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Estimation of methane emissions from reservoirs for hydroelectric generation in Costa Rica

Estimaciones de las emisiones de metano de embalses para la generación hidroeléctrica en Costa Rica

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ABSTRACT: Greenhouse gas emissions are related to non-renewable sources. For this reason, the methodological guide for the estimation of methane and carbon dioxide emissions in flooded lands was published in 2006 by the Intergovernmental Panel on Climate Change. Since 2016, several studies have been carried out in temperate and tropical zones reservoirs. Costa Rica is a Central American country known for its large hydroelectric resources and its highly renewable electricity generation matrix. This work represents the first study for 11 of 24 hydroelectric plants managed by the Costa Rican Electricity Institute. Methane emissions, energy density and emission factors for electricity generation are determined. Furthermore, a static mathematical model is used to determine these factors with little input data. It is estimated that the greatest contribution to methane emissions corresponds to the Arenal reservoir, which has the largest surface area and the lowest energy density.

RESUMEN: Las emisiones de gases de efecto invernadero están relacionadas con fuentes no renovables; sin embargo, la guía metodológica para la estimación de las emisiones de metano y dióxido de carbono en terrenos inundados fue publicada en el año 2006 por el Grupo Intergubernamental de Expertos sobre el Cambio Climático. Diez años después, se han realizado varios estudios sobre la estimación de gas metano en yacimientos ubicados en zonas templadas y tropicales. Costa Rica es un país centroamericano conocido por sus grandes recursos hidroeléctricos y su matriz de generación eléctrica altamente renovable. Este trabajo es el primer estudio, para 11 de los 24 embalses hidroeléctricos gestionados por el Instituto Costarricense de Electricidad, donde se determinan las emisiones de metano, la densidad energética y los factores de emisión para la generación de electricidad. Se utiliza un modelo matemático estático para determinar estos factores con escasos datos de entrada, estimando que el mayor aporte en emisiones de metano corresponde al embalse del Arenal, que es el de mayor superficie y el de menor densidad energética.

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1. Introduction

Since the development of countries and the production of electricity are closely related, hydropower is just one

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of many different types of technologies that have been developed to meet this need [1]. Among the regions of the world, Latin America has developed enough potential for this type of generation. According to Jang *et al.* [2, 3], this has made it possible to offer the service to more people at the lowest possible price. Policies for new facilities or expansion of existing ones have been halted due to the vulnerability of water reservoirs, electricity production, and other infrastructure to climate change and other extreme weather events [4, 5].

One of the problems facing civilization is climate change caused by greenhouse gases (GHG) from anthropogenic and natural sources [6]. The Paris Agreement aims to end global poverty, reduce emissions everywhere, and limit the increase in average global temperature to 1.5 °C by 2030 [7, 8].

The energy industry will emit more than 33,884.1 million tons of $\mathrm{CO_2}$-eq into the environment in 2021, according to the most recent statistical data from British Petroleum (bp) [9]. South America's contribution to this total is only 4.7% (1,586.9 million tons of $\mathrm{CO_2}$-eq), partly because most of its generation depends on hydropower. By way of illustration, the generation for the same year is 40.26 and 6.55 EJ (input-equivalent), or 16.3%, globally and in South America, respectively [9].

Global environmental trends and regulations aim to reduce GHG emissions by standardizing procedures and continuously improving ecosystem conservation. Therefore, renewable energy sources should replace fossil fuel technology [10]. Hydroelectric power production increased by more than 60% worldwide between 1995 and 2010, according to data from the United Nations Educational, Scientific, and Cultural Organization (UNESCO), notably benefiting countries in Latin America, Africa, and Asia [11].

For a time, it was thought that new hydroelectric dams did not emit GHG [12]. Enriquez and Cremona [13] affirm that state the main contribution of water reservoirs to climate change is through the emissions of CO_2 and methane (CH_4) to the earth's atmosphere, through the water surface [14–16], and that also increases its carbon footprint [17]. This is true even though they favor the accumulation of carbon dioxide (CO_2) in their sediments and do not participate. In addition to lakes, marshes, open inland water bodies, karst waterfalls, and other natural sources, these emissions may also come from reservoirs used for hydropower [18–20], reservoirs used for other purposes [21, 22], and other hydropower [19].

