Tucuruí hydroelectric dam turbines is located at an average depth of 35 m, with a high methane concentration at a pressure of around three atmospheres[1] and an estimated temperature of 15 °C. This water pressure is suddenly eased after running through the turbines to the tailrace, flowing downstream from the hydroelectric dam, while it is drawn into the spillway at a depth of no more than twenty meters, far shallower than the water intake point for the turbines.

The author of these comments uses the data published by us (Rosa et al., 1997) on the methane concentration measured by Tundisi[2], who worked in cooperation with our research group. Fearnside commits a series of errors: he is confused about the transformation of units to express the Henry's constant, obtaining a value that is completely wrong; he errs when calculating the methane concentration in the water

Climatic Change (2006)
DOI: 10.1007/s10584-005-9046-6

downstream from Tucuruí; he errs when describing the trivial fact that the carbon dioxide in Coca-Cola escapes when opening the bottle; he takes a measurement that we published – taken in a limited area of the Tucuruí hydroelectric reservoir during a specific period of time – and extrapolates it quite groundlessly whatsoever to cover the entire hydroelectric reservoir all the time; in this specific case, he makes improper use of the Global Warming Potential (GWP) of Lashof and Ahuja adopted by the Intergovernmental Panel on Climate Change (IPCC) for very general emission comparisons; with his hypotheses, he reaches a methane emission rate in terms of carbon equivalent in the form of CO_2 that is 1900% higher than the figure we found through different hypothesis presented here.

The Fearnside comments open with an initial mistake that becomes clear further on in his text. He states the obvious: when a bottle of Coca-Cola is opened, bubbles are released that consist of CO_2^- the most important greenhouse gas – which is dissolved in this carbonated soft drink. He explains this fact through Henry's Law, which states that the solubility of a gas in a liquid is proportional to the partial pressure of the same gas on its surface. By easing the pressure through opening the bottle, the solubility drops and the gas escapes. Fearnside draws a parallel with the tailrace below a hydroelectric dam. He calculates the concentration of methane dissolved in the water that would be in balance with the atmospheric methane. He is mistaken with regard to the partial methane pressure in the atmosphere, but this mistake is irrelevant.

The methane concentration in equilibrium in the water calculated by Fearnside using the Henry formula (0.035 mg/L) is wrong. The equilibrium concentration that we calculated using the correct value for the Henry's constant is completely different. However, as we will show, the correct value of the equilibrium concentration is far lower than that of Fearnside calculation and than the methane concentration in the turbine water intake, according Fearnside assumption of 7.5 mg/L, based on the Tundisi measurements in 1989 that we published (Rosa et al., 1997) and that he extrapolates. To reach this concentration as uniform in the reservoir and constant for many years, a very arbitrary approximation was drawn up in the editorial comment. Under way almost without interruption since 1992, our research project has been demonstrating the marked variability of the data collected at different times at specific sampling points, as well as different reservoir sampling points.

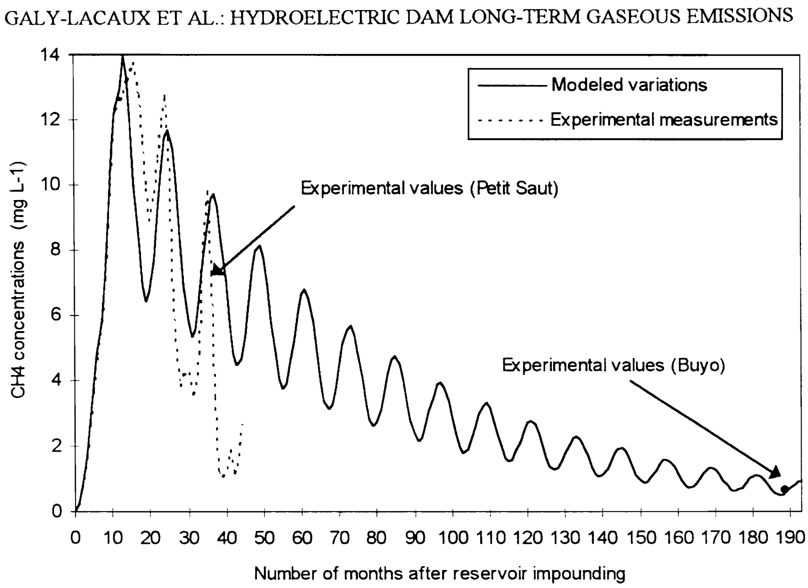
The value measured at a depth of thirty meters was 6 mg/L, as shown in Table I (Rosa et al., 1997), reproduced by Fearnside in his Figure 1 (Fearnside, 2004). The measurement was taken four years after the Tucuruí hydroelectric dam was filled (November 1984) and extrapolated by Fearnside to 1991.

