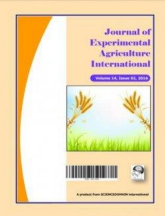

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Watershed as Planning Parameter for the Distribution of Royalties of Hydroelectric Power Plants

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present distribution system of resource compensation for water use is a procedure that compensates Brazilian municipalities and states whose land is flooded by the dam of a hydroelectric power plant with installed capacity higher or equal to 30 MW. The Constitution of 1988 states that all municipalities that contribute to the production of electric energy are eligible to obtain a share in the economic results of the exploitation of water resources for energy generation, and not only those municipalities whose land has been flooded. Therefore, this paper proposes a new methodology for the distribution of royalties by the installation of hydroelectric power plants. We obtained the upstream watershed limits of 45 MW hydropower plant the power plant dam, determined the participation area of each municipality that belongs to it and we obtained the data of distribution of royalties by the Camargos hydroelectric power plants in 2015.The software QGis 2.18.13 was using to data processing. The current form of financial compensation apportionment to the municipalities

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benefits only those whose land has been flooded. The new methodology proposed for royalty distribution is based on the General Equation of the Electric Power Generated. The methodology proposed in this paper also compensates the municipalities of the watershed, whose land has not been flooded. Besides, it enables all municipalities of a given watershed to receive resources for the preservation of their water and soil, thus promoting energy security in Brazil.

Keywords: Financial compensation; energy security; environmental preservation; water security; water producer; water basin management.

1. INTRODUCTION

Brazil has a vast hydroelectric potential that can be amplied to generate electricity. Thus, most of the electricity generated in the country comes from hydroelectric plants, which provide more than 90% of the electrical energy generated in humid periods. In 2015, hydropower accounted for 64% of the Brazilian electrical energy matrix [1]. In 2015, the Southeastern and Midwestern regions produced around 45% of all electricity in Brazil.

In 2014 and 2015 Brazil faced the most severe drought in 80 years. To grasp the importance of such drought by the end of the dry season the equivalent hydropower dam´s capacity were only 17%, whereas the historical average had been much higher than the double of that figure [2].

Despite the droughts, this type of generation has some indisputable competitive advantages. It is one of the cheapest ways to generate electricity, with low level of air emission. The hydro dams help in regulating water flow and increasing water availability in the dry season not only for energy generation but also for irrigation and navigation. Thus, these may be some of the reasons why Brazil uses a significant share of hydropower in its energy matrix.

However, when a hydroelectric power plant is implanted, a certain area must be evacuated and flooded. Thus, municipalities whose areas are occupied by the dam and the reservoir receive royalties for the occupation of their land by water for its use to generate electricity.

The royalties are called financial compensation for the use of hydric power, F, which is granted due to the exploitation of water resources for electricity generation purposes, corresponding to 6.75% of the generated electricity value, for power plants with capacity of 30 MW or above [3]. Equation 1 represents a mathematical formula to obtain F:

$$F = 0.0675\ e\ t \quad [1]$$

where:

F: Financial compensation for the use of hydric power (U$);
e: Electricity generated (MWh); and
t: Reference tariff (U$/MWh).

According to National Electric Energy Agency (ANEEL), out of this 6.75% tax, 6.00% is destined to the states, municipalities, Ministry of Mines and Energy (MME), Ministry of Environment (ME) and the National Scientific and Technological Development Fund (NFund) [3]. The remaining percentage (0.75%) is allocated to the National Water Agency (ANA), that uses it to implement the national water resources policy and management system.

The 6.00% are distributed as follows: 45% for the state where the plant is located; 45% for the municipalities flooded by the dam; and 10% for specific ministries and national research fund. The 10% are distributed as follows: 3% for the Ministry of Environment (ME); 3% for the Ministry of Mines and Energy (MME); and the remaining 4% for the National Scientific and Technological Development Fund (NFund) [3]. The amount allocated to each municipality depends on the proportion of the area flooded by the water of the reservoir and the energy generated by the power plant. Fig. 1 outlines the percentage distribution of these royalties.

In 2015, according to ANEEL [4], the royalties from hydro power plants, including the bi-national Itaipú hydroelectric power plant (Brazil and Paraguay) totaled approximately US$ 769.2 million. It should be noted that 40% of it are concentrated in few municipalities whose area is flooded by the dams of the hydroelectric plants rather than all the municipalities in the watershed of those reservoirs.

