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Freshwater Reservoirs: Global Warming's Best Kept Secret

Beau Baily

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Freshwater Reservoirs: Global Warming’s Best Kept Secret

Beau Baily[†]

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I. INTRODUCTION

Modern needs for clean energy and the unclean methods used to harness that energy are in tension. As the world’s population increases, access to energy is in increasingly high demand, especially in developing countries. As global awareness of climate change grows, the burning of fossil fuels is finally being recognized as an unacceptable practice, and governments are turning more and more to hydroelectric, large-scale dam projects to harness energy.¹ The problem is that construction of these projects may be just as harmful to the environment as fossil fuel burning itself, if not more.

Greenhouse gas emissions from reservoirs need to be monitored, mitigated, and regulated to decelerate global warming’s adverse effects on the planet and to achieve the Paris Agreement’s goal of limiting the rise in the earth’s global temperature to two degrees above pre-industrial levels.² In order to reach that goal, the Intergovernmental Panel on Climate Change (IPPC) set a budget representing the total amount of greenhouse gas that can be emitted into the atmosphere while still accomplishing the Paris Agreement’s goal of limiting the rise of the earth’s temperature. Reservoir emissions were not included in that budget, which means the budget is an inaccurate representation of the amount of greenhouse gases being emitted into the atmosphere. This underestimation demonstrates the need for stricter monitoring efforts of reservoir emissions.

Reservoir emissions also need to be mitigated. According to the most recent study, reservoirs contribute 1.5% of all human caused greenhouse gas emissions into the atmosphere and are thus considered to be hazardous sources of greenhouse gases, particularly methane, which is more devastating to the environment than carbon dioxide.³ In order to mitigate reservoir emissions, the dam industry needs to be regulated. Despite the adverse effects that dams and reservoirs place on society from a biodiversity, en-

¹ Christiane Zarfl et al., *A Global Boom in Hydropower Dam Construction*, 77 *AQUATIC SCIENCES* 161 (2015).

² Paris Agreement, Mar. 14, 2016, T.I.A.S. No. 16-1104.

³ Bridget R. Deemer, *Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis*, 66 *BIOSCIENCE* 949, 960-61 (2016).

vironmental, and cultural standpoint, dams are being planned and constructed at unprecedented rates.⁴ Currently, the dam industry is self-regulated and profit driven which de-incentivizes dam builders from giving appropriate weight to the negative environmental effects related to dam building.⁵ One study predicts that, if dams are constructed as planned, their greenhouse gas emissions will exceed those avoided (from scaling back fossil fuel burning) by up to ten times because of the reservoirs that will accompany them.⁶

This article will discuss fresh-water reservoir emissions, their environmental impacts, and ways to mitigate those impacts. Section one will provide an overview of what reservoirs are and how they adversely affect the environment. Section two will examine the methods used to assess reservoir emissions and why these methods are important. Section three will explain the inadequacies of the self-regulated dam industry. Finally, section four will explore the solution of monitoring, mitigating, and regulating reservoirs and the dam industry in order to ease the tension between the demand for clean energy and the unclean methods used to harness energy from hydropower.

II. RESERVOIRS: WHAT THEY ARE AND HOW DO THEY EMIT?

Reservoirs are human-made bodies of water that are usually located in areas where lakes are scarce or where the water in lakes or rivers is unsuitable for human use.⁷ Reservoirs are important to society because they address needs such as drinking water, irrigation, and power generation, although most reservoirs are not developed for hydroelectric production.⁸ Without reservoirs, humans in certain parts of the world would not have access to water that is essential for basic human needs. Even though the earth is about 71% water, nearly 97% of that water is found in oceans.⁹ Of the remaining 3% of the earth's water that is freshwater, 70% is frozen, or underground and inaccessible.¹⁰ In order to make up for this lack of fresh water, more and more countries are turning to different types of freshwater reservoirs, which are most commonly constructed by building

⁴ Zarfl, *supra* note 1, at 162.

⁵ Peter Bosshard, THE DAM INDUSTRY, THE WORLD COMMISSION ON DAMS AND THE HSAF PROCESS, 3(2) Water Alternatives 58, 59 (2010).

⁶ *Id.* at 65.

⁷ *Man-made Lakes (Reservoirs)*, UNITED NATIONS ENVIRONMENT PROGRAMME, http://www.unep.or.jp/ietc/Publications/Short_Series/LakeReservoirs-1/3.asp [<https://perma.cc/KU7R-5BSQ>] (last visited Apr. 8, 2018) [hereinafter Reservoirs].

⁸ Vincent L. St. Louis et al., RESERVOIR SURFACES AS SOURCES OF GREENHOUSE GASES TO THE ATMOSPHERE: A GLOBAL ESTIMATE, 50 BIOSCIENCE 766 (2000).

⁹ *How Much Water is There on, in, and Above the Earth?*, USGS (Dec. 2, 2016), <https://water.usgs.gov/edu/earthhowmuch.html> [<https://perma.cc/P5X8-WXBH>].

¹⁰ Reservoirs, *supra* note 7.

a dam across a flowing river to divert water into a human-made basin.¹¹ These types of reservoirs are known as “valley reservoirs.” In contrast, “off-river storage reservoirs” do not involve dams; they are constructed by pumping water from a river into an enclosure created near the river.¹² It is important to note that some studies that measure greenhouse gas emissions from reservoirs include estimates of emissions only from valley reservoirs. As a result, their estimates are likely too low and, thus, not suitable for painting the whole picture.

Because reservoirs are built to serve specified needs, they can vary in size, which is an important variable in determining the greenhouse gas emissions of a reservoir. Larger reservoirs will emit more greenhouse gases than smaller reservoirs because a greater surface area is flooded with water. This is because the flooding water is the mechanism that triggers reservoir emissions. Before flooding, the land serves as a “greenhouse sink” that stores organic carbon in the plants and soils within the sink and prevents greenhouse gas from entering the earth’s atmosphere.¹³ Once the land is flooded, plants die and can no longer absorb greenhouse gases.¹⁴ Organic carbon from the dead plants is decomposed by bacteria and converted into carbon dioxide, methane, and nitrous oxide. Because there are no plants or soil to absorb the gases, there is nowhere for the gases to go but into the atmosphere.¹⁵ Instead of existing as a greenhouse sink that merely stores organic carbon and prevents the release of greenhouse gas into the atmosphere, the flooded land becomes a greenhouse gas source where carbon is converted into gas and released into the atmosphere. Recent studies show that methane is the dominant gas that reservoirs release into the atmosphere.¹⁶ This is problematic given that the global warming potential of methane is 25 times stronger than carbon dioxide.¹⁷

Another factor that determines how much gas a reservoir emits is location. For example, reservoirs in tropical climates have a greater impact on global warming than reservoirs in temperate climates because tropical climates possess more nutrients and vegetation. When water floods an area

¹¹ *Id.*

¹² *Id.*

¹³ Claire Salisbury, *Top Scientists: Amazon's Tapajos Dam Complex a Crisis in the Making*, MONGABAY (Nov. 28, 2016), <https://news.mongabay.com/2016/11/top-scientists-amazons-tapajos-dam-complex-a-crisis-in-the-making/> [<https://perma.cc/RGQ5-VRL4>].