The Intergovernmental Panel on Climate Change (IPCC) has shown that 22% of total CH_4 emissions are attributed to water storage in reservoirs and lakes, due to flooded land [11]. Annual CH_4 emissions are only 3% by weight of those associated with CO_2 (0.56 $GtCH_4$/year versus 14.5 $GtCO_2$/year). However, CH_4 has a radiative forcing approximately 120 times greater than CO_2 immediately after its emission [23]. In this framework, CH_4 emissions from reservoirs could represent 12% of global emissions of this gas [24].

Aspects such as the morphology of the reservoir, its use, the physicochemical characteristics of the water, the external contributions of carbon by runoff and organic matter carried by the rivers that feed it and, finally, the point of the life cycle at which it is located must be taken into account in order to quantify the contribution of emissions to climate change [15, 16, 25]. There are significant temporal variations with respect to tropical zones [26–28], such as in Costa Rica [29] and Colombia [30], or temperate zones [19, 22]. Their own evaporation processes, accelerated by climate change, also give them spatial properties [5, 20]. In warmer latitudes, emissions are higher, which adds a negative argument regarding the use of hydropower in these regions [11]. The IPCC offers methodological guidance; there are several approaches that use direct measurement to obtain their estimate [31, 32].

It should be noted that the methodology provided by the IPCC is not complete enough to provide accurate measurements of CH_4 emissions, as these depend on variables such as depth, age of the reservoir, as well as climate and previous use, and pre-flood use; however, it is applicable for estimates where direct measurements are not taken [31].

Due to the regulations implemented to achieve carbon neutrality in the country's energy and transportation sectors, Costa Rica, a natural resource-rich nation in Latin America, has an energy matrix focused on renewable sources [33]. More than 65% of the country's electricity is produced by hydroelectricity, with an installed capacity of 2,343 MW [34]. This indicates that their reservoirs contribute to GHG emissions from electricity generation. The objective of this work is to estimate CH_4 emissions from the reservoirs of 11 hydroelectric generation plants in the country managed by the Costa Rican Electricity Institute (ICE).

This article includes a section on CH_4 emissions from land flooded by hydroelectric reservoirs, such as diffusive, bubble, or gas emissions, and outgassing emissions. Subsequently, a section is dedicated to the CO_2 emissions that were produced in the first ten years of the formation of the reservoir. In addition, the 11 reservoirs in Costa Rica are included with their years of operation.

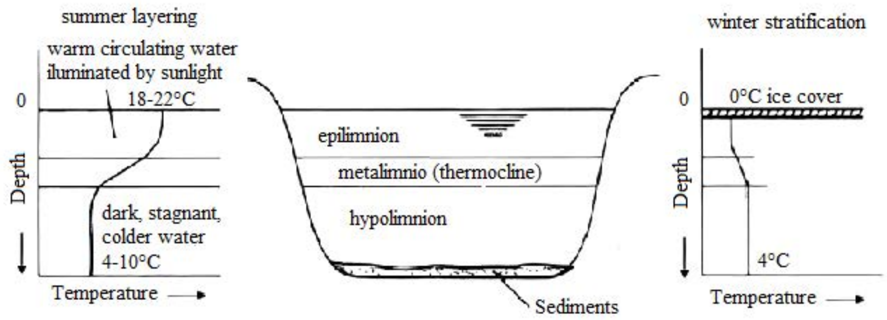

Figure 1 Thermal stratification of a deep lake [40, 41]

2. Development

2.1 CH_4 emissions

The construction of reservoirs and hydroelectric dams because of the flooding of large areas of land is one of the human consequences. In the reservoir construction stage, large amounts of organic matter present in the soil after flooding lead to its decomposition, forming and releasing CO_2 and CH_4 [15, 25]. In the deepest part of the reservoirs (hypolimnion), the water layer has little oxygen, and only under these conditions, does CH_4 have the particularity of oxidizing and turning into CO_2 when it reaches the surface [35]- In reservoirs located in tropical areas, with little water, they do not allow CH_4 bubbles to oxidize and therefore tend to contribute high GHG emissions [36–39].

