BIOMASS RELATED GHG EMISSIONS IN TUCURUÍ AND BELO MONTE HYDROELECTRIC PLANTS: AN INTUITIVE COMPARISON WITH THERMO ELECTRICAL POWER

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ABSTRACT: Brazil, the 7th world economic power according with the IMF, is one of the Country in the world with the cleanest energy matrix. Since the 80s public opinion and official debates have been more and more concerned about the pollution generated from any kind of source of energy and now new commitments in that sense are contained into the ten-year plan (Programa de Aceleração do Crescimento). The main part of energy production in Brazil nowadays is based on hydroelectricity but the water source is well concentrated, especially in the Amazon Region, and the hydroelectricity impact is so far not well known. Thus, simple and new methods to calculate how much hydroelectricity is clean are needed, indeed. In this sense a method based on the evaluation of GHG emissions of Tucuruí and Belo Monte (two of the main projects all over the Country) is going to be presented. Every result must be compared with the performance of other source of energy that could actually represents an alternative (the thermoelectricity in the Amazon Region), also facing the challenge of the increasing demand of energy by diversify the energy matrix.

KEYWORDS: GHG emissions, Hydroelectric, Thermo electrical.

EMISSÕES DE GEE RELACIONADAS À BIOMASSA NAS USINAS HIDRELÉTRICAS DE TUCURUÍ E BELO MONTE: UMA COMPARAÇÃO INTUITIVA COM A ENERGIA ELÉTRICA TÉRMICA

RESUMO: O Brasil, a 7ª potência econômica mundial segundo o FMI, é um dos países do mundo com a matriz energética mais limpa. Desde a década de 80, a opinião pública e os debates oficiais têm estado cada vez mais preocupados com a poluição gerada por qualquer tipo de fonte de energia e agora novos compromissos nesse sentido estão contidos no programa de aceleração do crescimento. A principal parte da produção de energia no Brasil atualmente é baseada na hidroeletricidade, mas a fonte de água está bem concentrada, especialmente na região amazônica, e o impacto da hidroeletricidade não é tão conhecido até o momento. Assim, métodos simples e novos para calcular quanta hidreletricidade está limpa são necessários. Nesse sentido, será apresentado um método baseado na avaliação das emissões de GEE de Tucuruí e Belo Monte (dois dos principais projetos em todo o País). Todo resultado tem que ser comparado com o desempenho de outra fonte de energia que possa, na verdade, representar uma alternativa (a termoeletricidade na Amazônia), enfrentando também o desafio da crescente demanda de energia por diversificar a matriz energética.

PALAVRAS-CHAVE: Emissões de GEE, Hidroelétricas, Termoelétricas.

EMISIONES DE GEI RELACIONADAS CON LA BIOMASA EN LAS CENTRALES HIDROELÉCTRICAS DE TUCURUÍ Y BELO MONTE: UNA COMPARACIÓN INTUITIVA CON LA ENERGÍA ELÉCTRICA TÉRMICA

RESUMEN: Brasil, la 7ª potencia económica mundial según el FMI, es uno de los países del mundo con la matriz energética más limpia. Desde la década de los 80, la opinión pública y los debates oficiales han estado cada vez más preocupados por la contaminación generada por cualquier tipo de fuente de energía y ahora nuevos compromisos en este sentido están contenidos en el programa de aceleración del crecimiento. La principal parte de la producción de energía en Brasil actualmente se basa en la hidroelectricidad, pero la fuente de agua está bien concentrada, especialmente en la región amazónica, y el impacto de la hidroelectricidad no es tan conocido hasta el momento. Así, métodos simples y nuevos para calcular cuánta hidroelectricidad está limpia son necesarios. En este sentido, se presentará un método basado en la evaluación de las emisiones de GEI de Tucuruí y Belo Monte (dos de los principales proyectos en todo el país). Todo resultado tiene que ser comparado con el desempeño de otra fuente de energía que pueda, en realidad, representar una alternativa (la termoelectricidad en la Amazonia), enfrentando también el desafío de la creciente demanda de energía por diversificar la matriz energética.

PALABRAS CLAVE: Emisiones de GEI, Hidroeléctrica, Termoeléctrica.

INTRODUCTION

According with the disposition of the *Ministério de Minas e Energia* (MME) and fulfilling the commitment of reducing GHG emission by 2020, in 2011 Brazil decided to strongly rely on the hydroelectric sector both to enlarge and to make clean its energy matrix (SANTOS et al., 2012).