The Law 7,990, of December 28, 1989 established the royalty distribution to states and municipalities as described by [5]:

> "Art. 1 The use of water resources for the purpose of power generation and mineral resources by any of the regimes established by law shall entail compensation to the states, Federal District and Municipalities, to be calculated, distributed and applied as established in this Law."
>
> and
>
> "Art. 5. When the utilization of hydraulic potential reaches more than one state or municipality, the distribution of the percentages referred to in this Law shall be in proportion, taking into account the flooded areas ….."

It is about time to discuss the Law 7,990 from 1989, which determines how the royalties are calculated and distributed to municipalities involved with hydroelectric generation methodology. We emphasize that the resources distribution from electricity generation has been denied to municipalities that contribute to the water flow required for electricity generation in power plants, whose area is not necessarily flooded, though.

One important legal argument to prove that those municipalities and states are also entitled to receive royalties is stated in Brazilian Federal Constitution, 1988 in Title III - State Organization, Chapter II - the Union [6]:

> "Art. 20. The following are property of the Union:
> (...)
> III - the lakes, rivers and any watercourses in lands within its domain or that wash more than one state, …;
> (...)
> VIII - the hydraulic energy potentials;
> (...)
> § 1 – it is ensured under the law, to the states, the Federal District and to the municipalities, as well as to the direct administration of the Union, participation in the economic results as royalties of: oil or natural gas exploitation, water resources for purposes of electricity generation and other mineral resources production…"

Thus, it is possible to verify that water resources are public and the law guarantees the share in the results of their exploitation in municipalities upstream of the hydroelectric plant reservoirs. Therefore, since the current model does not comply with the Constitution, new regulations are needed for the distribution of royalties to municipalities in the basin of the hydropower.

As previously mentioned, the current National Electrical Energy Agency methodology only rewards the municipalities flooded by the water from the dam and disregards the fact that, in a hydroelectric power plant, energy generation depends on both the height of the waterfall and the flow rate, according to Oliveira [7].

Therefore, there is a mismatch between the legal and technical approach in the current mode of royalty distribution.

So, the present study aimed to propose a new distribution methodology of the royalties from the commercial exploitation of water resources for energy generation by adopting the watershed as a parameter for planning royalty distribution.

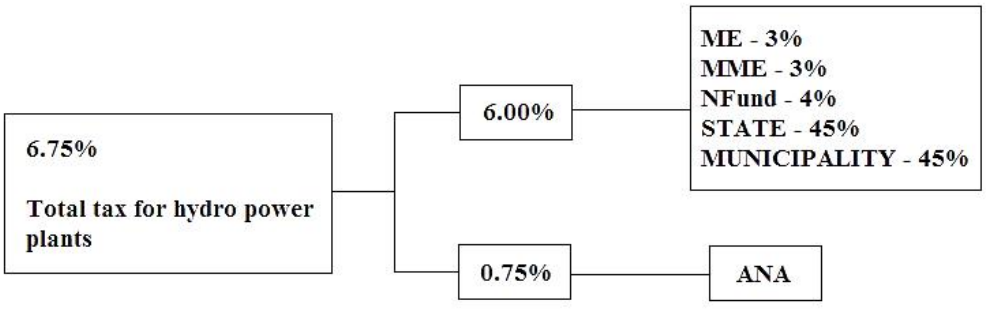

Fig. 1. Distribution of royalties of hydro power plants equal to or above 30 MW.
Source: [3]

2. MATERIALS AND METHODS

2.1 Characterization of the Study Area

We studied the Camargos hydropower plant to exemplify the purpose of this research. The construction of this plant began in 1956 and it started to operate in 1960. Located in the municipality of Itutinga, in the state of Minas Gerais, the Camargos hydropower plant dam is 608 m long, with maximum height of 36 m, reservoir volume equal to 0.792 km³ and an installed capacity of 45 MW [8]. The Camargos Dam area comprises the municipalities of Itutinga, Nazareno, Carrancas, São João Del Rei, Andrelândia, São Vicente de Minas and Madre de Deus de Minas. Its lake was formed by damming the Rio Grande by the Camargos dam and the reservoir area is 75.20 km² [9].

The Camargo hydroelectric plant was chosen for the study because this plant facilitates the exemplification and the understanding of the proposed methodology of distribution of royalties, besides its data are easier to obtain.

2.2 Municipal Limits and Hydrography

The boundary of the hydrographic basin for to the Camargos hydro power plant dam was obtained from data of the work of Menezes [10].