In tropical latitudes, a thermal stratification of the water is formed, depending on its density and temperature, which are classified as epilimnion (superficial layer), metalimnion (intermediate layer) and, finally, hypolimnion (bottom of the reservoir). In this stratification, which causes extreme temperature changes between the layers, there is no mixing between the epilimnion and the hypolimnion without the presence of an external factor such as wind or temperature variations. These variations force the mixture to generate a variation in the stability of the water column, causing effects on the dynamics of the oxygen present and the formation and emission of GHG in hydroelectric reservoirs [25]. Figure 1 shows the vertical temperature profile of the reservoirs.

Some of the variables that affect the decomposition of organic matter in a reservoir are age, temperature, depth, geographic location, water residence time, shape and volume, and the amount and type of flooded vegetation [35]. The age of the reservoir and the type and amount of vegetation, which have been shown to increase in the period immediately after reservoir creation, have the greatest impact on CH_4 emissions [42].

According to the IPCC [31], CH_4 emissions in flooded land can be caused by:

- Diffusive emissions originated by molecular propagation through the air-water interface.
- Emissions of bubbles or gases from the sediment through the water column in the form of bubbles. This is a major source of CH_4 emissions, especially in temperate and tropical regions. However, country-specific factors are required to estimate these emissions.
- Outgassing emissions because of a sudden change in hydrostatic pressure as well as large air/water exchange surface. This occurs when water flows through any outlet or a turbine.

Based on the methodology established by the IPCC [31], each of the emissions reflects a tier. Levels 1, 2, and 3 reflect diffusive, bubble, or gas emissions and finally refer to the complete approach that includes the previous two (2) plus outgassing, respectively. However, Level 2, bubble, or gas emissions, is applicable in temperate zones, where there are ice and ice-free seasons. Finally, the choice of the estimation method depends on the availability of data and emission factors in each country.

2.2 CO_2 emissions

The GHG fluxes are significantly affected by the time elapsed since a significant area of land was inundated. The rate of change of post-flood emissions may depend on the location of the reservoir; however, it appears to vary over a ten (10) year period [43]. Evidence suggests that CO_2 emissions during the first ten (10) years are the result of the decomposition of organic matter previously existing in the land before the flood. Beyond this period, CO_2 emissions are sustained by the transfer of organic matter between reservoir inlets and floods. For this reason, only the first ten (10) years after the flood are considered to estimate emissions [43]. After a flood and any cleanup, CO_2 emissions from land converted to flooded land can occur through the same pathways as CH_4 emissions, i.e., diffusive, bubbling, and outgassing emissions.

2.3 Reservoirs in Costa Rica

In 2011, the installed hydroelectric generation capacity in Central America was estimated at around 5,000 MW, of which Costa Rica represented approximately 1,644 MW [44]. According to [34], Costa Rica has a diverse energy matrix with different types of generation (Table 1), where more than 85% comes from renewable sources. Gross electricity generation for the year 2019 was 11,312.85 GWh, of which 99.15% corresponds to energy generated with renewable sources and only 0.85% with thermoelectric energy. Hydroelectric generation is the one with the highest proportion, with 69.18% of the total, showing the relevance of this type of source for the country. The general information of the reservoirs under study belonging to the National Electric System (SEN) is shown in Table 2, and the geographic location of the reservoirs under study can be detailed in Figure 2.

Table 1 Generation in Costa Rica (2020) [45]

Generation Source	Installed capacity (MW)	% of total
Hydroelectric	2,331,291	65.91
Thermoelectric	474,112	13.40
Geothermal	261,860	7.40
Bagasse	71,000	2.01
Wind	393,515	11.13
Solar	5,400	0.15
Total	3,537,178	100.00

2.4 Energy generated in hydroelectric reservoirs

The reservoirs under study have a total power of 1,412 MW, which represents 60.27% of the total power plants of the ICE group. This represents 65.70% of the total installed capacity and 2,343 MW of installed hydroelectric generation (public and private), which is combined with other generation sources [28]. Table 3 shows the electric power generated by these reservoirs. This information is presented by the National Energy Control Center (CENCE) and will be used to estimate the Emission Factor of Electricity Generation (EFEG) resulting from the use of hydroelectric sources.