In 2011 the percentage of renewable energy sources in the energetic matrix of Brazil was more than 45% of total sources, setting the Country in the best position into the BRICS group (OECD, 2011). The Federal Government is carrying on making cleaner and cleaner its matrix by investing in hydroelectricity (loads of big and smaller plants are in design, in progress or are yet operating)[1] and in other renewable source (in 2020 the use of oil and its derivative is going to decrease, and this will be compensated by an increase of the use of natural gasses or other source such as those ones derived from sugar cane) (PDE 2020). Despite that, hydroelectricity (covering about 70% of electricity production) (ANEEL 2011) keep on preserving a main role in the production of the electric power in Brazil[2].

IS THIS MATRIX REALLY CLEAN?

Hydropower is often promoted by government as a "clean" source of energy, in contrast with fossil fuels. But hydroelectric dams are not free of impact, although fossil contribution to global warming is better known, no doubt (FEARNSIDE, 2000). Whit regards to the matter above, only since the 80s important achievements have been occurred. The *Estudio e Relatorio de impacto ambiental* (EIA/RIMA) assumed great importance as tools of the *Politica National do Meio Ambiente* (PNMA - lei 6938/81). The EIA/RIMA has been based since 1986 on a

[1] According with the Plano Decenal de Expansão de Energia 2020, 31 new projects of hydroelectric plants are in design for the period 2011-2020, and 14 of these are localized in the Amazon Region (MME/EPE 2011).

[2] Between 2010 and 2020 the electricity consumption is expected to increase by 4.9%. The growth will be greater in the North, 9,3% (MME, 2012).

CONAMA[3] resolution that specified basic criteria and general recommendations to write an environmental assessment (Resolução n°001/1986), and in the 1987 a further disposition was emitted defining the content about the license of projects of public interest such as the production of electricity (Resolução n°006/1987). Moreover, noteworthy are the dispositions contained into the Constitução defining environment as a "common good"[4]. Eventually, since 1997 has been available a list of activities (included hydroelectric plants) needed to be submitted to an assessment producing an environmental license. The environmental related achievements above indicated (including the Rio Conference in 1992) underline a wide and growing interest in this field. To this days there exists a wide literature on the relationship between human project oriented to power generation and the related environmental impact. This paper is based on two broad research lines of this literature: the hydroelectricity sector and the GHG (Greenhouse gasses) emissions.

GHG EMISSIONS FROM TROPICAL DAMS

The current literature assesses that the main GHG emissions in hydroelectric plants are related both to the beginning temporary phase of the construction of the plant and to a permanent element, the reservoir. Some deepened studies (complicated and expensive) regarding the temporary phase were already faced (such as LCA[5]) often linked to specific case studies (RADAAL et al., 2011).

However, this note is only focused on the reservoir related impact and this choice derives from some evaluations. We considered that a too much complex method, even if more accurate, it's not useful in advising the

[3] Conselho Nacional do Meio Ambiente.
[4] Art. 225, CAPÍTULO VI (do Meio Ambiente), TÍTULO VIII (da Ordem Social), Costitução da República Federativa do Brasil, 1988.
[5] Life Cycle Assessment.

policy makers. Moreover, there is an active public debate concerning the reservoirs which impact it's perceived to be affecting both the environmental and the social field. Furthermore, the size of the reservoir represents the main discriminating factor between small and big hydroelectric plants: in the small hydroelectric plants the GHG emission of the reservoir are nearly zero, being principally concentrated in the construction phase (the opposite of big plants); a little reservoir also measures a minor social and environmental impact (other than GHG emissions)[6] (RADAAL et al., 2011).

Eventually, focusing only on reservoirs will allow a simpler comparison between two of the main hydroelectric projects localized in the Brazilian state of Pará, in the Amazon Region, Tucuruí and Belo Monte, with two different kind of reservoir which implies different level of GHG emission. Main reservoir related GHG[7] emissions are CO_2, CH_4, N_2O. The present analysis is going to consider only CO_2 and CH_4 because they represent together the biggest quantity of gas emission in relation of the total GHG emission, whereas the N_2O covers a little percentage of the total. The mayor part of emissions is composed by CO_2 indeed, but the global worming potential of CH_4 is 20-40 times bigger that of CO_2 (per g basis), so the percentage of CH_4 is important (COMMERFORD, 2011). However, it is proper underlining that, even there's not a rich literature that take into account the N_2O, the conversion factor of N_2O is very huge too and this entails a further in-depth analysis over and above the present note (FEARNSIDE, 2000).