The territorial divisions of the municipalities of Minas Gerais were obtained from digital mesh data provided by IBGE [11] based on the year 2015, the last database available.

The boundary of the watershed was superimposed on the territorial divisions of the municipalities of Minas Gerais intercepted by the hydrographic basin using QGIS 2.18.13.

From the overlap was determined the area of drainage that each municipality contributes with the hydrographic basin upstream of the dam of the Camargos hydro power plant.

2.3 Financial Data

The financial data were obtained from public data available on the website of the National Electric Energy Agency (ANEEL). The year taken as the basis and that was analyzed is 2015, since it is the last year with all royalties available.

Table 1 presents the financial data used in the development of this article. It presents the municipalities that have their lands flooded by the Camargos hydro power plant dam, as well as the royalties, destined to the municipalities, and received in 2015.

Fig. 2 shows the Camargos hydro power plant reservoir and the municipalities intercepted by the dam.

2.4 Equation

The new methodology proposed for royalty distribution is based on the General Equation of the Electric Power Generated by the use of a waterfall in a hydroelectric plant. The general mathematical formula of electric power is shown on equation 2, [12].

$$G = \eta \rho g Q H \quad [2]$$

where:

G : Generated electric power (W);
η : Conversion energy efficiency, (%);
ρ : Specific mass (kg/m^3);
g : Acceleration of gravity (m/s^2);
Q : Water flow (m^3/s); and
H : Height of the waterfall (m).

Table 1. Municipalities that received royalties from the Camargos hydroelectric plant in 2015

Municipality	Flooded area (km²)	Flooded area (%)	Royalties (US$.year^{-1})
Andrelândia	0.20	0.27	132.58
Carrancas	26.60	35.37	17,633.50
Itutinga	6.90	9.18	4,574.10
Madre de Deus de Minas	15.50	20.60	10,275.16
Nazareno	5.60	7.45	3,712.32
São João del Rei	18.70	24.87	12,396.49
São Vicente de Minas	1.70	2.26	1,126.95
Total in 2015	75.20	100.00	49,851.11

Exchange rate: US$ 1.00 = R$ 3.25
Source: [4].

Fig.2. Camargos hydro power plant reservoir and the municipalities intercepted by the dam.

3. RESULTS AND DISCUSSION

All municipalities and their area belonging to Camargos hydro power plant dam watershed were identified. Table 2 presents the results of all municipalities that belong to the contribution basin of the plant reservoir under study, as well as their drainage areas.

Equation 2 evidences that the electric power generated in a hydroelectric plant varies according to the flow (Q) and the waterfall height (H) alone, since the remaining terms are constants. In other words, the generation of electricity in a power plant depends not only on the flooded area, which will provide the waterfall needed, but also on the water flow available, which depends on the water produced by all municipalities up the reservoir and contribute in the drainage area.

Since the generated electric power (G) is a direct function of only two variables, namely, flow rate (Q) and the height of the waterfall (H), the relative importance of both is the same, 50% each.

The new methodology proposed in this article prescribes that 50% of the royalties allocated to the municipalities will be distributed to all municipalities that contribute to the waterfall, and the remaining 50% will be allocated to all municipalities that collaborate with the water flow at the dam. This methodology is different from the current one, in which 100% of the royalties is given only to municipalities whose areas are flooded by the dam reservoir. It's based on the General Equation of the Electric Power Generated, described in equation 2.

The municipalities upstream the dam contribute with the water flow, since they are the key to the composition of the flow of the primary watercourse. This is due to water infiltration into the soil and the runoff in the river beds that occur in these municipalities.

At the same time, these municipalities have a given cost to preserve the remaining forest. In addition, they avoid the silting of dams, reduce erosion and contribute to infiltration and percolation, thus supplying the water table [13]. Therefore, these municipalities extend the life of the hydroelectric plant downstream and its water flow. Is it fair to deny them participation in the royalties?

The surface inflow supplies the surface water during rainy periods, and the subsurface flow supplies it during dry and rainy periods [14]. The areas related to those flows are called drainage areas or watershed [15]. Drainage areas produce flow to the river, so those areas can be called as water producers, and the municipalities located in those areas are water producer municipalities [4].

All municipalities that belong to the watershed upstream of Camargos hydroelectric dam are entitled to receive royalties because they produce the water that arrives at the dam. In addition, as mentioned previously the Brazilian Federal Constitution provides them the right to part of the royalties.