3. Methodology

3.1 CH_4 emissions

According to the Kyoto Protocol [56], a project with a power density lower than $5 \mathrm{MW}/\mathrm{km}^2$ is not considered

Table 2 General information on hydroelectric reservoirs under study (2020) based on [47–52]

Dam or Reservoir	Year of start of operation	Installed Capacity (MW)	Surface area ((ha)
Arenal	1979	157.4	8,780.00
Reventazón	2010-2016	305.5	700.00
Cachí	1966	160.0	324.00
Angostura	1992-2000	172.2	256.00
Pirris	2011	134.0	114.00
Dam or Reservoir	**Year of start of operation**	**Installed Capacity (MW)**	**Surface area ((ha)**
Sandillal	1992	32.0	71.00
Peñas Blancas	2000-2002	37.7	23.00
Garita I	1953-1958	37.4	7.60
Río Macho	1978	120.0	6.00
Cari Blanco	2003-2007	82.0	0.48

Table 3 Electricity generated by the hydroelectric power plants under study based on [34, 53–55]

Dam or Reservoir	Energy (MWh)			
	2016	2017	2018	2019
Arenal	763,624.01	642,770.30	765,709.25	725,805.50
Reventazón	748,660.39	979,820.81	635,080.16	845,631.50
Cachí	513,258.72	392,740.57	370,599.97	414,901.23
Angostura	674,339.90	654,222.44	553,716.32	601,565.06
Pirris	419,332.82	548,628.39	336,855.73	372,906.01
Sandillal	143,381.83	118,696.05	144,171.64	137,053.89
Peñas Blancas	152,169.90	153,468.27	157,367.74	136,991.84
Garita 1 y 2	182,125.86	175,771.58	180,678.27	159,634.81
Río Macho	192,937.09	498,425.13	536,535.71	418,563.15
Cari Blanco	226,838.40	254,722.37	261,866.47	181,702.20

emission-free. According to the IPCC methodological guidelines [31], Equation (1) is used to estimate the diffusive emissions of CH_4 in (1).

$$CH_4 E = P * E\left(CH_4\right)_{dif} * A_t * 10^{-6} \qquad (1)$$

Where:

- CH_4 E: total CH_4 emissions from floodplains $(\mathrm{GgCH_4}$ year $^{-1})$
- P: Ice-free period expressed in days per year $^{-1}$ (365 days, for our case study).
- $E\left(\mathrm{CH_4}\right)_{\mathrm{dif}}$: Daily average of diffusive emissions $(\mathrm{kg}$ of $\mathrm{CH_4 ha}^{-1}$ day $^{-1})$
- A_t: average total surface of the flooded surface (ha).

Table 4 shows the average daily value of diffusive emissions, data taken from [31].

According to the IPCC, hydroelectric reservoirs are classified with a climate called very humid tropical [31]. This is based on the geographic location of the reservoirs (latitude and longitude) and the Köppen-Geiger global climate classification [12]. To make comparisons of the emissions of the different GHG, the conversion factors to

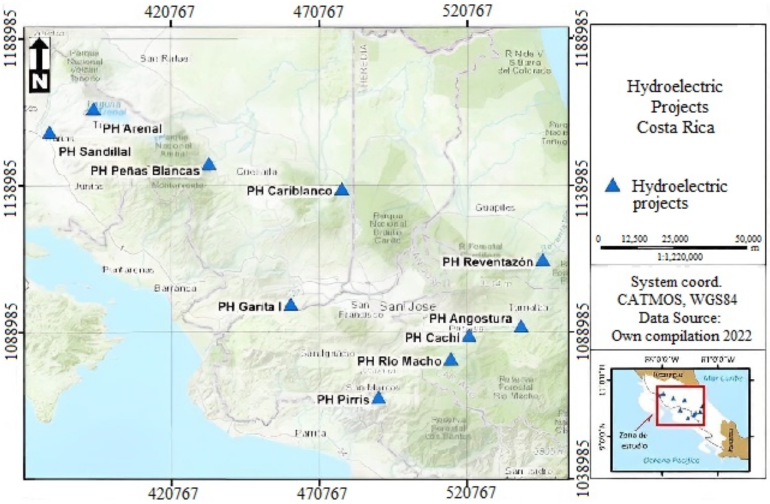

Figure 2 Geographical location of the Costa Rican hydroelectric reservoirs under study [46]