The CO_2 and CH_4 emissions are related to different factors, such as temperature, depth, amount and type of vegetation flooded, but also

[6] Small Hydroelectric Centrals (SHC) are more expensive than big ones, at least at the start point. The installation costs could reach a double expense compared with big plants (Norte Energia).

[7] CO_2 is Carbon dioxide, CH_4 is Methane, N_2O is Nitrous oxide.

geographic location and reservoir age (STEINHURST et al., 2012).

In fact, a lower pressure and a warmer water reduce the solubility of gas, helping the release of GHG, while the decay of dead trees left projecting out of the water and the decay of sediments at the bottom of the reservoir are the main source, respectively, of CO_2 and CH_4 (FEARNSIDE; PUEYO, 2012).

Thus, the initial flooding phase is associated with particularly high rates of both bacterial activity and GHG production, but at further stages the emissions tend to decline, more rapidly in cold-water than in warm-water (the latter is the case of the Amazon Region)[8].

The GHG emissions never stops permanently because organic matter inputs from inflowing rivers, algal production and regrowth of plants along shores during drawdowns periods represent a continuous source of organic carbon (BARROS et al., 2011).

AN ESTIMATE OF GHG EMISSIONS (CO_2 AND CH_4)

Considering the previews observations, a feasible way to assess CO_2 and CH_4 emissions from a reservoir is the use of a rough simplification from the chemical reaction of anaerobic decomposition:

$$\boldsymbol{C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4}$$

(Eq. 1)

The $C_6H_{12}O_6$ is glucose[9] that is found in plant life that decompose to carbon dioxide and methane (COMMERFORD, 2011). By using it, a simple but clear assessment of the GHG emission of Tucuruí and Belo Monte could be

[8] In this sense the tropical rain forest is “at a disadvantage starting off”.

[9] In a conventional way the glucose is taken into account because it represent the basic sugar contained in every vegetal tissue.

achieved, allowing then further various useful comparisons.

First of all, some clarifications are needed. First, the present analysis is based on data collections of different nature due to the different nature of the two selected projects. In fact, while Tucuruí is one of the most ancient hydroelectric plant in Brazil, Belo Monte represents only a source of forecast data. Second, we will use only the reservoir extension in order to calculate GHG emissions of the two hydroelectric plants in exam. Third, according with the disposition contained into the Tokyo Protocol (1997) we are going to use a "conversion factor" to show the entire considered emission in terms of only CO_2. The conversion factor we are going to use is 1 CH_4 = 21 CO_2, and this factor is related to a 100-year time frame.[10] Lastly, we are going to include in our calculation only the biomass value (leaving out the soil carbon, of which we present only a qualitative specification). Data are summarized in the following table.

Table 1. Leaving out the soil carbon, of which we present only a qualitative specification.

	Tucuruí	Belo Monte	Source
Reservoir surface	2850 km²	503 km²	Eletronorte / Norte Energia, 2014
Conversion Factor	21		Kyoto Protocol, 1997
Biomass	20 kg C/m²		Kelly et al. 1994
Soil Carbon	Low (tropical rain forest)		Kelly et al. 1994

[10] Commonly known as GWP (Global-warming potential), it represent a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of the heat trapped by a certain mass of the gas in question to the amount of the heat trapped by a similar mass of carbon dioxide. The GWP is calculated over a specific time interval, 20, 100 or 500 years. The GWP of methane chosen in the analysis is calculated over 100 years and refer to IPCC Second Assessment Report (SAR) of 1995 with values adopted for the Kyoto Protocol's First Commitment Period. GWP values have been updated in successive IPCC report, for example the CH_4 GWP value in the Fifth Assessment Report (AR5) is 28 (IPCC Report, 2014).

By multiplying the quantity of biomass by the dimension of the reservoir surface[11] (for each one of the plants) it leads to an approximate global value of the total CO_2 and CH_4 emission. Such an evaluated emission must be divided into two equal parts, according with the Eq. 1. At a later stage, only the CH_4 part thus obtained must be transformed into its CO_2 equivalent through the conversion factor.

