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Assessment of Greenhouse Gas (GHG) Emission from Hydropower Reservoirs in Malaysia †

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Abstract: This paper presents a preliminary assessment of greenhouse gas (GHG) emissions from all major hydropower reservoirs in Malaysia from the period of 1930–2017. The GHG emissions are calculated based on the Tier 1 method as recommended in International Government Panel on Climate Change (IPCC) guidelines. The results showed that approximately 151.64 Gg of annual methane emission released from hydropower dams in Peninsular Malaysia. While in East Malaysia, hydropower dams release 235.7 Gg of methane emission annually. Bakun dam contributes the most 41.26% of total annual methane emission from hydropower dams in Malaysia. Ulu Jelai hydroelectric dam with design power capacity of 372 MW contributes the least CH_4 emission of 0.02 Gg CH_4 yr^{-1}. It is seen that high head hydroelectric dam with small reservoir surface area is the most sustainable hydropower dam in reducing the GHG emission. However, long-term measurements must be made in order to clarify the net GHG emissions from reservoir surface, turbines, spillway and downstream river of hydropower dams in Malaysia.

Keywords: Hydropower; life cycle assessment; renewable energy; greenhouse gases; tropical reservoir

1. Introduction

Freshwater reservoirs have always providing many benefits to human activities which including drinking water supply, agricultural needs, hydropower generation and industrial purposes [1]. However, greenhouse gas (GHG) emissions including carbon dioxide (CO_2) and methane (CH_4) from hydropower reservoirs have been increasingly concerned recently [2], and some studies have questioned the green credentials of hydropower reservoirs [3]. The human-induced carbon emission from hydropower reservoirs represents a crucial component in global carbon cycling and becomes increasingly interested [2,4–6]. Barros et al. [2] estimated the carbon emissions of 176 Tg CO_2/year and 4.4 Tg CH_4/year from global hydroelectric reservoirs. According to Ivan et al. [7], the world's large dams contributed about 104 million metric tons of methane annually from reservoir surface, turbines, spillways and river downstream. This implied that methane emissions from dam are responsible for at least 4% of the total warming impact of human activities. St. Louis et al. [8] estimated that CH4 emissions from reservoirs could represent 12% of global CH_4 emissions.

Methane is produced at the bottom of dam from the degradation of plants, organic matters (plankton, algae, etc.) and soils flooded by the reservoirs. Gases are released from the surface of the dam, at turbines and spillways, and for tens of kilometers downstream. It was understand and believed that about 15 percent of all methane emissions came from the surface of hydropower dams [4]. Rivers downstream of dams accounted for a significant fraction (9–33% for CH4 and 7–25% for CO_2) of the emissions across the reservoir surfaces classically taken into account for reservoirs [9]. One of the dam-related process that have the highest warming impact is occurred during the release of methane-rich deep water through outlet of dam and most of the dissolved methane is released directly into the atmosphere [10]. The Brazil's National Institute for Space Research (INPE) researchers estimate that 95% of dam methane emissions are from spillways, turbines and downstream [7].

Studies shows that dams in tropical environments can release higher amount of greenhouse gas due to high value of sediment areas and organic material [7]. Almost 90% of CH_4 emission is suggested to be released from the reservoir in the tropics [11]. Hydropower plants in the tropical area with large reservoirs related to their developing capacity can have a higher impact on global warming compare to dams in other zones [11,12]. Malaysia is moving toward the implementation of sustainable clean energy generation in the near future. Therefore, the government of Malaysia has planned to build more hydropower dams to meet the increasing power demand in the long term. However, there is little study regarding the GHG emission from hydropower reservoirs in Malaysia. Hence, this paper is aimed to conduct a preliminary assessment on the GHG emissions from major hydropower reservoirs in Malaysia from the period of 1930–2017.

2. Materials and Methods

2.1. GHG Emission Estimation

The Tier 1 method as recommended in International Government Panel on Climate Change (IPCC) guidelines is used to evaluate or estimate the CH_4 emissions from flooded land [13]. The IPCC 2006 guidelines provides a default value for the diffusion flux of methane from tropical reservoir surfaces. This is calculated as the median value from a series of published measurements in different reservoirs. The median is used instead of the mean because the distribution of values is highly skewed. Equation (1) is used with diffusion flux factor provided in Table 1 and country-specific total area of flooded land to calculate the CH_4 emissions from hydropower dam:

$$CH_4\ Emission = P \cdot E(CH_4) \cdot A_{flood\_total\_surface} \cdot 10^{-6} \quad (1)$$

where:

$CH_4\ Emission$ = Total CH_4 emission from flooded land, Gg CH_4 yr^{-1}

P = Ice-free period, days yr^{-1} (usually 365 for annual inventory estimates, or less in country with ice-cover period)

$E(CH_4)$ = Average daily diffusive emissions, kg CH_4 ha^{-1} day^{-1}

$A_{flood\_total\_surface}$ = Total flooded surface area, including flooded land, lakes and rivers, ha.

