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RESERVOIRS AND GREENHOUSE GAS EMISSIONS

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ABSTRACT

Very few know that reservoirs also constitute majorly for the greenhouse gas emissions especially methane which is 80 times powerful than the gas carbon dioxide. This paper discusses how methane is emitted from reservoirs and what are the different ways of greenhouse gas emissions from reservoirs. This paper analyses about the interesting fact that methane can be collected from the water surface and how it can be monetized and used further efficiently. Emissions from lakes and reservoirs are distinguished. The foreign companies which take initiatives for reduction of methane gas and their strategies are discussed. Usually, it is not so simple to calculate methane. However, methane calculating methods are analysed and looked upon how to ulitize the same in our country. Because greenhouse gases influence widely in climate changes which is a major concern in the current scenario. Usage of methane gas such as turning that into hydrogen and green natural gas and generating electricity from that are discussed in detail in this paper. Comparative analysis is made and hence concluded. The process of creating methane biogas by anaerobic digestion is discussed. Then the reference of Tucurui dam in Northern Brazil has been focused on in this paper.

KEYWORDS: greenhouse gas, methane, carbon dioxide, hydrogen, Tucurui dam

INTRODUCTION

Reservoirs, particularly those created for hydroelectric power generation, have long been considered a cornerstone of renewable energy strategies worldwide. However, emerging research over the past few decades has revealed a less benign side to these water bodies: their significant contribution to greenhouse gas (GHG) emissions. Contrary to the traditional perception of
hydroelectricity as a clean and environmentally friendly energy source, reservoirs—especially in tropical regions—can emit substantial quantities of methane (CH_4), carbon dioxide (CO_2), and

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nitrous oxide (N_2O), primarily due to the decomposition of organic matter submerged during dam construction. These emissions challenge existing legal, environmental, and policy frameworks aimed at combating climate change. As such, the intersection of reservoir
management and greenhouse gas emissions is becoming an increasingly important area of focus for environmental law, international climate commitments, and sustainable development goals. This assignment explores the environmental impact of reservoirs with a particular emphasis on GHG emissions, using the Tucuruí Reservoir in Northern Brazil as a case study, and examines
the legal and regulatory approaches being employed or considered to mitigate these impacts.

SIGNIFICANCE OF RESERVOIRS

Prevention is better than cure. Therefore reservoirs are artificial rivers or lakes which are constrcted by mankind for the mass storage of water. Why water has to be stored? We live in a world where the certainty of water availability cannot be determined. There shall be a time when there is no scarcity for water and the other time it turns topsy turvy where all the living and non- living things on earth shall suffer. Water is the major source of living beings. One can even survive without food but not without water. Reservoirs are constructed to save water for the purpose of water management, providing a stable water supply for various purposes, including irrigation, hydroelectric power, and flood control, while also serving as a source for drinking water and recreation and so on. They are designed to store water for later use. They ensure a consistent and reliable water supply, especially during dry seasons or periods of low rainfall, which is vital for domestic, agricultural, and industrial needs. Many reservoirs serve as the raw water source for water treatment plants, which then deliver clean drinking water to communities. Reservoirs play a crucial role in managing river flows by storing excess water during periods of high rainfall or snowmelt, preventing or mitigating the risk of floods. Reservoirs are often used to generate electricity through hydroelectric power plants, which utilize the stored water's potential energy to turn turbines. The stored water in reservoirs is essential for irrigating crops, supporting agriculture and food production, especially in regions with seasonal rainfall patterns. Reservoirs can also be used for recreational activities such as fishing, boating, and swimming, contributing to the overall

quality of life. Reservoirs can also serve as habitats for various aquatic species, supporting biodiversity and providing ecological services.