In his publication, Fearnside raised the concentration to 7.5 mg/L, taking as a reference the findings, at the Petit Saut hydroelectric dam in French Guiana, obtained in the work by Galy-Lacaux et al. (1999), with whom our group in Brazil has a research agreement covering the study of this matter in these two countries. The work by Galy-Lacaux refers to greenhouse gases emissions during a period that begins with filling the dam in 1994 through to the operations stage in 1997.

TABLE I
Gas concentrations (mg/L) in water at the Tucuruí hydroelectric dam (March 1989)

Depth (m)	CH_4 Concentration (mg L^{-1})	O_2 Concentration (mg L^{-1})
0	0.0	5.0
5	0.0	4.0
10	0.0	3.0
15	2.0	1.0
20	3.0	0.0
25	5.0	0.0
30	6.0	0.0

Source: Rosa et al., 1997.



Graph 1. Concentration measurements and mathematical extrapolation of CH_4 concentration in the petit saut hydroelectric dam over time.

This paper noted significant seasonal variations in the CH_4 concentration in the dam water. The average concentration results showed that the CH_4 dissolved in the water peaked at 14 mg/L in May 1995, with a steep drop in the measurements of the average concentration value in April 1997, down to 1 mg/L.

Graph 1 clearly shows the drop in CH_4 concentrations over time, according Galy-Lacaux group.

Average concentration measurements in hydroelectric dams were also carried out in 1995 in Côte d'Ivoire. At the Buyo dam, which at that time was sixteen years old, the average concentrations varied from 1.5 mg CH_4 L^{-1} at the dam bottom to zero in the surface layer. At the Taabo hydroelectric dam – which was seventeen years old at that time – the methane concentration varied from 0.6 mg L^{-1} up to 0.7 mg L^{-1}. Measurements were also taken at the Ayame I dam, which was 37 years old, indicating average concentrations of around 1 mg CH_4 L^{-1}. Based on the research projects at the African dams, and Petit Saut in French Guiana, the researchers reached the conclusion that there was a significant downtrend in dam water methane concentrations. At Petit Saut, there was a 28% drop in the average methane concentration in the water during a two-year period. However, Fearnside uses the data extended through extrapolation, with no solid grounds.

Fearnside makes a mistake in his calculations, as he takes Henry's constant at 25 °C as equal to 67.4 kPa/mol/m^3, and switches units, obtaining 0.681 at/mol/L, a value that is not correct. If we take 1 at $= 1.013 \times 10^5$Pa we reach the correct value of 665 at/mol/L. Consequently, the equilibrium concentration of methane in the water is lower than the value that he calculates, at least by a factor of thousand. If we drop the temperature up to few degrees centigrade (changing Henry constant) and multiply by tree the pressure, the methane solubility in water remains too small. So the Fearnside reasoning does not explain what he tries to explain.

His remarks are misleading when explaining the retention of methane in the reservoir at the water intake depth, in contrast to the mehane emission in tailrace or spillway, based on the temperature variation, up from 15 °C to 25 °C, resulting in an 18% reduction in the solubility, and a pressure variation from 3 to 1 at. As shown in Table I, reproduced from our publication, in the conditions under which the measurements were taken in the reservoir, the methane is contrained to the anoxic layer below a depth of ten meters, where Tundisi measured a nil oxygen concentration. Consequently, the thermocline is responsible for this effect, which prevents methane from rising to the surface. Above ten meters – which is the layer where there is oxygen – the methane level is nil, as shown in Table I.

Far from evenly be in steady state, hydroelectric dam phenomena are highly dynamic and certainly more complicated than a bottle of Coca-Cola. And Fearnside is even wrong about the bottle of soda pop, when he says that the CO_2 escapes in just a few seconds after it is opened. This does not even correspond to the truth, noted through empirical observation. Part of the gas is expelled when the cap is removed, while the remainder is clearly visible as bubbles floating steadily up through the liquid. We can carry out this test and note the emissions decreasing slowly, even with the Coca-Cola at room temperature rather than chilled. Even in a full glass, part of the gas remains in the Coca-Cola for a time, forming gas bubbles for many minutes, rather than just a few seconds. However, Fearnside seems unaware of empirical observation, clinging to his idealized convictions, whose theoretical grounds are certainly open to discussion.