Tucuruí and Belo Monte: an application

The area flooded by Tucuruí, as with most hydroelectric dams, was not a wetland prior to flooding, but rather was an area of rapids on the river that had topography sloping steeply enough to maintain well drained soils (FEARNSIDE, 2000). Moreover, during the fulfilling of the reservoir little relevance was given to the question of the emission of biomasses in decomposition. The application of the formula (Eq.1) to this kind of flooded area leads to the following results.

$$285 \cdot 10^7 \text{ m}^2 \times 20 \text{ kg} \frac{\text{C}}{\text{m}^2} = 57 \cdot 10^9 \text{ kg of Carbon}$$
$$\rightarrow 285 \cdot 10^5 \text{t of CH}_4 + 285 \cdot 10^5 \text{t of CO}_2$$

The CH_4 part can be expressed in CO_2 value by using the conversion factor.

Tucuruí Hydroelectric plant GHG emissions:

$$285 \cdot 10^5 \times 21 + 285 \cdot 10^5 = \mathbf{627 \cdot 10^6 \text{ t of } CO_2 \text{ Equivalent}}$$

(Eq. 2)

[11] Plant biomass varies in different ecosystem, from 7 kg C/Km² in grasslands to 20 kg C/Km² in tropical rain forests, and so does soil carbon, low in the tropics too high in boreal peat lands (KELLY et al. 1994).

Conversely, the Belo Monte area prior to flooding was mostly covered by ombrophiles forest of palms and lianas, or destined to pasture. Learning the Tucuruí lessons, the official intention of the Norte Energia is to provide an adequate deforestation program preceding the replenishment of the reservoir aimed to reduce the reservoir emissions related to the decay of biomasses (NORTE ENERGIA, 2014).[12]

$$503 \cdot 10^6 \mathrm{m}^2 \times 20\ \mathrm{kg}\frac{\mathrm{C}}{\mathrm{m}^2} = 10{,}06 \cdot 10^9\ \mathrm{kg\ of\ Carbon}$$
$$\rightarrow 503 \cdot 10^4 \mathrm{t\ of\ CH_4} + 503 \cdot 10^4 \mathrm{t\ of\ CO_2}$$

Belo Monte Hydroelectric plant GHG emissions:

$$503 \cdot 10^4 \times 21 + 503 \cdot 10^4 = 110{,}66 \cdot 10^6\ \mathrm{t\ of\ CO_2\ eq}$$
$$\cong \mathbf{111 \cdot 10^6\ t\ of\ CO_2\ Equivalent}$$

(Eq. 3)

Results show that Tucuruí has the worse impact in terms of GHG (CO_2, CH_4) emissions with a potential emission of $627 \cdot 10^6$ t of CO_2 equivalent (Eq. 3). This is mainly due to the magnitude of its reservoir. In this sense one of the most important decision taken during the conception of Belo Monte was to reduce[13] the size of reservoir (from 1225 km² to 503 km²),

[12] This is a controversial point. In fact the deforestation itself emits CO_2 even if the final goal is to reduce de biomass left decomposing. To the other side avoiding a preliminary deforestation will lead to a greater amount of biomass. In both cases, a further phase of deforestation in the area surrounding the dams is nearly unavoidable. The realization of the hydroelectric complex Tucuruí entailed an increase in deforestation rates in neighboring municipalities. Currently the municipalities where it is building the Belo Monte hydroelectric complex (Altamira and São Félix do Xingu) record, since 2012, the highest levels of deforestation in the state of Pará (PRODES, 2014).

[13] The decision to reduce the reservoir extension has been made to avoid the flooding of indigenous protected area (Norte Energia, 2014). Nevertheless, the social question linked to the construction of this dam is still open and hotly debated (SANTOS et al. 2012).

even with bad results in terms of efficiency of the plant. Due to the smaller reservoir Belo Monte gains a potential GHG emission of $111 \cdot 10^6$ t of CO_2 equivalent (Eq. 3).

HYDROELECTRIC X THERMOELECTRIC

With the data obtained it is possible proceed in comparing the emissions generated by these hydroelectric plants with the emission generated by a supposed thermoelectric plant alimented by natural gas.[14] For a more complete dissertation it is fair to separate the Tucuruí case in two phases[15]. All data needed are shown in the following table.