GREENHOUSE GASES FROM RESERVOIRS

The emission of greenhouse gases such as nitrous oxide, methane and carbon dioxide from reservoirs constitute a debate always. They are emitted by the biochemical process that is caused within the reservoir water. A recent research concluded that that man-made reservoirs account for about 0.5 percent of global anthropogenic GHG emissions, which is less than previously estimated. One has to understand how greenhouse gases are emitted from a reservoir or waterbody. Methane and nitrous oxide are way more impactful that the carbon dioxide. We know that human beings inhale oxygen and exhale carbon dioxide but the plants inhale carbon dioxide and exhale oxygen and hence balances the nature. Therefore the more the plants, the more the environmental safety. The carbon dioxide inhaled by the plants remains inherent and when they are decomposed or dead, it dissolves into the atmosphere hence creating a live biomass. Sometimes when it rains, the dead or decomposed plants are suppressed into the waterbody by the rain water and hence they settle in the under soil of the waterbody and they emit carbon dioxide during its decomposition. They emitted carbon dioxide, dissolves into the waterbody and reaches the surface of the waterbody and they in turn consumed by the fish or the zooplanktons sometimes. Those living things, when they consume these carbon dioxide emit the same during its death. Therefore the emission, dissolution, etc of the green house gases is a never ending cycle. These aspects are regarding the emission of carbon dioxide. Where our content methane is generated in the non oxygen zone only. When it dissolves with oxygen, it is not that toxic but as the depth of the water increases, the oxygen level decreases and hence the level of the oxygen shall be almost nil in the lower soil of the waterbody and methane is formed there. But the emission of the green house gases vary with regard to the processes that occur in parallel to varying degrees, depending on the topographical, geological, and climatological conditions, as well as the biological configuration of the water body.

IMPORTANT FACTORS INFLUENCING GHG EMISSIONS FROM RESERVOIRS

Firstly, the presence of carbon stock in the soil of the waterbody is the reason for the emission of green house gases from the reservoirs. GHG emissions are more likely to occur when there is more carbon in the soil, flooded biomass, or carried into the reservoir from upstream rivers. The rate of emissions typically falls exponentially with reservoir age because the amount of carbon in biomass and soil declines when it is converted into GHGs and discharged into the atmosphere.

The next factor is the dissolved oxygen present in the water. In the non oxygen zones, methane is produced. But if it combines with the oxygen present in the water, it is turned into carbon dioxide. Therefore, oxygen plays a vital role in influencing green house gas emission from reservoirs.

Then the most commonly the temperature of air and water of the atmosphere. This is due to the fact that many of the mechanisms that lead to increased emissions are impacted by higher temperatures. First, the pace at which organic matter decomposes is directly influenced by temperature, with higher temperatures causing faster rates. Secondly, more oxygen can dissolve in water at lower temperatures, and vice versa, the higher the water temperature, the less oxygen can dissolve. In addition to creating a significant temperature differential between the surface and deeper water, high air temperatures at the water's surface also encourage stratification. As a result, temperature influences both the generation and release of CH4 and CO2 from reservoirs.

Next, in consideration to the water quality, the poorer the water quality, the higher the dissolution of oxygen and the higher the emission of green house gases. Similarly, inflows and the shape of the reservoir affect the level and distribution of dissolved oxygen in the reservoir. The inflow and bathymetry influence the water retention time in the different parts of the reservoir. Water retention time in turn affects how much time is available for biological processes to occur. The volume and variation of inflows also affect how much oxygen is transported into the reservoir and how well the inflowing fresh water is mixed with the water already present in the reservoir.[1]

[1] Greenhouse Gases from Reservoirs Caused by Biogeochemical Processes, 2017 International Bank for Reconstruction and Development / The World Bank, www.worldbank.org, accessed on 8-4-2024 at 4.14 pm

THE G-RES TOOL and IEA HYDRO FRAMEWORK

The G-res is a tool created by the UNESCO/IHA green house gas research project. . The objective of the tool is to quantify the portion of GHG emissions that can be legitimately attributed to the creation of the reservoir over its lifetime. Without measuring the exact or approximate amount of green house emissions from the waterbody, its prevention cannot be done. Therefore this tool plays a vital role in measuring the emissions from the reservoir. By using established emission standards, the G-res tool also allows the user to estimate the emissions associated with the construction and material of the dam infrastructure elements. To get an emissions estimate for the dam and reservoir's whole life cycle, these project-specific emissions are added to the reservoir emissions.

In the case of multipurpose dams and reservoirs, the G-res tool goes one step further and recommends how the lifespan emissions should be distributed by sector. The reservoir's operating regime—that is, the uses that are given priority—determines the allocation.

It is a very brilliantly made tool which is available online and can be accessed by anyone using it. It is designed to have variables which represent each and every data such as climate, temperature, soil type etc., the user can also give minute details as input, if readily available through the collected data. Also the tools is not time consuming. A maximum of one day shall be used by the tool to give the results of the green house gas emissions from the reservoirs.