¹⁴ St. Louis, *supra* note 8, at 766.

¹⁵ *Id.*

¹⁶ Deemer, *supra* note 3, at 949.

¹⁷ *Methane Emissions*, EPA (Apr. 14, 2017) <https://www.epa.gov/ghgemissions/overview-greenhouse-gases#methane> [<https://perma.cc/BKW2-8K9L>].

high in nutrients, more plants decompose, and more organic carbon is converted into gas with nowhere to go but up into the atmosphere.¹⁸ A 2011 study concluded that the highest emission rates are from the tropical Amazon region¹⁹ where Brazil is planning to build more than forty dams, including the Belo Monte Dam currently under construction, which will be the world's third largest dam.²⁰

Dams with negligible emissions do not exist.²¹ This is contrary to what the International Hydropower Association would lead people to believe, stating in a report that there are reservoirs where emissions are not an issue.²² While hydropower and energy generated from hydroelectric dams is generally a carbon neutral source of energy and emits thirty times less the amount of greenhouse gases than coal, it is the construction of all reservoirs that cause emissions.²³

Those who support building reservoirs have called attention to inconsistent data within studies to point out unreliability, and argue the benefits of clean hydropower energy outweigh the environmental costs.²⁴ Furthermore, the methods used to measure reservoir emissions are site-specific and complex, making it near impossible for widespread use of one consistent method.²⁵ To understand why these arguments are weak, it is necessary to explore the science behind measuring reservoir emissions.

III. MEASURING RESERVOIR EMISSIONS

In 2000, Biochemist Vincent St. Louis released the first study examining the extent of greenhouse gas emissions from reservoirs.²⁶ At the time, hydropower was widely viewed as a carbon free source of energy,

¹⁸ Sarah DeWeerd, *Dam Greenhouse Gas Emissions Really Add Up*, CONSERVATION MAG. (Oct. 11, 2016), <http://www.conservationmagazine.org/2016/10/dam-greenhouse-gas-emissions-really-add/> [https://perma.cc/565E-7SPH].

¹⁹ Nathan Barros et al., CARBON EMISSION FROM HYDROELECTRIC RESERVOIRS LINKED TO RESERVOIR AGE AND LATITUDE, 4 NATURE GEOSCIENCE 593, 593 (2011).

²⁰ Salisbury, *supra* note 13, at 12; Zoe Sullivan, *Brazil's Belo Monte Dam Ruinous for Indigenous Cultures*, AMAZON WATCH (Dec. 8, 2016), <http://amazonwatch.org/news/2016/1208-brazils-disposessed-belo-monte-dam-ruinous-for-indigenous-cultures> [https://perma.cc/XYE6-VV4Q].

²¹ Philip Fearnside, *Dams with Big Reservoirs: Brazil's Hydroelectric Plans Threaten its Paris Climate Commitments*, THE GLOBALIST (Jan. 29, 2017), <https://www.theglobalist.com/dams-climate-change-global-warming-brazil-paris-agreement/> [https://perma.cc/6QGE-W3FU].

²² *Greenhouse Gas Emissions*, INT'L HYDROPOWER ASS'N, <https://www.hydropower.org/greenhouse-gas-emissions> [https://perma.cc/Y84U-EW2X] (last visited April 8, 2018).

²³ *Id.*

²⁴ Jes Burns, *WSU: Hydropower Dams Contribute to Climate Change*, CROSSCUT (Sept. 30, 2016), <http://crosscut.com/2016/09/wsuhydropowerdamscontributeclimatechange/> [https://perma.cc/NR27-MAUJ].

²⁵ See Deemer, *supra* note 3, at 950-952.

²⁶ Warren Cornwall, *Hundreds of New Dams Could Mean Trouble for our Climate*, SCIENCE (Sept. 28, 2016), <http://www.sciencemag.org/news/2016/09/hundreds-new-dams-could-mean-trouble-our-climate> [https://perma.cc/M9S9-5Y2U].

and prior to 1994, there was no data available that measured carbon dioxide and methane emissions from reservoirs.²⁷ However, twenty-one studies from existing reservoir sites in the seven years leading up to St. Louis's study all showed emissions of carbon dioxide and nitrogen from the flooded terrain caused by reservoir construction.²⁸ The purpose of St. Louis's study was to determine if reservoir emissions *could* be significant on a global basis in addition to determining whether the scientific community should improve its understanding of the climate impacts of reservoir development.²⁹ He concluded that "reservoirs are sources of greenhouse gases to the atmosphere and their surface areas have increased to the point where they should be included in global inventories of anthropogenic emissions of greenhouse gases."³⁰ St. Louis's findings sparked more studies in the sixteen years that followed. This section will focus on 1) the methods used to determine reservoir emissions, and 2) three case studies conducted between 2000 and 2015 that measured emissions from reservoirs located throughout the world.

A. Methods

There are four main methods used to calculate a reservoir's level of GHG emissions. The methods employed to calculate reservoir emissions vary because the techniques used measure different factors from different sample sizes. Some methods are more accurate than others depending on the region's climate and landscape, so the conditions of the reservoir generally will determine what method a scientist will use.³¹ The most accurate techniques to determine methane emissions, the dominant reservoir greenhouse gas emission, will measure ebullition - the action of bubbling or boiling. This is because methane is released through bubbles that float up to the water's surface.

1. Floating Static Chamber Method

Floating static chambers calculate the linear rate of gas accumulation in a chamber over time.³² In practice, this looks like a large water jug floating on the water. The gas rising from the water is captured in the device, and the amount of gas that flows from the water's surface is measured. However, the floating static chamber is difficult to use in open stretches

²⁷ St. Louis, *supra* note 8, at 766.

²⁸ *Id.* at 769.

²⁹ *Id.* at 767 (emphasis added).

³⁰ *Id.* at 766.

³¹ *Id.* at 767.

³² *Id.*

of water with high winds that create waves in the water,³³ so this method works best in sheltered conditions.