Table 4 CH_4 emissions from flooded lands [31]

Weather	Diffusive Emissions ($\mathrm{kgCH_4ha^{-1}day^{-1}}$)		
	Median	**Minimal**	**Maximum**
Polar/very humid boreal	0.086	0.011	0.30
Cool temperate, humid	0.061	0.001	0.20
Warm temperate, humid	0.150	-0.050	1.10
Warm temperate, dry	0.044	0.032	0.09
Tropical, very humid	0.630	0.067	1.30
Tropical, dry	0.295	0.070	1.10

CO_2 equivalent ($\mathrm{CO_2}$-eq) are used [11]. For this purpose, the Global Warming Potential (GWP) with a value of 21 for CH_4 is used [12]. Equation (2) shows the calculation of $\mathrm{CO_2}$-eq emissions.

$$\mathrm{CO}_{2-eq} \text{ of } \mathrm{CH}_4 = \text{ Molecular weight of } \mathrm{CH}_4 * GWP_{\mathrm{CH}_4} \quad (2)$$

3.2 CO_2 emissions

According to IPCC methodological guidelines [43], the estimate of CO_2 diffusive emissions is given by Equation (3).

$$CO_2E = P * E\left(\mathrm{CO}_2\right)_{\text{dif}} * A_t * f_A * 10^{-6} \quad (3)$$

Where:

- CO_2 E: total CO_2 emissions from flooded land ($\mathrm{GgCO_2}$ year $^{-1}$)
- P: Ice-free period given in days per year $^{-1}$ (365 days, for our case study).
- $\underline{\underline{E}}\left(\mathrm{CO}_2\right)_{\text{dif}}$: Daily average of diffusive emissions (kg of $\mathrm{CO_2ha^{-1}}$ day $^{-1}$)
- A_t: average total area of the flooded surface (ha)
- f_A: fraction of the total reservoir area that has been flooded in the last ten years (a value of 100% = 1 is used in our case study).

Table 5 shows the daily average value of diffusive emissions for CO_2.

Table 5 CO_2 emissions from flooded lands [43]

Weather	Diffusive Emissions ($\mathrm{kgCO_2ha^{-1}day^{-1}}$)		
	Median	**Minimal**	**Maximum**
Polar/very humid boreal	11.8	0.8	34.5
Cool temperate, humid	15.2	4.5	86.3
Warm temperate, humid	8.1	-10.3	57.5
Warm temperate, dry	5.2	-12.0	31.0
Tropical, very humid	44.9	11.5	90.9
Tropical, dry	39.1	11.7	58.7

4. Results

4.1 Emissions

Table 6 shows the CH_4, CO_2 and $\mathrm{CO_2}$-eq emissions per year for each reservoir. It should be mentioned that due to their age, the Reventazón and Pirris reservoirs, and the IPCC's recommendations [43], emissions are predicted to be added to GHG emissions until 2020 and 2021 for each reservoir, respectively. After this year, only CH_4 emissions are considered for each reservoir. Table 6 shows the CH_4 emissions per year, where the highest contribution is given by the Arenal reservoir with 2.0190 Gg.

4.2 Energy density

Table 7 shows the energy density of hydropower plants using data of Table 1. Additionally, this table shows that the highest density corresponds to Cari Blanco, with more than 17,000 MW/km^2.