Although he selected Coca-Cola as an example, which is highly symbolic of his way of thinking, he could just as well have selected *guaraná* – a carbonated soft drink that is very popular in Brazil, flavored with Amazon berries. It is easier to see the bubbles as guaraná is tansparent while coca-cola is dark. People in Brazil often sit around a table to chat as they drink it, with the bottles open and the glasses full for half an hour or more, without losing completely the bubbles. Instead of fast food, the Brazilian custom is a leisurely drink.

Consequently, the gas does not escape in a few seconds from either the soda-pop bottle or the hydroelectric dam tailrace, as quite groundlessly affirmed by Fearnside.

At the experimental level, the dropping pressure and rising temperature of the tailrace offer no indications of any sudden methane emissions into the atmosphere. If this did in fact occur, the region downstream from the hydroelectric dam would have almost nil methane concentrations, which is not confirmed by the measurements.

Moreover, the measurements taken in water that has run through the turbines to the aerator at Petit Saut (there is no counterpart facility at Tucuruí after the dam), located 100 m downstream from the hydroelectric dam, show significant methane emissions (Galy-Lacaux et al., 1999). However, according to the Fearnside suppositions, these emissions would have taken place before the aerator, meaning immediately after leaving the turbines. So, where would the methane measured in the aerator have come from?

Additionally, the measurements taken by our group close to the tailraces at the Xingó and Miranda hydro-power complexes indicate significant methane levels in the water, comparable to that measured in the reservoir (Rosa et al., 2002).

At Tucuruí, the spillway runs from a height of 74 m at the top of the dam wall when it is raised the sluice gates 20 m height. Depending on the way the sluice gates are open, it is possible to open a gap at a depth of twenty meters.

It is difficult to measure methane flows into the atmosphere at the spillway, where the water is extremely turbulent, flowing downwards with all its potential energy turned into kinetic energy for the mass of fluid in movement. It is difficult to establish the amount of gas released without a value found through experimental measurements. In contrast, the water drawn into the penstocks transfers most of its energy to spinning the turbines, and then flows into the tailrace below the dam with far less turbulence than the spillway water. The water goes out from each turbine trhough big holes at the botton of a channel from 20 m to 35 m deep and its velocity at the end of the channel is 1.4 m/s or about 5 km/h.

When calculating hydroelectric dam gas emissions, Fearnside admits that all the water might have run through the spillway or all the water might have run through the turbine in the course of a year. In the worst case, which he views wrongly as the latter hypothesis, he estimates emissions at 1.2×10^6 tons of CH_4 a year. Taking a Global Warming Potential of 21 (IPCC, 1996) he obtains equivalent carbon emissions in the form of CO_2 equal to 7 Mtons of CO_2 a year[3]. He then adds the CH_4 and CO_2 emissions not only for the hydroelectric dam tailrace, but also for the water surface and dead trees that at times appear above the water. Not all the emitted CO_2 should be included in the calculations, as it was pumped from the atmosphere, as explained in our paper (Santos et al., 2005).

He then concludes that the emissions by Tucuruí are equivalent to 10 Mtons of carbon in the form of CO_2, rating them as approximately equal to the fuel emissions of the City of São Paulo. However, his calculation gives a value that is 1900% higher than ours, as will be shown.

Let us consider the possibility that there are massive methane emissions at the spillway, where the flow is extremely turbulent, as shown by Fearnside. In this case the water leaves the hydroelectric dam at a depth of no more than twenty meters where, as shown in Table I, the methane concentration is no more than 3 mg/L, far lower than the 7.5 mg/L used by Fearnside to calculate his emissions figure of 1.2 Mtons of methane a year.

Moreover, all the water is never spilled, as the purpose of a hydro-power plant is to generate electricity by running water through its turbines. The proportion of water spills depends on the hydro-power complex under analysis, and may be as low as 3.5% at Itaipu, although far higher at Tucuruí, as the inflow rate varies greatly, peaking during early months of the year. After April it goes down fastly and becomes nil from June up to December. Let us assume that the average amount of water spilled is 40%, although this figure should be substantially lower when all the new turbines come into operation at Tucuruí, whose capacity is being doubled.