2. Thin Boundary Layer Method

Another method scientists employ is the “thin boundary layer” method. This method requires knowledge of the change in carbon dioxide and methane concentration. Gases formed from the decomposing vegetation rise through the water, and a small portion of the gases are captured by an inverted funnel trap. A formula is then applied to gases captured in the funnel traps.³⁴ This method works best in windy areas. Most studies rely on a combination of the floating static chamber and the thin boundary layer methods. Some studies have suggested that both methods come to similar results, while other studies have suggested the boundary layer method underestimates the amount of emissions.³⁵

Because methods that do not measure ebullition fail to accurately measure how much methane is released into the atmosphere, recent studies make this measurement a point of emphasis. For example, recent measurements have employed modified funnel traps to measure ebullition floating just below the water’s surface.³⁶ The modified funnel captures the bubbles as they rise through the water. Modified funnels feature a chamber that is more “air-tight,” and electronic units that empty the chamber when it fills.³⁷ This prevents the chamber from filling faster than the ebullition can be measured, which allows for a more accurate measurement than those found in older studies.³⁸

3. Acoustic Techniques

Acoustic techniques are a more convenient way to measure ebullition because they do not involve the burdensome process of deploying funnel traps.³⁹ The bubble size can be made uniform through acoustic signals, and then an echo sounder can be mounted to a boat in order to estimate the flow of the bubbles, which allows for more comprehensive coverage and a more accurate measurement.⁴⁰ The drawback to this method is that it only works within certain depth ranges, usually one to 100 meters, and can be costly and difficult to calibrate.⁴¹

³³ *Id.* at 767-768.

³⁴ *See id.*

³⁵ *Id.*

³⁶ Deemer, *supra* note 3, at 951.

³⁷ *Id.*

³⁸ *Id.*

³⁹ *Id.*

⁴⁰ *Id.*

⁴¹ *Id.*

4. Eddy Covariance

Eddy Covariance techniques calculate GHG emissions by determining the amount of carbon dioxide that passes from the flooded plants into the atmosphere.⁴² A device on a tripod measures variables, such as the fluctuation of vertical wind speeds and percentage of carbon dioxide in relation to other substances.⁴³ This method is most accurate when wind, temperature, humidity, and carbon dioxide are steady, and the underlying vegetation is comprised of similar plants on flat ground.⁴⁴ The calculations involve a number of assumptions, and the device used to capture the measurements is expensive. However, the measurements are highly accurate if the assumptions are satisfied.⁴⁵

In sum, the floating static chamber and thin boundary layer methods are used depending on the reservoir's location. The former method works best in sheltered conditions, while the latter is appropriate to use where wind is attendant; however, most studies use a combination of both. Acoustic techniques and eddy covariance methods are also employed, but can be expensive and less versatile.

B. Case Studies

1. St. Louis, 2000

The data that St. Louis compiled in his study was obtained mostly with floating static chambers and/or the thin boundary layer method, which St. Louis determined was reasonable due to the size of the reservoirs and wind speeds in the area.⁴⁶ He stated that the estimates were conservative because ebullition was not usually measured at the time.⁴⁷ The importance of ebullition was not yet known.

The average carbon dioxide and methane emission measurements were vastly inconsistent. For example, the Petit Saut reservoir in French Guyana emitted on average 4460 units ($\text{mg} \cdot \text{m}^2 \cdot \text{d}$) in carbon dioxide and 1140 units in methane, while the much larger Robert-Bourassa reservoir

⁴² Dennis D. Baldocchi, *Assessing the Eddy Covariance Technique for Evaluating Carbon Dioxide Exchange Rates of Ecosystems: Past, Present and Future*, 9 GLOBAL CHANGE BIOLOGY at 479 (2003).

⁴³ *Id.*

⁴⁴ *Id.*

⁴⁵ C. Burba and D. Anderson, *Introduction to The Eddy Covariance Method: General Guidelines, And Conventional Workflow*, LI-COR Biosciences at 13 (2007) <http://www.instrumentalia.com.ar/pdf/Invernadero.pdf> [<https://perma.cc/X6S9-8UUK>].

⁴⁶ St. Louis, *supra* note 8, at 768.

⁴⁷ *Id.*

in Quebec emitted on average only 1500 units in carbon dioxide and thirteen units in methane.⁴⁸ The temperate Robert-Bourassa reservoir emitted substantially less GHG than much smaller tropical Petit Saut reservoir. This inconsistency can be explained by several factors that cause reservoirs in tropical climates, such as French Guyana, to emit more greenhouse gas than reservoirs in temperate climates, such as Quebec.

One factor is the amount of organic carbon released when the terrain is flooded. Areas with a higher amount of organic carbon will emit more greenhouse gas than areas lacking organic carbon. According to St. Louis, the largest amounts of organic carbon are in peatlands, which are found mostly in tropical areas, while the smallest amounts of organic carbon are in temperate areas.⁴⁹ In total, reservoirs in temperate areas emitted an average of 1400 units of carbon dioxide and twenty units of methane, while reservoirs in tropical areas emitted an average of 3500 units of carbon dioxide and 200 units of methane.⁵⁰ Even though the dam in Quebec is much larger, the fact that it emitted much less gas than the smaller dam in French Guyana is entirely consistent with a larger trend that tropical reservoirs emit more than temperate reservoirs. While size is a factor to determine emissions, size should not be used to compare a temperate reservoir to a tropical reservoir. Critics are quick to point out inconsistent emission measurements, such as illustrating the differences between the Quebec and French Guyana dams, but are much less quick to focus on the scientific reasoning explaining the inconsistencies.⁵¹

Another factor found to influence reservoir emissions is the reservoir's age. Emissions from reservoirs should slow over time as the amount of decomposing vegetation decreases.⁵² Therefore, the older the reservoir, the less gas it emits. This also helps explain why the French Guyana reservoir emitted more than the Quebec reservoir, as the French Guyana reservoir was much younger. Alarming, most reservoirs currently planned for construction are to be located in tropical areas.⁵³ Because these reservoirs will be brand new and in tropical climates, they will be among the most impactful to climate change. Obviously, the solution cannot be merely waiting out the emissions until they become negligible because the damage will have already been done to the atmosphere.

⁴⁸ *Id.*

⁴⁹ *Id.* at 770.

⁵⁰ *Id.*

⁵¹ See *Reports on Emissions From Reservoirs*, OFF. ENERGY EFFICIENCY & RENEWABLE ENERGY (July 21, 2017), <https://www.energy.gov/eere/water/articles/reports-emissions-reservoirs> [<https://perma.cc/PE64-M4CX>] (discussing the wide range of measurements from different reservoir studies, but not the scientific explanations for those wide ranges).