Table 2. The emission generated by a supposed thermoelectric plant alimented by natural gas

	Tucuruì (Source: Eletronorte, 2014)		Belo Monte (Source: Norte Energia, 2014)
	Phase 1	Phase 2	
Installed capacity	4.245 MW	8.530 MW	11.233 MW
Average annual production	21.428 GWh / y	39.510 GWh / y	38.790 GWh/y

Hydroelectric power generation produce a large pulse of carbon dioxide emissions in the first year after filling the reservoir, while thermal generation produces a constant flux of gases in proportion to the power (FEARNSIDE, 2001). The GHG emission from thermoelectric plants is constant year by year and it is proportioned to the energy production amount, so it is

[14] The main alternative to the hydropower in the North Region of Brazil is thermo-power. In our comparative analysis we consider a combined cycle thermoelectric power plant fueled with natural gas.

[15] In the first phase (1984-2010) the installed capacity was 4245 MW, but in the second phase (post 2010) it turned into 8530 MW (Eletronorte).

450 t of CO_2 eq / GWh.[16] In order to calculate the annual emission of an equivalent thermoelectric plant the previous value will be multiplied by the average annual production of each plant.

FIRST SCENARIO

According with the chosen conversion factor (CH_4 = 21) a proper analysis could be referred to a 100-year time frame.

Actually this scenario only takes into account the Tucurui's energy production inherent to the second phase. That's because in the future it is planned a further expansion of energy production. Thus, the value concerning the second phase (middle period) could be taken as good average approximation of all three expected periods.

Proceeding in the calculation of a hypothetical thermoelectric plant emissions, we obtain the following values.

If a thermo-electric plant produces the same amount of the Tucuruí's power generation (100 year time frame):

$$17.779.500\ \frac{t\ CO_2\ eq}{y} \times 100\ y = 1.779.500.000\ t\ CO_2\ eq\ \cong \mathbf{1.779} \cdot \mathbf{10^6}\ \boldsymbol{t\ of\ CO_2\ Equivalent}.$$

(Eq. 4)

Once calculated (Eq. 4) the entire CO_2 (including the CO_2 equivalent of CH_4), it is possible to evaluate the GAP in the emission between thermoelectric (hypothetical) and hydroelectric

[16] The amount of CH_4 emissions in a natural gas plant is fairly small: 0,0472 t / GWh. Multiplyng this value by the conversion factor of 21, the equivalent of CO_2 is 0,9912 t / GWh. Instead only the amount of CO_2 emissions for this kind of power plant is 449 t / GWh (WCD, 2000).

(Tucuruí, Eq. 2) plant. That's indicated as "net emissions".

$$1.779 \cdot 10^6\ t\ CO_2\ eq - 627 \cdot 10^6 t\ CO_2\ eq = \mathbf{1.152\ \cdot 10^6\ t\ of\ CO_2\ Equivalent}$$
$$Net\ emissions\ (Natural\ Gas - Hydroelectric)$$

(Eq. 5)

If a thermo-electric plant produces the same amount of the Belo Monte's power generation (100 year time frame):

$$17.455.500\ \frac{t\ CO_2\ eq}{y} \times\ 100\ y = 1.745.550.000\ t\ CO_2\ eq$$
$$\cong \mathbf{1.745 \cdot 10^6\ t\ of\ CO_2\ Equivalent}$$

(Eq. 6)

Once calculated (Eq. 6) the entire CO_2 (including the CO_2 equivalent of CH_4), it is possible to evaluate the GAP in the emission between a thermoelectric (hypothetical) and hydroelectric (Belo Monte, Eq. 3) plant.

$$1.745 \cdot 10^6\ t\ CO_2\ eq - 110 \cdot 10^6\ t\ CO_2\ eq = \mathbf{1.634\ \cdot 10^6\ t\ of\ CO_2\ Equivalent}$$
$$Net\ emissions\ (Natural\ Gas - Hydroelectric)$$

(Eq. 7)

In the case of Tucuruí net emissions (as "emissions avoided") amount to $1.745{\cdot}10^6$ t of CO_2 equivalent (Eq. 5), while in the case of Belo Monte amount to $1.634{\cdot}10^6$ t of CO_2 equivalent (Eq. 7). The positive result in both situations above indicates the worse performance of thermoelectric plants. That's because, in such a long period (100 year) the hydroelectric technology it is presumed to be one of the clearest source of energy production. The long period considered indeed allows the complete amortization of initial costs which represent the greatest part of the total amount.

SECOND SCENARIO

It could be also interesting to choose a 40 years' time-frame, that's the exact age of the Tucuruí Plant (closed in 1984). In this case we are going to maintain the same conversion factor (CH_4 = 21). Moreover, since we are considering the current age of Tucuruí dam, we consider the two phases of its history and the related average annual production. Results show that in the case of Tucuruí the equivalent emission of a natural gas power plant amounts to 418·10^6 t of CO_2 equivalent (Eq. 8), in the case of Belo Monte it amounts to 698·10^6 t of CO_2 equivalent instead (Eq. 10).