Finally, the GWP value used by Fearnside is not the most appropriate to this case. As he himself wrote, there are other ways of calculating the CH_4 and CO_2 ratio in terms of climate change. This point has long prompted discussions between our research group and Fearnside (Rosa et al., 1995; Rosa et al., 1996). The GWP of a gas was defined by Lashof and Ahuja in 1990 as the ratio between the accumulated radiactive forcing for a time equal to zero through to a time t, resulting from the addition of one gas mass unit into the atmosphere at zero time and the accumulated radiactive forcing during the same period of time resulting from the addition of one CO_2 mass unit into the atmosphere at zero time (Lashof and Ahuja, 1990).

This definition includes the removal of gases from the atmosphere which is calculated over time through various processes that may be represented through superimposing decreasing exponentials that multiply the initial pulse (IPCC, 2001). Consequently, the additional concentration of the gas due to the pulse at $t = 0$ will drop over time, and should integrate with it by time t in order to obtain the accumulated effect. Using this definition, if an additional quantity of gas is left in the atmosphere forever, this will increase the temperature indefinitely, as the radiactive forcing will not diminish. This effect does not seem to correspond to the real situation, where a new balance is reached at a certain temperature that is higher than the initial level. Due to the response of the climate system, this saturation effect may also be represented by superimposing decreasing exponentials, requiring a second integration over time. The formula reached through this method may be found in the references: (Hasselman et al., 1993; Enting, 1998; Elzen et al., 1999; Meira Filho and Miguez, 2000; Rosa, 1997; Rosa and Ribeiro, 2001; Rosa, Ribeiro, Muylaert and Campos, 2003).

Generalized in this manner, the GWP corresponds more closely to the real physical situation in our case, for calculating the methane effect over a 100-year period, considered by Fearnside in relation to the CO_2 effect, whose average lifetime in the atmosphere is around 140 years, in contrast with the average lifetime of methane at fourteen years. Using formula 77 of the reference (Meira Filho and Miguez, 2000), the generalized GWP is approximately 7.

Taking all these factors into account that we have examined (the fraction of spilled water compared to the flow-rate; the methane concentration in the dam at the spillway depth divided by the value used by Fearnside supposedly at the turbine water intake; and the relation between the generalized GWP given above and the GWP used by Fearnside), the methane emissions from the hydroelectric dam tailrace as estimated by Fearnside and expressed in terms of carbon in the form of CO_2 equivalent is reduced by a factor of 0.05.

We come to the conclusion that Fearnside, based on his hypotheses, reaches a CO_2 equivalent for methane emissions at the dam that is twenty times higher than the figure calculated through our own hypotheses. In other words, this implies an increase of 1900%. Consequently, the comparison drawn by the author with fossil fuel emissions in the City of São Paulo is quite absurd.

We should bear in mind that our hypotheses assume that all the methane in the spilled water is actually released. However, in this turbulent flow, according to hydrodynamics (Bird et al., 1960), three separate layers are generally formed: the laminar sub layer, the buffer zone and the turbulent zone. It may be assumed that all the methane contained in the inner layers is not fully released, which would lower our estimate. Moreover, we are taking the Fearnside hypothesis that the methane concentrations in the water as measured at some points at a certain time (Rosa et al., 1997) may be generalized to cover the entire reservoir at all times. Due to reservoir dynamics, this extrapolation is somewhat improbable.

In our paper published in Climatic Change (Rosa et al., 2004), we propose to measure the methane concentration in the water upstream and downstream from the power dam. We have already submitted a request to the regional power authority (Eletronorte) to carry out these measurements at Tucuruí. Fearnside ignores our proposal to measure this concentration, although it is mentioned in our paper that he critiques.

Regarding emissions from wilderness areas before damming the river, Fearnside affirms that methane emissions are rated as negligible, based on the assumption that hydro-power plants are always built on rivers with fast-flowing currents.

Gas flows measured in the rivers of Amazonia (the future area for the Belo Monte hydro-power dam) disclose the opposite. Our study carried out in wilderness areas, as well as Amazon rainforest soils, croplands, pastures, rivers and floodlands, has demonstrated massive greenhouse gases potential (Santos, 2004). Consequently, any study of the environmental changes engendered by building the dam must necessarily take these natural emission rates into consideration. In order to quantify the net anthropic impact of building a hydro-power dam on the generation of greenhouse gases, the background emissions must be subtracted from the emissions measured at the dam.