⁵² *Id.*

⁵³ See Zarfl, *supra* note 1.

A third factor St. Louis found to determine reservoir emissions is water temperature. Warmer water facilitates the decomposition of organic matter better than colder water.⁵⁴ Naturally, tropical climates feature warmer water than temperate climates, which further explains the discrepancy in emissions between reservoirs in tropical versus temperate climates.

In conclusion, reservoir size is not as large of a factor in determining GHG emissions as climate, age, and water temperature. Furthermore, St. Louis's study indicated that globally, reservoir emissions may equate to 7% of the global warming potential of other documented human-caused emissions of methane, carbon dioxide, and nitrogen - a percentage similar to contributions from other inventoried sources at the time.⁵⁵ St. Louis anticipated that emissions from reservoirs would increase as more reservoirs were created to meet energy needs and recreation demands, which is a prediction turning out to be true.⁵⁶

2. Barros, 2011

In 2011, Nathan Barros released another influential study that reaffirmed many of St. Louis's findings but estimated that reservoirs emit much less than previously thought. However, Barros's findings were based on a smaller data set than St. Louis because Barros only analyzed emissions from hydroelectric reservoirs, which comprise just 20% of all reservoirs.⁵⁷ Meanwhile, St. Louis's study recognized that most reservoirs are not developed for hydroelectric production.⁵⁸ Additionally, Barros did not indicate which methods of measurement were utilized to create the data he based his conclusions off of making it difficult to assess the study's credibility. Still, all reservoirs were found to emit methane in Barros's study.⁵⁹

Barros confirmed climate, age, and temperature as factors that contributed to the amount of gas a reservoir emits. Reservoirs in tropical climates emitted about three times more methane than reservoirs in temperate climates, and a little more than seven times the carbon dioxide.⁶⁰ Barros also stated that among all the variables considered, age was most determinative of the amount of gas a reservoir emits.⁶¹

⁵⁴ St. Louis, *supra* note 8, at 771.

⁵⁵ *Id.* at 767.

⁵⁶ *Id.* at 774; *See* Zarfl, *supra* note 1.

⁵⁷ Barros et al., *supra* note 19.

⁵⁸ St. Louis, *supra* note 8, at 766.

⁵⁹ Barros et al., *supra* note 19, at 593.

⁶⁰ *Id.* at 595.

⁶¹ *Id.* at 594.

Barros estimated that hydroelectric reservoirs emit about 48 TgC of carbon dioxide and 3 TgC of methane.⁶² Based on these findings, he concluded that hydroelectric reservoirs did not seem to be “major players in the global carbon budget at present.”⁶³ However, Barros noted that globally, only 17% of the potential hydroelectric sites had been used, and future locations should be carefully selected, with special emphasis on the Amazon region where reservoirs emit more greenhouse gases than in other regions.⁶⁴ As stated above, the world’s third largest hydroelectric dam is under construction in Brazil, which will destroy about 370,658 acres of rainforest and displace 40,000 people, in addition to being located in a region where reservoir emissions are highest.⁶⁵

3. Deemer, 2016

Most recently, in 2016, a group of scientists at Washington State University set out to

generate a global estimate of greenhouse gas emissions from all reservoirs.⁶⁶ This study was much more comprehensive than Barros’s study, which consisted only of hydroelectric reservoirs. The WSU study also considered the effects that different collection methods had on the data, and took a second look at the factors that predict emissions.⁶⁷ Ebullition was measured in 52% of the cases by using funnels, sometimes in combination with other methods such as the floating chamber.⁶⁸ Two of the measurements compiled used eddy covariance, and two more used acoustic methods.⁶⁹ The WSU study had the benefit of a more comprehensive data set, and a better balance between reservoirs in tropical and temperate climates, as well as improved data of the global surface area of reservoirs.⁷⁰

Whereas previous studies indicated age and location as the most important factors by which to predict reservoir emissions, the WSU study indicated factors such as nutrient status and “associated primary productivity,” such as chlorophyll *a*⁷¹ (predictive of methane) and nitrate concentrations (predictive of nitrogen), as well as average annual precipitation

⁶² Barros et al., *supra* note 19, at 594.

⁶³ *Id.* at 596.

⁶⁴ *Id.* at 593, 596.

⁶⁵ Sullivan, *supra* note 20.

⁶⁶ Deemer, *supra* note 3, at 949.

⁶⁷ *Id.*

⁶⁸ *Id.* at 951-952.

⁶⁹ *Id.*

⁷⁰ *Id.* at 956.

⁷¹ Chlorophyll *a* is what plants use to photosynthesize. Waters with high levels of nutrients may have high concentrations of chlorophyll *a*. *Indicators: Chlorophyll a*, NAT’L AQUATIC RESOURCES SURVEYS, <https://www.epa.gov/national-aquatic-resource-surveys/indicators-chlorophyll> [<https://perma.cc/23KH-MQLY>] (last updated Aug. 16, 2016).

(predictive of carbon dioxide emissions) as being most indicative of accurate reservoir emissions.⁷² While age and location are broad, general factors that give a sense whether emissions will be lower or higher than average, nutrient status and primary productivity are more precise. The higher the nutrient content of the area, the larger the emissions.⁷³ Areas high in nutrient content are generally found in tropical climates.

In conclusion, the WSU study estimated that greenhouse gas emissions from reservoirs make up about 1.5% of global, human caused greenhouse gas emissions.⁷⁴ For perspective, if reservoirs were a country, they would be the eighth largest greenhouse gas emitter for methane and carbon dioxide in the world.⁷⁵ According to the WSU study, estimates of methane emissions have increased by 25% over the past 15 years as science has improved.⁷⁶ Reservoir emissions are more devastating than previously thought and will only become worse as more dams are constructed in the coming years. Based on their findings, the authors of the WSU study suggest methane emissions from reservoirs, which compare to emissions from rice paddy fields and biomass burning, should be incorporated into the Intergovernmental Panel on Climate Change's budgets that estimate global greenhouse gas emissions.⁷⁷ They called for policymakers and dam constructors to, at the very least, weigh greenhouse gas related costs with reservoir benefits when planning to construct or decommission a dam.⁷⁸

IV. DAM REGULATION

Due to the demand for clean energy, dams are being planned and constructed at unprecedented rates, and with dams come reservoirs.⁷⁹ In 2014, a study by Christiane Zarfl determined 3,700 major dams are either in planning stages or under construction, primarily in countries located in South America, Africa, and Asia.⁸⁰ These countries share the characteristic of being located in tropical climates, meaning that the reservoirs that accompany the dams will make a large contribution to global warming. It is also of note that this study's estimate was conservative because it focused on dams designed for hydropower production and excluded dams primarily designed for water supply, flood prevention, and recreation.⁸¹

⁷² *Id.* at 955.