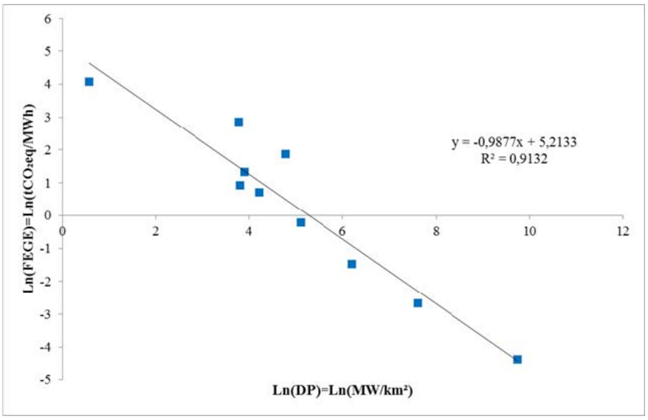

Figure 3 Mathematical model of the relationship between energy density and EFEG

Table 6 Emissions of CH_4, CO_2 and CO_2-eq for the reservoirs under study

Dam or Reservoir	GgCH_4/year	GgCO_2/year	tCO_2-eq/year
Arenal	2.0190	-	42,398.18
Reventazón	0.1610	11.4720	14,852.22
Cachí	0.0745	-	1,564.58
Angostura	0.0589	-	1,236.21
Pirris	0.0262	1.8683	2,418.79
Sandillal	0.0163	-	342.86
Peñas Blancas	0.0053	-	111.07
Garita I	0.0017	-	36.70
Río Macho	0.0014	-	28.97
Cari Blanco	0.0001	-	2.32

Table 7 Energy density of the reservoirs studied

Dam or Reservoir	Energy Density (MW/km^2)
Arenal	1.79
Reventazón	43.64
Cachí	49.38
Angostura	67.27
Pirris	117.54
Sandillal	45.03
Peñas Blancas	164.09
Garita	1 491.58
Macho River	2,000.00
Cari Blanco	17,083.33

Table 8 EFEG for the period 2016 - 2019 for the reservoirs under study

Dam or Reservoir	Emission Factor (EFEG) = (tCO_2-eq/MWh) * 10^{-3}			
	2016	2017	2018	2019
Arenal	55.52	65.96	55.37	58.42
Reventazón	19.84	15.16	23.39	17.56
Cachí	3.50	3.98	4.22	3.77
Angostura	1.83	1.89	2.23	2.05
Pirris	5.77	4.41	7.18	6.49
Sandillal	2.39	2.89	2.38	2.50
Peñas Blancas	0.73	0.72	0.71	0.81
Garita I	0.20	0.21	0.20	0.23
Río Macho	0.15	0.06	0.05	0.07
Cari Blanco	0.01	0.01	0.01	0.01

4.3 Emission Factor of Electricity Generation

Based on the CO_2-eq emissions for each reservoir, extracted from Table 6, and the data shown in Table 3 regarding the energy generated per year, the EFEG for the reservoirs under study are determined as shown in Table 8.

4.4 Mathematical model

Maybe a non-dynamic mathematical model, that was created by looking at each reservoir's EFEG for the year 2019 and comparing it with its energy density is applied to create an equation for recalculating the GHG emission estimations. This section is based on the IHA [57] indicating that run-of-river hydroelectric plants or with a power density of not less than 5 W/m^2 will not necessarily have to carry out their GHG emissions assessment based on their life cycle. In addition, [58] determines the mathematical model using the EFEG and the Power Density of the reservoirs for Colombia.

Due to the large scale between the energy density data and the EFEG, the Neperian logarithm tool is applied to make the data easier to handle. A scatter plot is also used to plot these transformed values. Equation 4 shown in Figure 3 is derived from the trend line, together with the coefficient of determination (R^2 =0.9132), which indicates a correlation (R) of the data of 95.56%.

$$y = -0.9877x + 5.2133 \tag{4}$$

Where:

x: Neperian logarithm of the energy density of the selected reservoir.

y: Neperian logarithm of EFEG.