So far, we have demonstrated the errors and inconsistencies in the estimates drawn up by Fearnside from a scientific standpoint. But in the final portion of his comments, he adopts a stance that is not at all scientific, with political insinuations about a statement made by José Miguez at a meeting held in February 2002.

We are not empowered to explain the declaration made by José Miguez, which was maliciously construed by Fearnside. We can only state that we have done a hard effort in the past to convince Eletrobras to agree with our pioneering project of measuring GHG emissions in hydroelectric reservoirs. There were not any influence of Eletrobras, which belongs to the Brazilian Government, on our findings, which have been published freely in scientific periodicals and available to anyone wishing to access them, to the extent that they are the source of the data used by Fearnside himself – who has not done any measurement at hydroelectric dams. And, as university professors and researchers, we woul not accept any such a kind of influence, as it is well known in the Brazilian scientific community. So, if Fearnside has any relation with this community he knows that and his insinuation about Miguez phrase is intelectually dishonest. Moreover, we have carried out research projects at hydroelectric dams belonging to other companies, including the privately owned Light power distribution utility – whose main shareholder is Electricité de France (EDF). In addition we have been supported by highly respected Brazilian entities such as the National Research Council (CNPq) and the Ministry of Science and Technology. At the moment, we are part of a group of researchers from several different universities and research centers set up to measure carbon flows and determine their origins at ten hydroelectric dams owned by the Furnas power generation utility. This study involves several institutions,[4] and includes again Tundisi, who was a co-founder of our group at the Graduate Engineering Programs Coordination Unit, Rio de Janeiro Federal University (COPPE/UFRJ) and the Water Resources and Applied Ecology Center, São Paulo University (CRHEA/USP).

This subject must not be vulgarized through demagogic positions based on suppositions, or lead to naïf speculations on the complex phenomenology of hydroelectric dams. Fearnside takes advantage of having English as mother language and of his American origim, to publish too much abroad saying always the same thing.

The insinuations of Fearnside are farfetched and unethical about the fact that one of the authors, the founder of our group, Luiz Pinguelli Rosa, was appointed to head up Eletrobras when President Luiz Inácio Lula da Silva took office in 2003.

Quite deliberately, Fearnside fails to mention that the meeting he refers to took place under the previous Administration, where Professor Pinguelli Rosa severely criticized the Government's energy policy. Brazil's privatization program transferred control of power utilities to major economic groups that then failed to allocate investments. In fact, the worst case is that one of these groups, headquartered in the USA, built up a debt of US$ 1.2 billion with a Government bank and refused to settle it.

Due to his views, Professor Pinguelli Rosa was involved in heated discussions with the previous Administrations, which is public knowledge and well-known in Brazil[5]. This situation finally resulted in electricity shortage and rationing in 2001, as the privatized power utilities had failed to allocate the expected investments, with severe effects on the nation's development and its population, who had to pay higher electricity rates. This led to the situation in which privately owned thermo-power plants were built and not brought into operation, purchasing electricity from the state-run hydro-power complexes at R$ 18/MWh and selling electricity at R$ 140/MWh to the distribution utilities, which transferred these high prices to the rates paid by the consumers.

There are powerful interests in play here, with a thermo-based lobby that is offset by those who unconditionally support the hydro-power option. Fearnside says that his position is unpopular and antagonistic, but it depends on whom, as his views seem to be against any hydro-power complex, in principle.

It was these issues that prompted Brazil's new Government to invite Pinguelli Rosa to head up the national power authority, Eletrobras, where he remained for fifteen months. He then returned to the university where he has always worked, and today coordinates the Brazilian Forum on Climate Change, which includes the President of Brazil, as well as Ministers, scientists, representatives of NGOs and corporations.

During his time at Eletrobras, this entity organized a competitive bidding procedure for 3,300 MW to be generated by small-scale generation facilities based on wind power, biomass and small hydro-power plants. Besides, the project of Belo Monte hydroplant, in phse of preliminary studies, was reformulated, decreasing the istalled capacity to reduce environmental impacts. He established the Environment Department at Eletrobras, and introduced a greenhouse gases emissions reduction program for the Eletrobras enterprises, which own both hydro- and thermo-power plants. Additionally, he invited IPCC Co-Chair Luiz Gilvam Meira Filho to serve as an advisor to Eletrobras. Consequently, the insinuations of Fearnside do not correspond to the real situation regarding the public positions adopted by Pinguelli Rosa, who was even supported by the Brazilian Power Dams Victims Movement (MAB), despite divergent views on the use of hydro-power in Brazil. This support is quite clear in a document that was prepared with the cooperation of this Movement, which it signed in February 2004.