⁷³ *Id.*

⁷⁴ *Id.* at 961.

⁷⁵ Burns, *supra* note 24.

⁷⁶ *Id.*

⁷⁷ Deemer, *supra* note 3, at 950.

⁷⁸ *Id.* at 961.

⁷⁹ Zarfl, *supra* note 1, at 162.

⁸⁰ *Id.* at 161.

⁸¹ *Id.* at 162.

One way to chill the adverse effects from reservoir emissions is to scale back dam building in tropical climates where nutrients are rich. Zarfl's study predicts that construction of these dams may exceed the emissions avoided from scaling back fossil fuel burning by up to ten times.⁸² The increase in electricity production from the planned dams will be minimal because global energy demand will only continue to increase. It is estimated that electricity production will rise only two percent between 2011 and 2040.⁸³ The results of Zarfl's study indicate that the hydropower boom will most likely fail to close the global electricity gap and fail to provide electricity to many people in the world who are without access.⁸⁴ Zarfl believes existing regulatory guidelines and standards must be advanced.⁸⁵ This section will focus on 1) The World Commission on Dams, which was put together to gage the effectiveness of dams and their standards, and 2) current dam regulations as outlined in the "Hydro Sustainability Protocol," which functions as more of a guideline than a regulation.

A. *The World Commission on Dams*

During the mid-twentieth century and the decades that followed, dams were viewed as the premiere way to harness electricity, irrigation, and flood control services.⁸⁶ Attitudes began to change in the 1990s as the social, environmental, and economic costs were taken into consideration.⁸⁷ A better scientific understanding indicated that the benefits derived from dams are not as great as previously believed.⁸⁸ Despite growing concerns, dams continued to evolve into a lucrative industry. Somewhere between thirty-two and forty-six billion dollars were invested in dam projects during the nineties, and at least two trillion dollars was invested overall during the entire twentieth century.⁸⁹ The dam industry is comprised of developers, engineers, and corporations that all compete with one another to turn the highest profit, which makes it against the industry's interest to concern

⁸² *Id.* at 168.

⁸³ *Id.* at 166.

⁸⁴ *Id.* at 168.

⁸⁵ *Id.*

⁸⁶ WORLD COMM'N ON DAMS, DAMS AND DEVELOPMENT: A NEW FRAMEWORK FOR DECISION-MAKING 48 (2000) [Hereinafter World Commission Report].

⁸⁷ *Id.*

⁸⁸ Bosshard, *supra* note 5, at 58.

⁸⁹ World Comm'n on Dams, *supra* note 84.

itself with policy issues surrounding dam construction.⁹⁰ The environmental problems associated with dam building go largely unaddressed.⁹¹ International society campaigns were able to halt dam projects planned for construction in India, Nepal, and China, but the President of the International Commission on Large Dams declared the debate on dams to be “an uninformed distraction which did not warrant any soul searching.”⁹²

In 1998, the World Commission on Dams was formed to review the effectiveness of dam development and recommend new standards.⁹³ The commission gathered information and data, and heard view points from multiple sources, including the dam industry and civil society groups.⁹⁴ The civil society groups were far more effective advocates because the dam industry disagreed on numerous issues.⁹⁵ One disagreement concerned whether public acceptance should be a prerequisite to dam construction, an idea which was never adopted.⁹⁶

The World Commission on Dams accomplished exactly what it hoped for – a compromise. In its final report in 2000, the commission stated, “dams have made an important and significant contribution to human development,” but “in too many cases an unacceptable and often unnecessary price has been paid to secure those benefits.”⁹⁷ While nothing in the report was binding on the dam industry, the commission recommended guidelines for the best ways to move forward on dam projects. One of the most important recommendations, and one that was never adopted by the industry, afforded involuntary risk bearers legal rights to ensure that the risks to them and the benefits to the dam industry could be negotiated on a more equitable basis.⁹⁸ The commission determined that if the rights of both parties were in conflict, then good faith contractual negotiations were the only avenue for the various interests of the parties to be reconciled,⁹⁹ The recommendations essentially suggested that dam construction be governed by contract law between dam builders and affected parties, with courts settling disagreements that could not be remedied between the parties themselves.¹⁰⁰

Responses to the final report were mixed within the dam industry. Most organizations within the industry did not want to fully accept the

⁹⁰ Bosshard, *supra* note 5, at 58.

⁹¹ *Id.*

⁹² *Id.* at 60.

⁹³ World Comm'n on Dams, *supra* note 84.

⁹⁴ *Id.*

⁹⁵ Bosshard, *supra* note 5, at 61.

⁹⁶ *Id.* at 61.

⁹⁷ Bosshard, *supra* note 5, at 310.

⁹⁸ *Id.*

⁹⁹ *Id.* at 206.

¹⁰⁰ *Id.*

report's guidelines or fully reject them either. The International Hydro-power Association (IHA) took issue with the practicability of allowing all affected people to be part of the negotiation process, and referred to the approach as "heavily legalistic" and "a lawyer's dream."¹⁰¹ The World Bank publicly endorsed the commission, but behind the scenes they served as the report's strongest opposition, with the Bank's senior water advisor urging governments in developing countries to reject the report's recommendations.¹⁰² In the end, no specific obligations were placed on dam builders.

B. The Hydro Sustainability Assessment Protocol

Dam projects continued to be highly controversial in the early twenty-first century following the World Commission on Dams' final report.¹⁰³ The IHA began creating its own set of guidelines for dam projects and came up with the Hydro Sustainability Assessment Protocol. The procedure for creating the protocol illuminates its deficiencies. Most importantly, dam-affected communities are afforded no right to participate in the decision-making process for dam projects, and compliance with the protocol by dam builders is voluntary.¹⁰⁴

The IHA adopted sustainability guidelines in 2003, but knew it needed support from entities outside the dam industry to achieve credibility. It assembled a forum of interested parties to participate in the process. Among the parties present were government agencies, financial institutions, and environmentalist groups.¹⁰⁵ The first problem with the protocol was that there was no agreed upon goal between the parties participating in the forum. The environmental groups wanted to create a protocol entirely different than the IHA's 2003 guidelines, but the IHA insisted on merely revising the '03 version.¹⁰⁶ At the forum's conclusion, the IHA adopted a revision to its 2003 guidelines and allowed the forum's participants to endorse the protocol.¹⁰⁷ The IHA had the final say on any guidelines implemented into the protocol with the illusion that parties representing environmental and social concerns made impactful contributions.¹⁰⁸

¹⁰¹ UNITED NATIONS ENV'T PROGRAMME, ANALYSIS OF REACTIONS ON THE WORLD COMMISSION ON DAMS REPORT 35 (2003).