It is important to note that the coefficient of determination R^2 expresses the proportion of the total variation of the values of the variable and that are caused or explained by a

Table 9 EFEG for the period 2016 - 2019 for the reservoirs under study

Reservoir	EFEG estimated (tCO_2-eq/MWh) * 10^{-3}	
	Mathematical model	IPCC Methodology
Arenal	103.208	58.415
Reventazón	4.409	17.563
Cachí	3.903	3.771
Angostura	2.876	2.055
Pirris	1.657	6.486
Sandillal	4.275	2.502
Peñas Blancas	1.192	0.811
Garita I	0.403	0.230
Río Macho	0.101	0.069
Cari Blanco	0.012	0.013
Median of data	2.267	2.055

Table 10 EFEG for the period 2016-2019 for Costa Rica

EFEG= (tCO_2-eq/MWh) * 10^{-3}				
2016	**2017**	**2018**	**2019**	**2019***
89.49	95.29	95.74	91.92	122.04

*With the mathematical model

linear relationship with the values of the random variable *x* [59]. For this section, the correlation coefficient (R) shows a close relationship between the random variables considered, such as energy density (variable *x*) and EFEG (variable *y*).

Table 9 shows the new EFEG values obtained using Equation 4, where there is proximity in the values with certain exceptions. Table 10 shows the EFEG for the period 2016-2019 obtained from the IPCC methodology and additional for the year 2019 as part of the use of the mathematical model. This emission accounting model used in this work differs from the methodology used by the National Meteorological Institute (IMN) of Costa Rica for the annual calculation of emission factors, which only considers emissions from non-renewable energy [60].

5. Conclusions

Regarding the estimated CH_4 emissions of the reservoirs under study, a high contribution of 85.39% of the total corresponds to the Arenal dam, with more than 2.0 Gg of this GHG per year, having the lowest energy density (less than 2.0 MW/km^2). The Cari Blanco dam has more than 17,000 MW/km^2 with the lowest CH_4 emissions. This shows an inverse relationship between GHG emissions and energy density.

Applying the static mathematical model proposed as a new way of computing the EFEG, a good approximation of the results obtained can be seen, with certain exceptions due to the nature of the model. Comparing the medians of the data sets, it was not determined a high disparity, thus taking the model obtained as a valid approximation method with a smaller amount of input data.
All of Costa Rica's EFEG for the years 2016 to 2019 provided by the reservoirs under consideration, accounting for more than 55% of the nation's installed hydroelectric capacity, is less than 100 tCO_2-eq/MWh*10-3.

6. Declaration of competing interest

We declare that we have no significant competing interests, including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

7. knowledgements

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9. Author contributions

Conceptualization: R.O. Pérez, R. Ramírez, L. Suárez and C. Vásquez; Methodology: R. O. Pérez and L. Suárez; Validation: R. O. Pérez and L. Suárez; Formal analysis: R.O. Pérez, R. Ramírez and C. Vásquez; Investigation: R. O. Pérez and C. Vásquez; Data curation: R. O. Pérez, R. Ramírez and C. Vásquez; Writing—original draft preparation and visualization: R. O. Pérez, C. Vásquez, M. Gaitán and M. Gómez. All authors have read and agreed to the published version of the manuscript.

10. Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

11. Complements

Table 11 Complementary information on hydroelectric reservoirs under study (2020) based on [47–52]

Reservoir	River	Location	
		State/City	Coordinates
Arenal	River and streams of the Arenal Lagoon basin	Guanacaste	10°32'00"N 84°56'00"O
Reventazón	Reventazón	Limón	10°04'33"N 83°34'25"O
Cachí	Reventazón	Cartago	9°49'38"N 83°49'00"O
Angostura	Reventazón, Tuis and Turrialba	Cartago	9°52'00"N 83°40'00"O
Pirrís	Middle basin of the Pirrís river	San José	9°38'35"N 84°05'54"O
Sandillal	Sandillal reservoir and Santa Rosa River	Guanacaste	10°27'42"N 85°05'54"O
Peñas Blancas	Peñas Blancas	Alajuela	10°23'4"N 84°34'45"O
Garita I	Grande de Alajuela, Poás, Ciruelas and Alajuela	Alajuela	9°59'21"N 84°20'26"O
Río Macho	Río Macho, Tapantí, Porras Blanco, Badilla, Humo, Villegas and Pejibaye.	Cartago	9°46'31"N 83°50'28"O
Cari Blanco	Cari Blanco	Alajuela	10°14'33"N 84°9'50"O

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