We have never affirmed that all the adversaries of hydro-power complexes belong to the lobby supporting their thermo-based counterparts, and Fearnside has no reason to assert this, as he did in his comment. Neither do we have links to any business group or Government, in terms of supporting ideological positions. We hope Fearnside should recognize he went offlimits with his political claiming and insinuations at the end of his comment, published by Climatic Change, putting our old debate in terms that oblige us to write the present response.

As we wrote in our paper, we agree that hydro-power complexes have negative impacts on ecosystems, as well as deleterious social effects in the areas where they are built, and may also contribute to the greenhouse effect. However, our commitment is to strive to portray the real situation for the issue of hydroelectric dams and the greenhouse effect with the greatest possible scientific accuracy.

Therefore we must go ahead with our measurements of GHG emissions from hydroelectric reservoirs and the next step, according our proposal (Rosa et al., 2004), shall be the measurement of methane concentration in the water, just before and after Tucurui dam at different times. The experimental test is the right way to solve controversies about nature, according the scientific method since Galileu and Newton Revolution of Science in the XVII Century.

Acknowledgments

We are grateful for the contributions of Adilson Elias Xavier and Carlos Henrique Eça de Almeida.

Notes

[1]Each water intake has a diameter of 22 m and, knowing its area and the number of intake points, we can calculate the water inflow speed and pressure at the intake point, less than the hydrostatic pressure.

[2]Since the start of the project measuring greenhouse gases in power dams, José Galízia Tundisi participated under a cooperation agreement between the Water Resources and Applied Ecology Center, São Paulo University (CRHEA/USP) and the Graduate Engineering Programs Coordination Unit, Rio de Janeiro Federal University (COPPE/UFRJ), leaving only to take office as the President of Brazil's National Research Council (CNPq) and replaced by Bohdan Mavienko.

[3]Actually using GWP $= 21$, the factor for obtaining the carbon mass in the form of CO_2 equivalent to the methane effect is $(12/44) \times 21 = 5.7$, giving 6.8 Mtons of carbon.

[4]Graduate Engineering Programs Coordination Unit, Rio de Janeiro Federal University (COPPE/UFRJ); International Ecology Institute (IIE), Juiz de Fora Federal University (UFJF); National Space Research Institute (INPE).

[5]Luiz Pinguelli Rosa is a member of the Brazilian Academy os Science, former Secretary General of the Brazilian Physical Society, former member of the Pugwash Council, and he has received from the American Physical Society the Forum Award on Physics and Society in 1992, for "laying the groundwork for the agreement between Argentina and Brazil to abstain from building any explosive nuclear device".

References

Bird, E. B., Stewart, W. E., and Lightfoot, E. N.: 1960, *Transport Phenomena*, John Wiley & Sons, New York, 1960, p. 156.

Brazilian Proposal: 1997, Proposed Elements of a Protocol to the United Nations Framework Convention on Climate Change. Presented by Brazil in Response to the Berlin Mandate (FCCC/AGBM/1997/MISC 1/ADD.3).

Enting, I. E.: 1998, Attribution of GHG Emissions, Concentrations and Radioactive Forcing, CSIRO, Australia, Technical Paper 38.

Fearnside, P. M.: 1996, Hydroelectric Dams in Brazilian Amazonia: Response to Rosa, Schaeffer & Santos, *Environmental Conservation*, **23**(2), Cambridge University Press, UK, 1996.

Fearnside, P. M.: 2004, Greenhouse Gas Emissions from Hydroelectric Dams: Controversies Provided A Springboard for Rethinking a Supposedly 'Clean' Energy Source, Editorial Comment, *Climatic Change*, **66**, 1–8, Netherlands.

Galy-Lacaux, C., Delmas, R., Kouadio, J., Richard, S., and Gosse, P.: 1999, 'Long-term greenhouse gas emissions from hydroelectric reservoirs in tropical forest regions', *Global Biogeochem. Cycles* **13**, 503–517.

Hasselmann, K., Sauc, R., Maier-Reimer, E. and Voss, R.: 1993, 'On the cold start transient simulations with coupled atmosphere-ocean models', *Climate Dynamics* **8**, 55–69.