¹⁰² Bosshard, *supra* note 5, at 61-62.

¹⁰³ *Id.* at 63.

¹⁰⁴ *Id.* at 64.

¹⁰⁵ *Id.*

¹⁰⁶ *Id.*

¹⁰⁷ *Id.* at 65.

¹⁰⁸ *Id.*

Those affected by dams did not participate in the forum at all.¹⁰⁹ The International Social and Environmental Accreditation and Labeling Alliance, which sets codes of good practice in setting social and environmental standards states that, “Consensus should be the result of a process seeking to take into account the views of interested stakeholders, particularly those directly affected ...”¹¹⁰ The IHA’s decision not to give more weight to environmentalists or even listen to dam-affected people is especially disappointing considering that the IHA released a four-page document at the 2003 United Nations climate convention regarding reservoir emissions that made claims that were “irrelevant, incomplete or simply wrong,” according to the International Rivers Network – a nonprofit human rights organization comprised of a staff of experts on dams, energy, and water policy.¹¹¹ For example, the IHA claimed in the document that gross emission factors for northern reservoirs do not exceed 40 kt CO₂e/TWh when in fact, studies have shown the upper limit of gross emissions from Churchill Falls in Canada to be 70 kt CO₂e/TWh, which is nearly double.¹¹²

The final version of the protocol assesses a dam project in about twenty different areas, including environmental and social impacts, water quality, biodiversity, labor and working conditions, and the impact on indigenous people, among others.¹¹³ Each topic is assessed on a scale of one to five. A score of five in an area means that the project is being conducted in the “best proven practice,” while a score of three is “basic good practice.”¹¹⁴ The protocol is not binding on any dam builder; rather, it serves as a mere scorecard. There would be essentially nothing to stop a dam builder from proceeding with the project if a category did not score a three. The protocol is accompanied by brief scoring criteria to guide project assessors in how to arrive at a score; however, the language is vague and leaves room for interpretation by the assessors who are selected and paid by the project developers.¹¹⁵ Basically, it is in the assessor’s discretion to decide which score to assign to a topic. Once the assessor determines that a project meets or does not meet all the criteria, the assessor has to determine how many “significant gaps” exist in preventing the project from

¹⁰⁹ *Id.*

¹¹⁰ ISEAL ALLIANCE, SETTING SOCIAL AND ENVIRONMENTAL STANDARDS 7 (2014).

¹¹¹ PATRICK MCCULLY, INT’L RIVERS NETWORK, TROPICAL HYDROPOWER IS A SIGNIFICANT SOURCE OF GREENHOUSE GAS EMISSIONS: A RESPONSE TO THE INTERNATIONAL HYDROPOWER ASSOCIATION 1 (2004).

¹¹² *Id.* at 8.

¹¹³ International Hydropower Association, *Scoring and Structure*, HYDROPOWER SUSTAINABILITY ASSESSMENT PROTOCOL (Jan. 3, 2018) <http://www.hydrosustainability.org/Protocol/Scoring-and-Structure.aspx> [<https://perma.cc/M4B5-NV4A>].

¹¹⁴ *Id.*

¹¹⁵ *See id.*

meeting all the criteria.¹¹⁶ The protocol does not define what a “significant gap” is.¹¹⁷ People impacted by the projects and environmentalists have no say in what constitutes basic good practice. This is alarming given the IHA’s history of incorrect reservoir emission claims.¹¹⁸

The language in the final protocol is also vague and toothless.¹¹⁹ For example, to receive a score constituting basic good practice in a category, plans for the project in that category must take into account environmental and social economic objectives.¹²⁰ If an environmental hazard comes to light, it is no matter; the project can still move forward. The hazard just needs to be taken into account.¹²¹

A review of the protocol published for the Chaglla Hydropower Project in Peru that was assessed in 2015 exemplifies the toothlessness of the protocol. The executive summary states that the project will not generate “significant” emissions from construction activities from its “small” reservoir.¹²² However, neither “significant” nor “small” is defined. The estimated reservoir emissions determined to be insignificant are not listed in the report, and the dam’s location in Peru places it in an area where reservoir emissions are highest. Even if the emissions from Chaglla are insignificant, the emissions from all the reservoirs being constructed in South America as a whole surely are significant. Nonetheless, the Chaglla project scored a perfect five in the area of environmental and social issues management.¹²³

The report states that an inspection report raised a few minor non-conformities, but that verbal evidence indicated those were taken care of.¹²⁴ Whatever those non-conformities were, the public will never know because they were not stipulated in the report. The verbal evidence dismissing the non-conformities is absent from the report as well. An index of verbal and documentary evidence appears at the end of the report, but it is just that – an index of titles with no substantive reasoning.¹²⁵ Visual evidence is included, but it is largely irrelevant and includes pictures such

¹¹⁶ *Id.*

¹¹⁷ *See id.*

¹¹⁸ *See* Bosshard, *supra* note 5.

¹¹⁹ *See* HYDROPOWER SUSTAINABILITY ASSESSMENT PROTOCOL, OFFICIAL ASSESSMENT: CHAGLLA HYDROPOWER PROJECT 5 (2015) [Hereinafter Chaglla Assessment].

¹²⁰ Bosshard, *supra* note 5.

¹²¹ *Id.*

¹²² Chaglla Assessment, *supra* note 5.

¹²³ *Id.* at 7.

¹²⁴ *Id.* at 32.

¹²⁵ *Id.* at 144-72.

as a tourism bus with the caption, “biodiversity compensation boosts tourism measures,”¹²⁶ and another that shows the entrance of a national park.¹²⁷ Without the benefit of substantive context in the report, it can be argued that these pictures show that 1) biodiversity is being threatened to the point that economic compensation is needed; 2) a national park is threatened because a dam is being built in the area; and 3) money is of a greater value than the environment because these problems can be overlooked when the dam builders cover them with money. The entire Chaglla protocol is full of vague language and conclusory statements that suggest the readers take the project builders at their word, which is an inadequate regulation tool for building dams with reservoirs that could potentially emit large quantities of greenhouse gas into the atmosphere.