Table 1. Methane (CH_4) diffusion flux factor for flooded land.

Climate	Diffusive Emission $E(CH_4)$ (kg CH_4 $ha^{-1}day^{-1}$)				
	Median	**Min**	**Max**	N_m	N_{res}
Tropical, wet	0.630	0.067	1.3	303	6
Tropical, dry	0.295	0.070	1.1	230	5

N_m = number of measurements; N_{res} = number of reservoirs sampled.

2.2. Characteristics of Major Hydropower Dams in Malaysia

Some large hydropower projects in Malaysia are located in the state of Sarawak of East Malaysia which known as Batang Ai, Bakun, Murum and Baleh hydropower dams. The Bakun dam which is the largest hydropower dam in Malaysia commenced operation in 2011 with an installed capacity of 2400 MW and annual energy of 16,784 GWh per year. Currently, the Baleh hydropower dam, another large hydropower scheme with an installed capacity of 1285 MW has been under construction and expected to be commissioned in 2025 [14]. The total surface area of hydropower dams at full supply level in Malaysia are summarized in Table 2. These data were used to calculate the GHG emission from hydropower dams.

Table 2. List of major hydroelectric dams in Malaysia.

No.	Hydroelectric Dam	Surface Area (km^2)	Dam Height (m)	Design Power Capacity (MW)	Year of Commissioned	Annual Methane Emission ($GgCH_4yr^{-1}$)
1	Chenderoh	25	32	220	1930	5.75
2	Cameron Highlands	0.52	39.6	358	1963	0.12
3	Temenggor	153	127	348	1972	35.18
4	Bersia	5.7	33	238	1983	1.31
5	Kenering	40.5	48	120	1983	9.31
6	Kenyir	370	150	400	1985	85.08
7	Batang Ai	85	85	100	1985	19.55
8	Pergau	4.63	-	600	2000	1.06
9	Bakun	695	205	2400	2011	159.82
10	Murum	245	140	944	2015	56.34
11	Ulu Jelai	0.1	88	372	2016	0.02
12	Puah	60	78	250	2016	13.80
13	Baleh	588	188	1285	2024	-

3. Results and Discussion

The annual methane emission from each major hydropower dam in Malaysia is presented in Table 2. The total annual methane emission from major hydropower dams in Malaysia is estimated as 387.34 Gg CH_4 yr^{-1}. The results showed that approximately 151.64 Gg of annual methane emission released from hydropower dams in peninsular Malaysia with total percentage of 39.1%. While in East Malaysia, hydropower dams release 235.7 Gg of methane gas per year with total annual methane emission percentage of 60.9% in Malaysia. Currently, Bakun hydroelectric dam in Sarawak, Malaysia gave the most output on methane emission due to the large surface area of reservoir. Bakun dam contributes around 41.26% of total annual methane emission from hydropower dams in Malaysia. It is followed by kenyir dam and Murum dam with percentages of 21.97% and 14.54%, respectively. The percentages of total annual methane emission contributed by each major hydroelectric dams in Malaysia is calculated. Interestingly, Pergau dam with design power capacity of 600 MW which larger than that of Kenyir dam only contributes 0.27% of annual methane emission. Ulu Jelai hydroelectric dam with design power capacity of 372 MW contributes the least CH_4 emission of 0.02 Gg CH_4 yr^{-1}. It is seen that high head hydroelectric dam with small reservoir surface area is the most sustainable hydropower dam in reducing the GHG emission. Prior to 1970, there are only two dams operated and contributed a total CH_4 emission of 5.87 Gg CH_4 yr^{-1}. Five more hydropower dams have been built in the following 20 years and total CH_4 emission reached to 156.30 Gg CH_4 yr^{-1}. During the period of 2011–2018, the number of hydropower dams has increased to 12 major hydroelectric dams which give the total emission of 387.34 Gg CH_4 yr^{-1}. Bakun and Murum dams with huge reservoir surface area both contribute a total of 216.16 Gg CH_4 yr^{-1}. Currently, the Baleh hydropower dam which is another large hydropower scheme with an installed capacity of 1285 MW in Sarawak, Malaysia has been under construction and expected to be commissioned in 2025. If compared with Brazil and India with total annual CH_4 emissions of 21.8 $Tgyr^{-1}$ and 19.2 Tg yr^{-1} [7], respectively, the CH_4 emission from all hydropower dams in Malaysia is considered little or only 0.37% of total CH_4 emission from all hydropower dams around the world [7].

4. Conclusions

This paper has presented a preliminary assessment of methane emission from major hydropower dams in Malaysia from the periods of 1930–2017. In the near future, long-term measurements must be made to clarify and estimate the GHG emissions from reservoir surface, turbines, spillway and downstream river of hydropower reservoir in Malaysia, in order to estimate its net GHG emissions. Sustainable hydropower environmental impacts should be taken into account in the decision-making, especially with the development of new hydroelectric plant projects.

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