IEA is nothing but the International Energy Agency Technology Collaboration Program on Hydropower. It is a working group of International Energy Agency member countries and others who have a common interest in advancing hydropower worldwide. Its Mission "To encourage through awareness, knowledge and support, the sustainable use of water resources for the development and management of hydropower. "[2]The IEA Hydropower Implementing Agreement3 has developed guidelines for the quantitative analysis of net GHG emissions from reservoirs. Three documents provide a framework for conducting site-specific primary data collection and modeling to estimate and manage reservoir GHG emissions. Volume 1 consists of measurement programs and data analysis, volume 2 consists of modelling and volume 3 consists of management, mitigation and allocation.It does not provide a ready-to-use tool for estimating emissions, it describes in detail the steps involved in collecting field data, conducting data analysis,

[2] IEA Hydropower, https://www.ieahydro.org/, accessed on 8-4-2025 at 4.39 pm

and developing process-based modeling tools for estimation of GHG emissions from a reservoir. It offers recommendations for primary data collection methods and ideas for incorporating these into pre-impoundment emissions in the case of new reservoirs. The framework offers recommendations and specifications for modelling techniques to replicate greenhouse gas emissions during the reservoir's lifetime with regard to post-impoundment emissions. Additionally, it offers suggestions for the construction, adjustment, and verification of mechanistic models that explain the biogeochemical processes.

Primary data analysis and site-specific model development take a significant amount of time—typically at least one to two years. Typically, the core data gathering must span multiple seasons. A number of intricate and time-consuming components, including hydrodynamic modelling, water quality modelling, and GHG modelling, are used in the modelling process.

RESERVOIR METHANE CAPTURE MECHANISM

Hydropower in Brazil is the primary source of electricity. Although regarded as clean energy with low-carbon emissions, hydropower generation emits methane that can now be captured and utilized. The mechanism helps hydropower companies become even more sustainable and meet their emissions targets. The pilot will be comprised of five sets of methane and biogas plants. At scale, the instrument will avoid 6.8 million tons of carbon dioxide emissions per year, equivalent to 1.5 million automobiles or 3.7 million cattle heads.[3] The methane capture and biogas plants are owned and operated by Open Hydro, which also assumes any risks through the special purpose vehicle (SPV) at the heart of the instrument. Open Hydro is the software that helps companies that use water to measure, allocate and provide action plans to mitigate the GHG emissions from water. They map, quantify, and allocate emissions from water bodies to the different water users and identify actionable opportunities to respond to and reduce their GHG emissions.[4] Open Hydro works to decarbonise freshwater systems and accelerate climate action in water industries to

[3] Reservoir Methane Capture Mechanism, by Manuella Cantalice, Pedro de Aragão Fernandes and Felipe Borschiver, published on September 29 2022, https://www.climatepolicyinitiative.org/, accessed on 8-4-2025 at 6.12 pm

[4] Open hydro, opening hydropower to climatic resilience, https://openhydro.net/, accessed on 8-4-2025 at 6.22 pm

empower organisations to demonstrate their contributions to climate mitigation, resilience and adaption.[5]

The hydropower plant operator will supply water usage rights, Bluemethane will build the methane collection facility, and a local developer will handle the biogas factory. It is an initiative taken in the United Kingdom for reducing the methane emission from the waterbodies and to constitute a fresh water body and to reduce methane emission and to convert the captured methane into a renewable energy and to montize it. Bluemethane offers methane measuring service and methane capture technology.

The plant uses a closed-circuit hydro cyclone-style tank to capture methane. In order to produce energy that may be sold in the Brazilian market under the distributed energy framework, this captured methane is subsequently fed into a biogas plant. A third-party verifier's accurate measurement and oversight of these assets are necessary for revenue derived from the sale of carbon credits. Wastewater companies are already using anaerobic digestion, they take solid waste and churn it around without oxygen to create methane biogas, and at the end the liquid still has quite a lot of dissolved methane in it.

However, sampling over large areas is impractical, thus regional and global emissions are estimated by mathematical models. Modern methane satellite observations can assist with this, but there are drawbacks: clouds can obstruct observations, which is troublesome over the UK and wide areas of the tropics, and observations can be restricted by how frequently a satellite passes over a particular region.

Once collected from water, the methane can be transformed into biogas or upgraded to green natural gas which can be used for generation of electricity, fuel for vehicles etc., currently, majority of developed nations' hydrogen source is from methane. Using methane from hydropower for energy – such as by burning it or converting it to hydrogen – still releases carbon dioxide to the atmosphere, but no more than would eventually be released anyway by the organic matter decomposing at the bottom of reservoirs.