In summary, the Hydropower Sustainability Assessment Protocol, in general, is an inadequate tool to regulate dams for many reasons. Three of the biggest are 1) dam-affected people do not possess any legal rights in regard to dam implementation; 2) the dam industry is regulating itself and 3) the regulations are not regulations; they are guidelines. One of the key features of the World Commission on Dams’ final report was that involuntary risk bearers be provided with the legal rights to ensure that the risks to them and the benefits from dams could be negotiated on a more equitable basis.¹²⁸ This policy was not adopted by the dam industry. Instead, the fox guards the henhouse. The dam industry is a competitive, profit driven industry, which tends to incentivize developers to overlook environmental concerns for the benefit of the project’s profit. A more diverse bargaining scheme between the dam builders and dam-affected people would help offset this concern because environmentalists would be among the affected people participating in the negotiation process. They could then help ensure that environmental impacts are given appropriate consideration. Finally, the current guidelines on the dam industry are suggestive and vague. Dam builders are under no obligation to adhere to the standards proscribed by the Hydro Sustainability Assessment Protocol, and when they do, dam builders only give conclusory, unsupported reasoning for why their project meets the criteria of the protocol. A more comprehensive regulatory scheme could go a long way in monitoring and mitigating reservoir emissions so that a greater balance of energy harnessing and environmental protection is achieved.

¹²⁶ *Id.* at 178.

¹²⁷ *Id.* at 187.

¹²⁸ World Comm’n on Dams, *supra* note 84.

V. SOLUTIONS

Reservoir greenhouse gas emissions need to be monitored, mitigated, and regulated because they make up a meaningful percentage of human caused greenhouse gas emissions. Reservoirs are responsible for 1.5% of all human caused emissions.¹²⁹ That percentage may seem small, but it is actually quite alarming. Other practices such as biomass burning and rice farming are monitored and are of a similar percentage.¹³⁰ In addition, this could be the tip of the iceberg, as an unprecedented number of dams with reservoirs are under construction or are in the planning phase.¹³¹ It is near irrefutable that all reservoirs are a source of greenhouse gas and, if anything, emission estimates are underestimated.¹³² It is anticipated that emissions will increase as the demand for energy continues to grow.

The actions of national governments evidence the need for greater awareness of reservoir emissions. For example, in January 2017 Brazil's government announced a desire to build dams with "big reservoirs."¹³³ This plan is evidence of either 1) ignorance to reservoir emissions, or 2) a disregard to the importance of reservoir emissions. Either way, the plan is antithetical to the December 2015 Paris Agreement commitments, which Brazil signed in 2016 to work towards maintaining a global temperature around pre-industrial ages.¹³⁴ The impact of the reservoir emissions that accompany Brazil's dam projects will work against the goals of the Paris Agreement. It is the responsibility of national governments to consider the full effects of dam projects and reservoir emissions before implementing them. If the world is serious about combating global warming, then monitoring, mitigating, and regulating reservoir emissions is necessary.

A. Monitoring

The first step in combating reservoir emissions is to monitor them. Currently, the IPPC maintains a budget that comprises the amount of emissions the earth can emit while attempting to limit the global temperature to pre-industrial levels.¹³⁵ If emissions continue at the current rate, the IPPC budget will be exceeded and the Paris Agreement's goal will not be

¹²⁹ Deemer, *supra* note 3, at 961.

¹³⁰ *Id.*

¹³¹ Zarfl, *supra* note 1, at 161.

¹³² Gary Wockner, *Dams Cause Climate Change*, ECOWATCH (Aug. 14, 2014), <https://www.ecowatch.com/dams-cause-climate-change-they-are-not-clean-energy-1881943019.html> [<https://perma.cc/DR4P-FRDV>]; See St. Louis, *supra* note 8, at 774.

¹³³ Fearnside, *supra* note 21.

¹³⁴ *Id.*

¹³⁵ *Understanding the IPPC Reports*, WORLD RESOURCES INSTITUTE (last visited Apr. 8, 2018), <http://www.wri.org/ipcc-infographics> [<https://perma.cc/5KF7-FNZK>].

achieved.¹³⁶ Reservoir emissions are not included in this budget for the year 2017, but could be included when the IPCC sets a new budget in 2019.¹³⁷

The need for inclusion can be represented by an analogy. Imagine the IPCC budget is your bank account in which you have \$100 to spend. The pre-industrial global temperature goal represents debt avoidance. If you can avoid spending more than \$100, you can avoid going into debt, but if you spend more than \$100, you will go into debt. Similarly, if the IPCC budget is exceeded, the temperature reduction goal will not be met. The problem is that \$100 is an inaccurate representation of your bank account. You do not have as much money as you think you do and fail to account for additional expenses. Similarly, the IPCC budget is an inaccurate representation of how much emission can occur while still reaching the temperature reduction goal. This representation fails to consider the cost of reservoir emissions that are not included in the budget. Plain and simple, the goals of global temperature reduction will never be met without inclusion of reservoir emissions in the IPCC global budget.

The first step to monitoring reservoir emissions would include a requirement that countries register the surface area of all reservoirs within their borders. Even if the surface area is not the most indicative element, it is still needed to calculate emissions. There is no database for which to ascertain the global surface area of all reservoirs because many countries do not list or register their reservoirs, which makes predicting accurate emission estimates difficult.¹³⁸ Registering reservoirs and their surface areas into a database can help predict reservoir emissions with greater accuracy. Once the reservoirs are registered, the IPCC can have a more accurate sense of their emissions and include them in the budget.

B. Mitigation

Reservoir emissions will need to be mitigated in areas where emissions are most abundant in order to avoid the devastating consequences from the hydroelectric boom that the world is experiencing. One option is the GHG Risk Assessment Tool. In August 2012, UNESCO developed a beta version; and in 2015, it exhibited a revised prototype at the World Hydropower Congress in Beijing.¹³⁹ The tool is still in development, but the idea behind it guides the necessary steps that need to be taken to mitigate reservoir emissions.

¹³⁶ *Id.*

¹³⁷ Cornwall, *supra* note 26.

¹³⁸ See Deemer, *supra* note 3, at 956; See St. Louis, *supra* note 8, at 772.

¹³⁹ McCully, *supra* note 109.

The objectives of the risk assessment tool are to 1) develop standard guidance for net greenhouse gas estimations; 2) calculate emissions from a set of reservoirs; 3) develop tools to predict emissions; and 4) develop tools for mitigation.¹⁴⁰ The assessment tool serves as a mechanism to apply consistent methods to obtain the most accurate estimates of a reservoir's greenhouse gas emissions.¹⁴¹ Moreover, it can apply to both existing and planned reservoirs. Because methods of emission measurement are site specific, it is important to employ the correct methods in the right circumstances to achieve consistent and accurate emission estimates. Once these estimates are derived, expert scientists can determine a level that reservoir emissions are not to exceed. If a dam project or reservoir is estimated to exceed the stipulated level, then the project should not be permitted.