Table 2. Municipalities that belong to the watershed of the hydro power plant Camargos' dam and their respective drainage area

Municipality	Drainage Area (km²)
Andrelândia **	1,005.103
Carrancas **	374,222
Itutinga **	116,806
Madre de Deus de Minas **	493,997
Nazareno **	55,881
São João del Rei **	407,228
São Vicente de Minas **	391,396
Aiuruoca	271,231
Alagoa	139,471
Arantina	89,635
Baependi	0,289
Bocaina de Minas	258,359
Bom Jardim de Minas	220,833
Carvalhos	283,277
Conceição da Barra de Minas	0,625
Cruzália	0,238
Ibertioga	49,704
Itamonte	139,757
Liberdade	400,661
Lima Duarte	188,425
Minduri	218,648
Olaria	0,027
Passa-Vinte	1,248
Piedade do Rio Grande	322,722
Resende	0,499
Santa Rita de Ibitipoca	148,270
Santa Rita de Jacutinga	0,257
Santana do Garambeu	203,211
Seritinga	114,401
Serranos	211,328
Total	6,107.747

*** Municipalities whose land has been partly flooded by the dam of the Camargos hydroelectric power plant.*

Table 1 shows the municipalities and the royalty incomes they received in 2015 from Camargos hydro power plant. These values were obtained from the methodology in use, based on the Law 7,990 of 28 December 1989. Table 3 shows the amount of royalties proposed by the new distribution methodology, as well as the amount received in 2015 by the municipalities that belong to the Camargos hydro power plant. Please, note that the proposes new methodology to distributed the royalties from hydroelectric power plants the 50% due to water height and 50% due to the water flow are both equal to US$ 24,925.56, in 2015.

All the municipalities that are part of the contribution basin would receive royalties by the new methodology. As shown in Table 3, this distribution would be fairer, since all municipalities that contribute to the generation of electricity would receive royalties. Each municipality would be granted a portion of the compensation according to the percentage of contribution to the electricity generation.

The total drainage area of the contribution basin i.e. the watershed is the first parameter to distribute the royalties from hydroelectric generation. The logic is that this entire area drains water in the rainy and dry periods to the reservoir. It was considered that the water flow contribution to the hydro power plant is a function of the drainage area in the watershed, weighting 50%, in dollars of 2015 this was equivalent to US$ 24,925.56.

The second parameter to distribute the royalties from hydroelectric generation is the water height. Is was considered that the water height is a function of the flooded area, weighting the remaining 50% in dollars of 2015 this was equivalent again to US$ 24,925.56.

Table 3 shows that municipalities with flooded area receive income for two reasons. One is for their contribution to the flow of the dam and the other, for the water fall. Table 3 demonstrates the importance of the proposed methodology, which aims to favor a fair sharing of royalties for water producers according to the percentage of their contribution. Each municipality will define how to invest this income in its drainage basin for example: to the conservation of soil, water, biodiversity and/or for environmental services.

In many countries, international organizations and government agencies have implemented incentive policies for environmental services targeting the conservation of watersheds. In Brazil, the National Water Agency (ANA) has developed the Water Producer Program aiming to reduce the erosion and silting of water sources in rural areas and promote water and soil conservation measures. This program provides payment for farmers who contribute to the protection and recovery of water sources, thus generating benefits for the basin and the population [9,16,17].

Therefore, the royalties received by the municipalities could be used to intensify the actions of the Water Producer Program. It is a

strategic issue, since the preservation of soil and water decreases the silting of reservoirs and favors the maintenance of the fall rate, especially in periods of drought. Therefore, increased electricity generation is expected throughout the year. Besides, higher return of royalties to municipalities and states and increased energy security to those basins are other significant consequences.

Vegetation cover helps to prevent runoff and erosion, which take massive sedimentation to the riverbed and may result in the silting of the river and affect the flow and quality of the water that reaches the hydroelectric dam [18,19]. In addition, erosion intensifies sedimentation into the hydroelectric dam, which can silt it, increase its maintenance cost and decrease its total water volume capacity.

Furthermore, especially in the dry season, the water table supplies the river, which directly depends on a preserved soil with great water infiltration [20]. Areas where there is infiltration, surface flow and subsurface flow are called water producers [4].

According to Thompson et al. [21], a soil with greater vegetation cover has a higher rate of water infiltration. Hence, clear vegetation cutting negatively impacts the environment and reduces the amount of surface and ground water available [22].