[5] ibid

METHANE BIOGAS BY ANAEROBIC DIGESTION

Anaerobic digestion is nothing but the microbes or micro organisms break the organic matter in the absence of oxygen and hence emit biogas. The latter can be used as renewable source for various vehicle, electricity, heat etc., the process is usually done in a container called digestor in which the organic matter shall be emptied into and then it shall be tightly closed to prevent oxygen from entering the digestor. Then process happens with the micro organisms which break the stuff in to small components and thus emit the biogas. Digestate is the residual material left after the digestion process. It is composed of liquid and solid portions. These are often separated and handled independently, as each have value that can be realized with varying degrees of post processing.

Biogas is composed of methane, which is the primary component of natural gas, at a relatively high percentage (50 to 75 percent), carbon dioxide, hydrogen sulfide, water vapor, and trace amounts of other gases. The energy in biogas can be used like natural gas to provide heat, generate electricity, and power cooling systems, among other uses. Biogas can also be purified by removing the inert or low-value constituents to generate renewable natural gas. This can be sold and injected into the natural gas distribution system, compressed and used as vehicle fuel, or processed further to generate alternative transportation fuel, energy products, or other advanced biochemicals and bioproducts.[6]

Wastewaters generated from food- and beverage-processing industries often have little SS but high concentrations of soluble organic compounds (up to 50,000 mg/L of biological oxygen demand, BOD) such as starch, sugars, and proteins. Some common examples of these high-strength wastewaters come from cheese factories, wineries, breweries, distilleries, slaughterhouses, potato processing, and ice cream factories. The organic compounds in these wastewaters can be readily degraded and converted to methane biogas, but the initial major objective of anaerobic treatment of such wastewaters was to degrade and reduce the organic pollutants in the wastewaters to satisfy

[6] How Does Anaerobic Digestion Work?, United State Environmental Protection Agency, https://www.epa.gov/, accessed on 8-4-2025 at 7.13 pm

governmental discharge requirements. With the push for bioenergy, the focus of anaerobic treatment of high-strength organic wastewaters has been shifted to methane biogas production.[7]

TUCURUI DAM IN BRAZIL

The Tucuruí Reservoir in Northern Brazil, formed by the construction of the Tucuruí Dam on the Tocantins River, serves as a key hydroelectric power source but also presents complex environmental and legal challenges, particularly concerning greenhouse gas emissions. Despite being promoted as a clean energy alternative, large tropical reservoirs such as Tucuruí have been found to emit significant amounts of methane and carbon dioxide, primarily due to the anaerobic decomposition of submerged biomass and organic matter in a warm, oxygen-poor environment. These emissions not only contribute to global climate change but also raise questions about the environmental accountability of hydroelectric projects under both national and international legal frameworks. The legal treatment of such emissions remains underdeveloped in Brazil, although there is increasing pressure for stricter environmental assessments and ongoing monitoring as part of the licensing and operational phases of large infrastructure projects. In response to the environmental concerns, some mitigation measures have been explored, including the pre-emptive clearing of vegetation prior to flooding and the implementation of long-term emissions monitoring programs. From a legal standpoint, this situation invites a broader discussion on the adequacy of Brazil's environmental licensing regime, the role of public participation in environmental decision- making, and the extent to which greenhouse gas emissions from reservoirs should be incorporated into national climate commitments under international agreements like the Paris Accord. Moreover, it opens up potential legal debates regarding the liability of state and private actors for environmental harms associated with projects originally framed as sustainable. As climate litigation and environmental governance evolve, cases like Tucuruí may become central to redefining the legal boundaries between sustainable development and environmental protection in the context of energy production.

[7] Production of Methane Biogas as Fuel Through Anaerobic Digestion, by Zhongtang Yu and Floyd L. Schanbacher, https://www.researchgate.net/, accessed on 8-4-2025 at 7.17 pm

CONCLUSION

The issue of greenhouse gas emissions from reservoirs, particularly in tropical regions like the Tucuruí Reservoir in Northern Brazil, highlights a critical and often overlooked dimension of hydroelectric power. While dams are widely regarded as sources of clean and renewable energy, the reality is more nuanced, with significant environmental consequences arising from submerged biomass and long-term ecosystem changes that contribute to methane and carbon dioxide emissions. From a legal and policy perspective, these findings call for a reevaluation of how such projects are assessed, licensed, and regulated, especially in light of Brazil's commitments under international climate agreements. There is a growing need for comprehensive legal frameworks that not only recognize the environmental costs of hydroelectric reservoirs but also mandate effective mitigation strategies and long-term monitoring. As the global community intensifies efforts to combat climate change, addressing emissions from reservoirs must become an integral part of environmental governance, ensuring that energy development does not come at the expense of ecological and climate integrity.