Another way to mitigate reservoir emissions is to look at methane sources as a potential renewable energy source rather than as pollutants. While likely to be expensive, a study by F.M. Ramos proposes that the use of biogenic methane could increase the energy supply in countries with tropical climates.¹⁴² Ramos describes the process as simple. Methane in deep water, where it is richest in methane, can be transported to the surface and then extracted by bubbling or spraying into a sealed vessel.¹⁴³ Ramos states that, later, the methane can be pumped to consuming centers, stored locally, and then burned in order to generate electricity during high demand periods.¹⁴⁴ The methane could also be purified for transportation.¹⁴⁵

A similar approach has been successful for degassing carbon dioxide from lakes in Cameroon.¹⁴⁶ The idea is trending beyond reservoirs, too. In Switzerland, a company called Climeworks is running a three-year demonstration project involving a factory plant located above a waste heat recovery facility that sucks carbon from the air, captures it, and converts it to gas.¹⁴⁷ The gas is then sent through an underground pipeline to a

¹⁴⁰ INTERNATIONAL HYDROPOWER ASSOCIATION, GHG RISK ASSESSMENT TOOL (BETA VERSION) USER MANUAL, 1 (proposed Aug. 2012) http://www.ceeg.uqam.ca/Prairie/Publications_files/USER%20MANUAL-Risk%20Assessment%20Tool%20-%20BetaVersion.pdf [<https://perma.cc/H6CK-AQ5P>].

¹⁴¹ *Id.*

¹⁴² F.M. Ramos et al., *Methane stocks in tropical hydropower reservoirs as a potential energy source*, 93CLIMATIC CHANGE, 1 (2009).

¹⁴³ *Id.*

¹⁴⁴ *Id.* at 4.

¹⁴⁵ *Id.*

¹⁴⁶ *Id.*

¹⁴⁷ Christa Marshall, *In Switzerland, A Giant New Machine is Sucking Carbon Directly from the Air*, SCIENCE (June 1, 2017), <http://www.sciencemag.org/news/2017/06/switzerland-giant-new-machine-sucking-carbon-directly-air> [<https://perma.cc/S93S-YYDV>].

greenhouse where it is used to help grow vegetables.¹⁴⁸ Engineers say that this process is a needed option to keep global temperatures at controllable levels.¹⁴⁹ Similarly, rather than acting as a greenhouse gas, the methane from reservoirs could become a source of renewable energy.¹⁵⁰

C. Regulation

The third step in combating reservoir emissions involves regulating the dam industry. Current, self-imposed regulations are vague and non-binding. The Hydropower Sustainability Assessment Protocol is a good starting point even if it is presently inadequate.

A regulatory process could emulate the administrative rulemaking process in the United States government. One of the most important suggestions made by the World Commission on Dams was to legalize the dam building process and give voices to those affected by dam construction.¹⁵¹ Due to the adverse environmental impact of reservoir emissions, this should include every person because everybody is affected by the global climate. However, it may be unrealistic to allow every single person in the world to comment on a single dam project. Geographic restrictions to public comments could be imposed as long as environmentalists have a voice. Dam developers should be required to post an adequate notice of proposed dam building so that the public is aware of the dam's specifications, benefits, and what sacrifices would need to be made in order to construct the dam. Sacrifices would likely include social displacement, environmental impact, and degradation of biodiversity. Benefits would include clean water and energy. Next, the public should be given an opportunity to comment on the proposed dam construction. Once the comment period is over, the developers should be required to respond to vital questions, leaving none unanswered. The answers to the questions must be explained with reasoning that considers policy alternatives and new scientific evidence.

Currently, the Hydropower Sustainability Assessment Protocol provides a comment period.¹⁵² However, this period is rarely utilized, possibly because interested people know that the protocol is non-binding. This proposed regulatory structure would create a compromise between the dam industry, which does not want to give affected people legal rights in regard to the project, and concerned people, who currently do not have a leg to stand on.

¹⁴⁸ *Id.*

¹⁴⁹ *Id.*

¹⁵⁰ See Ramos et al., *supra* note 142.

¹⁵¹ See World Comm'n on Dams, *supra* note 84.

¹⁵² See Hydropower Sustainability Assessment Protocol, *supra* note 113.

After comments are addressed, a more detailed set of guidelines should be set to guide dam assessors in order to assess a dam's ability to function over the areas already assessed by the protocol, i.e. public health, economic viability, and environmental and social management. These assessors should be third parties, not hired by the dam builders. A score can be given in those areas, and if the scores do not meet a minimum threshold, then the dam project should not go forward. Currently, a score of three on a scale of one to five is considered basic good practice. Scientific experts should then conclude whether this is adequate protection, a higher threshold should be set, or the standards should be altered depending on the region the reservoir is in.

VI. CONCLUSION

Scientists universally agree that reservoirs emit greenhouse gas into the atmosphere, with methane being the most abundant. This is a cause for concern given that methane's global warming potential is much higher than other greenhouse gases. Critics cite inconsistent data as reason to be skeptical of reservoir impact on the environment; however, if anything, current estimates are conservative and reflect a smaller amount of emissions than what is actually occurring. Furthermore, the inconsistencies can be explained by the factors that determine reservoir emissions. Reservoirs in warm, tropical climates are more likely to emit more greenhouse gases than reservoirs in colder, drier climates. But energy is greatly needed in those warm, tropical climates, and governments are turning to hydroelectric dams and reservoirs as an answer despite their effect on the climate. In addition, reservoirs offer other benefits such as fresh water, irrigation, and recreation.

Reservoir emissions need to be monitored, mitigated, and regulated in order to combat the effects of global warming. Current regulations are inadequate because the dam industry is self-regulated and financially driven. The industry's current guidelines are vague and do not often address environmental concerns. Specifically, they do not satisfactorily address reservoir emissions. People affected by hydroelectric and environmental consequences should get a say in whether a project becomes implemented. The emissions can be mitigated through measurement and denial of a permit if emissions are expected to exceed certain levels. Eventually, greenhouse gases themselves can be converted into renewable energy.

Finally, it is important to, at the very least, monitor reservoir emissions. Even if the world is able to move toward the Paris Agreement's goal of lowering global temperatures, a false sense of confidence will veil the

reality that unaccounted reservoir emissions are still devastating to the atmosphere, and assertions towards a healthier climate will be incorrect. We cannot live in a world without reservoirs, but we cannot live in a world with too many reservoirs either.