As forecasted in the 2007 report from the Intergovernmental Panel on Climate Change (IPCC), due to increasing global temperature, significant changes are expected in the hydrological cycle, which will affect rainfall standards and increase evapotranspiration. These changes will affect the flow of rivers and groundwater supply [23]. Maybe, as a consequence of the events forecasted in the IPCC report, the droughts in 2001, 2014 and 2015 significantly affected the Brazilian energy sector. Therefore, investments in soil and water conservation policies would help minimizing the negative effects of hydrological cycle change.

The royalties could be total or partially used to decrease the impacts of humans on the environment, including actions to reduce deforestation areas. According to Bernsteinová et al. [24], the removal of vegetation cover can affect rain on site and runoff, which decreases water infiltration into the soil and its availability. The restoration of vegetation cover is one of the most effective ways to control runoff and prevent the loading of sediment into the rivers [25,18,26]. The restoration of vegetation cover is considered a great strategy to increase water production by municipalities, especially in the dry season.

In the current method of royalty granting, only 7 out of the 30 municipalities of Camargos hydro power plant basin are benefited, as shown in Table 1. It is unfair to benefit only these 7 municipalities, since other municipalities contribute to electricity generation. The proposed method provides for all 30 municipalities to receive royalties (Table 3). Flooded municipalities receive double compensation as they contribute to the flow and the waterfall. Those whose lands are not flooded by the dam receive a share according to the water they produce for the hydroelectric reservoir. It is worth mentioning that the watershed of Camargos hydro power plant is 6,107.7 km2, and only 75.2 km2 or around 1.23% of the total basin area is flooded.

Municipalities with flooded areas, which were considered, at first, as lost areas, can have their compensation justified in the current distribution model. The benefits they receive include: (i) the availability of water from the dam for irrigation, which maximizes the production area; (ii) water for the animals; (iii) fish farming activity, which could be a very profitable activity. Rocha [27], lists other benefits inherent to the very existence of the dam, including the potential for tourism and increased property valuation due to the proximity to the lake.

Lorenzon et al. [2] and [10] have proposed methods for the redistribution of the royalties from hydro power generation, in which water fall contributed with less than 50% of total royalties. Menezes et al. [10] proposed values around 24 %, while [2] proposed around 12%. In the present paper, we propose that both water fall, H, and water flow, Q, be equally valued as 50% of the total to be distributed as royalties, since, as shown in equation 2, both parameters, i. e. H and Q, are equally important for electrical power generation. Therefore, the values proposed by Lorenzon et al. [2] and [10] are argued.

As explained above, the method proposed in this paper is based on the premise that the royalties should be shared into two equal parts. One part is for the payment for the municipalities that contribute to the flow, and the other, to the municipalities that contribute to the water fall. On

the other hand, [2] and [10] use mathematical formulas without physical base to determine the contribution ratio of water flow and waterfall to generate electricity. One cannot compare the relative importance of two parameters that have different units, as the cited authors did. The results of the formulas they used were always different for the two parameters H and Q. This distribution method is not appropriate because the importance of flow and height of a waterfall must always be equal in the general equation of the electric power generated by the use of waterfall in a hydroelectric power plant (Equation 2).

Table 3. Royalties proposed in the new methodology and received by the municipalities of Camargos hydro power plant watershed, in 2015