Lashof, D. A. and Ahuja, D. R.: 1990, 'Relative contributions of greenhouse gas emissions to global warming', *Nature* **344**(6266), 529–531

IPCC: 1996, In: Houghton, J. T. and Meira, L. G. (eds.), *Climate Change* 1995 – *The Science of Climate Change*, Cambridge University Press, London.

IPCC: 2001, *Climate Change 2001 – Synthesis Report*, Cambridge University Press, London.

Meira Filho, L. G. and Miguez, J. D. G.: 2000, Revised Brazilian Proposal, Technical Note on the Relation of Time Dependence between GHG Emissions and Climate Change, Ministry of Science and Technology, Brasília, 2000.

Rosa, L. P. and Schaeffer, R.: 1994, 'Greenhouse gas emissions from hydroelectric reservoirs', *Ambio* **23**(2), pp. 164–165.

Rosa, L. P. and Schaeffer, R.: 1995, 'Global warming potentials: The case of emissions from dams', *Energy Policy* **23** (2), 149–158.

Rosa, L. P., Schaeffer, R. and Santos, M. A.: 1994, Methane and Carbon Dioxide Emissions of Hydroelectric Power Plants in the Amazon Compared to Thermoelectric Equivalents. Unpublished Report, Energy Planning Program, COPPE/UFRJ, August: (manuscript, 48 pp.).

Rosa, L. P., Schaeffer, R., and Santos, M. A.: 1996, 'Are hydroelectric dams in the Brazilian amazon significant sources of greenhouse gases?', *Environmental Conservation*, **66**(1), 2–6, Cambridge University Press, UK, 1996.

Rosa, L. P.: 1997, Activities implemented jointly to mitigate climate change', in: Chatterjee, K. (ed.), *Proceedings, Conference on Jointly Implemented Activities*, New Delhi (Chapter 2, Section I).

Rosa, L. P., Ribeiro, S. K.: 1997, 'The share of responsibility between developed and developing countries in climate change, greenhouse gas mitigation', in: Riemer, P. W. F., Smith, A. Y., Thambimuthu, K. V., (eds.), Proceedings, International Energy Agency Conference on GHG, Vancouver, Pergamon, 1998.

Rosa, L. P. and Ribeiro, S. K.: 2001, 'The present, past and future contributions to global warming of CO_2 emissions from fuels. A key for negotiation in the climate convention', *Climate Change* **48**, 289–308.

Rosa, L. P., Sikar, B. M., Santos, M. A., Monteiro, J. L., Sikar, E. M., Silva, M. B., Santos, E. O. and Junior, A. P. B.: 2002, Emissões de Gases de Efeito Estufa de Reservatórios Hidrelétricos, ANEEL Publication, Brasília, 2002.

Rosa, L. P., Santos, M. A., Matvienko, B., Santos, E. O. and Sikar, E.: 2004, 'Greenhouse gas emissions from hydroelectric reservoirs in tropical regions', *Climatic Change* **66**, 9–21, 2004, Netherlands.

Rosa, L. P., Santos, M. A., Tundisi, José Galízia, and Sikar, B. M.: 1997, 'Measurements of Greenhouse Gas Emission at the Samuel, Tucuruí and Balbina Dams, Brazil', in Rosa, L. P. and Santos, M. A. (eds.), Hydro-power Plants and Greenhouse Gas Emissions, COPPE publication, Rio de Janeiro, 1997.

Santos, M. A., Matvienko, B., Maddock, J. E. L., Santos, E. O., Silva, M. B., Rocha, C. H. E. A., Junior, A. P. B., and Sikar, E.: 2004, Emissões de Gases de Efeito Estufa do Reservatório

Hidrelétrico de Belo Monte – Fase de Pré-Enchimento do Reservatório, Final Technical Report COPPE/UFRJ-Eletrobras, August 2004, Rio de Janeiro.

Santos, M. A., Rosa, L. P., Sikar, B., Sikar, E., and Santos, E. O.: forthcoming publication, Gross Greenhouse Gas Fluxes from Hydro-power Reservoir Compared to Thermo Power Plants, Energy Policy, Elsevier.

Santos, M. A., Matvienko, B., Rosa, L. P., Sikar, E., and Santos, E. O.: 2005, Gross Greenhouse Gas Emissions from Brazilian Hydro Reservoirs, in Greenhouse Gas Emission – Fluxes and Processes, Springer, 2005, Berlin.

(Received 23 March 2005; in revised form 21 July 2005)