If a thermo-electric plant produces the same amount of the Tucuruí's power generation (40 year time frame):

$$Phase\ 1\ (1984-2010) \rightarrow 21.428\ \frac{GWh}{y} \times\ 450\ \frac{t\ CO_2\ eq}{GWh} = 9.642.600\ \frac{t\ CO_2\ eq}{y} \rightarrow \times\ 36\ y = 347.133.600\ t\ CO_2\ eq$$

$$Phase\ 2\ (2010-2014) \rightarrow 39.510\ \frac{GWh}{y} \times\ 450\ \frac{t\ CO_2\ eq}{GWh} = 17.779.500\ \frac{t\ CO_2\ eq}{y} \rightarrow \times\ 4\ y\ = 71.118.000\ t\ CO_2\ eq$$

$$Phase\ 1 + Phase\ 2 = 347.133.600\ t\ CO_2\ eq\ +\ 71.118.000\ t\ CO_2\ eq$$
$$= 418.251.600\ t\ CO_2\ eq$$
$$\cong \mathbf{418 \cdot 10^6}\ \boldsymbol{t\ of\ CO_2\ Equivalent}$$

(Eq. 8)

$$418 \cdot 10^6\ t\ CO_2\ eq -\ 627 \cdot 10^6\ t\ CO_2\ e = \mathbf{-209\ \cdot 10^6}\ \boldsymbol{t\ of\ CO_2\ Equivalent}$$
$$Net\ emissions\ (Natural\ Gas - Hydroelectric)$$

(Eq. 9)

If a thermo-electric plant produces the same amount of the Belo Monte's power generation (40 year time frame):

$$17.455.500 \frac{t\,CO_2\,eq}{y} \times\ 40\,y = 698.220.000\ t\,CO_2\,eq$$
$$\cong \mathbf{698 \cdot 10^6}\ \boldsymbol{t\ of\ CO_2\ Equivalent}$$

(Eq. 10)

$$698 \cdot 10^6\ t\,CO_2\,eq -\ 111 \cdot 10^6\ t\,CO_2\,eq = \mathbf{587\ \cdot 10^6}\ \boldsymbol{t\ of\ CO_2\ Equivalent}$$
$$Net\ emissions\ (Natural\ Gas - Hydroelectric)$$

(Eq. 11)

After reducing the time frame the results are quite different. While in the Belo Monte case it is better opting for a hydroelectric power production (looking at Eq. 11, in this case net emission are still positive: $587{\cdot}10^6$ t of CO_2 equivalent), in the Tucuruí case the thermoelectric plants turns out to be even more suitable instead (in fact, as show in the Eq. 9, in this case net emissions are negative: $-209{\cdot}10^6$ t of CO_2 equivalent). In a reduced time, frame there is less time to amortize the huge initial cost, indeed. Moreover, according with the preliminary evaluation that the magnitude of the reservoir is a pivot factor in assessing the GHG emission of a hydroelectric plant, the case of Belo Monte could be taken by way of example.

However, the recent choose of reducing the reservoir size leaded also to a minor amount of power generated.

CONCLUSIONS

The current fast growth of Brazil is strongly involving the Nord Region of the country, implicating a necessary increase in energy production. The water is a key factor for all human activities in there, including fluvial mobility and for this reason the use of water as a source of energy (even if clean) could generate heavy social and environmental impacts. The main concern is certainly related with the real benefit that the region itself will enjoy because of its proper spoiling. The real risk in fact is that Amazon will turn into an energetic suburb instead of reaching more elevate standard of human and economic development (PINTO, 2012).

For the reasons above, first it's important to achieve a fair management of the water source giving easy and useful tools to policy makers, and that's exactly what our model (Eq. 1, Eq. 2, Eq. 3) is trying to do. Second, it could be also advantageous diversify the energy matrix and thus consider the real alternative to hydropower in each one of the Brazilian regions, considering that the thermo-power is the only substantial substitute of hydroelectric in the Amazon Region. Eventually, an accurate evaluation of the medium and long impact of big hydroelectric plants and SHC (small ones) it is needed to achieve a more balanced scheme of hydroelectricity installations in the Amazon Region, and in the whole Brazil.

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