Municipality	D_A (km²)	F_A (km²)	R_Q (US$/year)	R_H (US$/year)	Total royalties proposed (US$/year)	Present royalties received (US$/year)
Andrelândia	1,005.103	0.2	4,101.80	66.29	4,168.09	132.58
Carrancas	374.222	26.6	1,527.19	8,816.75	10,343.94	17,633.50
Itutinga	116.806	6.9	476.68	2,287.05	2,763.74	4,574.10
Madre de Deus de Minas	493.997	15.5	2,015.99	5,137.58	7,153.57	10,275.16
Nazareno	55.881	5.6	228.05	1,856.16	2,084.21	3,712.32
São João del Rei	407.228	18.7	1,661.89	6,198.24	7,860.13	12,396.49
São Vicente de Minas	391.396	1.7	1,597.28	563.48	2,160.75	1,126.95
Aiuruoca	271.231	0.0	1,106.89	0.00	1,106.89	
Alagoa	139.471	0.0	569.18	0.00	569.18	
Arantina	89.635	0.0	365.80	0.00	365.80	
Baependi	0.289	0.0	1.18	0.00	1.18	
Bocaina de Minas	258.359	0.0	1,054.35	0.00	1,054.35	
Bom Jardim de Minas	220.833	0.0	901.21	0.00	901.21	
Carvalhos	283.277	0.0	1,156.05	0.00	1,156.05	
Conceição da Barra de Minas	0.625	0.0	2.55	0.00	2.55	
Cruzália	0.238	0.0	0.97	0.00	0.97	
Ibertioga	49.704	0.0	202.84	0.00	202.84	
Itamonte	139.757	0.0	570.34	0.00	570.34	
Liberdade	400.661	0.0	1,635.09	0.00	1,635.09	
Lima Duarte	188.425	0.0	768.96	0.00	768.96	
Minduri	218.648	0.0	892.30	0.00	892.30	
Olara	0.027	0.0	0.11	0.00	0.11	
Passa-Vinte	1.248	0.0	5.09	0.00	5.09	
Piedade do Rio Grande	322.722	0.0	1,317.02	0.00	1,317.02	
Resende	0.499	0.0	2.03	0.00	2.03	
Santa Rita de Ibitipoca	148.270	0.0	605.09	0.00	605.09	
Santa Rita de Jacutinga	0.257	0.0	1.05	0.00	1.05	
Santana do Garambeu	203.211	0.0	829.30	0.00	829.30	
Seritinga	114.401	0.0	466.87	0.00	466.87	
Serranos	211.328	0.0	862.42	0.00	862.42	
Total	6,107.747	75.2	24,925.56	24,925.56	49,851.12	49,851.12

FA: Flooded area; DA: Drainage area; RQ: Royalties due to flow rate; RH: Royalties due to waterfall height. Exchange rate: US$ 1.00 = R$ 3.25

Table 3 shows the financial figures related to the royalties, which can be considered low values. This is due to the fact that Camargos hydro power plant is a small hydroelectric power plant that generates only 45 MW. So, the electricity generation is low and consequently the royalties in 2015, which totaled US$ 49,851.12, were also low. In addition, rainfall in the Southeastern Brazil was low in 2015, which compromised electricity generation. We used this plant only to illustrate the proposed method.

In 2015, the hydroelectric power plant of Tucuruí I and II; Santo Antonio; and Ilha Solteira granted, respectively, US$ 25,830,116.37; US$ 7,788,573.29; and US$ 6,586,279.51, in royalties to the municipalities [4] Such income shows a substantial amount of money involved in compensation distribution. If the distribution were based on the proposed methodology, many other municipalities, besides the few flooded, would be granted royalties to improve the municipal budget, so that they could invest in water and soil preservation. These three power plants are second only to the Itaipu hydro power plant in electricity generation, in Brazil.

Farias [28] shows a linear growth trend royalties payment along the years. He also highlights the need for research on the compensation payment criteria, since the current method favors income and wealth concentration in a few municipalities.

The new methodology proposed is reliable and at the same time valid because it is based on the technical aspect of electric energy generation, described by equation 2, and also distributes the royalties proportionally to all municipalities that contribute to the generation of electric energy.

4. CONCLUSION

This research highlight the need to review the current criteria for royalty distribution for the electricity generation from water resources. The Brazilian Federal Constitution provides for the participation of all municipalities upstream the hydroelectric dam in the results of the exploitation of water resources even if they are not flooded.

The current distribution criterion promotes the concentration of wealth in municipalities bordering the dam and increases social and local disparities.

The methodology of royalty distribution proposed promotes a much fairer distribution for all municipalities participating in the basin and the hydroelectric power plant dam, since all of them contribute to the generation of electricity. It shares the financial taxation reserved to royalties into two parcels of 50%. One is for contributions to the flow of a river and the other, for contributions to the water fall height. The methodology is based on technical aspects of power generation as well as the concept of water production.

Furthermore, the new method proposes a better distribution of the wealth arising from the compensation for all the municipalities of the basin and reduces social inequality.

The present research aims to contribute with the discussion on the improvement of regulations regarding the distribution of royalties from hydro power plants. Such discussions will involve the federal agencies related to the subject, Water and Electrical Energy Agencies and finally, the legislative and executive powers, for the promulgation of new laws.

As a subject for further research, it is important to realize that a given unit of area, let us say 1 km², may have different water retention condition hence contributing in diverse ways to water flow along the year, since each soil may have unique characteristics related to water retention. Therefore, the ability to retain more or less water in the soil should be considered as a step even more precise than the drainage area and water fall height.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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