Understanding the Differences Between Hydropower and Reservoir Methane Emissions
DRAFT – April 20, 2023

INTRODUCTION

Hydropower plays an important role in integrating wind and solar resources, displacing fossil fuels, and providing other grid services. While hydropower generation does not directly emit methane, reservoirs, like all freshwater ecosystems, can be a source of greenhouse gas emissions. Since methane is a powerful greenhouse gas, it is important to understand the extent to which reservoirs utilized by hydropower may contribute to U.S. methane emissions.

CONTEXT

We are mindful of the advice from the U.S. Department of Energy's Oak Ridge National Laboratory, which warns against comparing carbon intensities across energy generation without contextualizing them within the electricity portfolio.

> "Energy sources are not directly comparable because they play different roles in supporting the electricity grid. Projects that support integration of variable renewables to the grid will likely lower the carbon footprint for the electricity portfolio as a whole by enabling the intermittent use of wind and solar and by displacing natural gas."[1]

Any evaluation that includes greenhouse gas emissions from reservoirs with hydropower, versus the emissions attributable to other uses at non-hydro or multi-purpose reservoirs, should be compared on an equivalent basis to the lifecycle emissions of other energy sources.[2]

This summary reflects our best understanding of the state of the science on reservoir emissions. While the focus here is on methane, it is also important to understand the role of carbon in order to provide context for associated methane emissions.

FINDINGS
All Freshwater Bodies Can Emit Carbon and Methane

Carbon enters river systems through terrestrial sources (e.g., soil, plant debris). Carbon and methane are also produced within water bodies as a result of organic material decomposition. Some carbon is buried in freshwater sediments and some is transformed through biochemical processes and emitted to the atmosphere as carbon dioxide and/or methane, or is carried downstream eventually discharging into oceans.

All freshwater ecosystems produce carbon and methane emissions, including wetlands, canals, ponds, lakes, and reservoirs.[3] Among other factors, water body size, depth, bathymetry, orientation, temperature, organic and nutrient inputs, sedimentation rate, and dissolved oxygen conditions can all

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[1] Renewable and Sustainable Energy Reviews, "Getting Lost Tracking the Carbon Footprint of Hydropower" (H. Jager et al. 2022).
[2] NREL, "*Life Cycle Assessment Harmonization*", https://www.nrel.gov/analysis/life-cycle-assessment.html
[3] U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018 | US EPA

affect emission levels.[4] For reservoirs, the latitude and age also affect emissions.[5] The level of organic inputs plays the most significant role in emissions, with low levels of oxygen and more dissolved organic carbon resulting in greater emissions. Water bodies with higher levels of nutrients and higher algae and plankton production (i.e., eutrophic) tend to have higher methane emissions.[6]

However, constructed reservoirs change how carbon and methane move through riverine systems in both positive and negative ways.[7] One source of methane emissions from freshwater bodies is ebullition (bubbles of methane). Because ebullition occurs only when methane bubbles are released from the sediment and reach the surface before they dissolve, it occurs at a much lower rate at sites deeper than 6 meters. This is particularly true for U.S. hydropower reservoirs as deeper reservoirs maximize power output. Ebullition rarely occurs at older reservoirs where any organic material decomposed decades ago, although the rate of ebullition can depend on other factors such as sediment composition, water flow rates, and water residence time in the water body.[8]

Constructed reservoirs impacts relating to greenhouse gas emissions

- Reservoirs can store carbon in sediments.[9]
  - It has been estimated that as much as 40% of carbon stored in inland water bodies is stored in reservoirs.[10]
  - Carbon burial is six times higher in reservoirs than natural lakes and exceeds carbon emissions in temperate climates, making reservoirs an important carbon sink.[11]

- Reservoirs, like all freshwater bodies, can emit greenhouse gases.[12]
  - Reservoirs are part of larger ecosystems with multiple sources that carry nutrients into them, such as from agricultural runoff. Thus, external factors must also be considered when evaluating carbon and methane emissions from reservoirs.[13]

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[4] Renewable and Sustainable Energy Reviews, "Getting Lost Tracking the Carbon Footprint of Hydropower" (H. Jager et al. 2022).
[5] Nature Geoscience, "Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude" (N. Barros et al. 2011)
[6] BioScience, "Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis" (BR Deemer et al. 2016).
[7] Renewable and Sustainable Energy Reviews, "Getting Lost Tracking the Carbon Footprint of Hydropower" (H. Jager et al. 2022).
[8] Limnology and Oceanography, "Productivity and depth regulate lake contributions to atmospheric methane" (WE West et al. 2015).
[9] Environmental Science & Technology, "Organic Carbon Burial in Lakes and Reservoirs of the Conterminous United States" (DW Clow et al. 2015).
[10] Renewable and Sustainable Energy Reviews, "Getting Lost Tracking the Carbon Footprint of Hydropower" (H. Jager et al. 2022).
[11] Renewable and Sustainable Energy Reviews, "Getting Lost Tracking the Carbon Footprint of Hydropower" (H. Jager et al. 2022).
[12] Environmental Science & Technology, "Organic Carbon Burial in Lakes and Reservoirs of the Conterminous United States" (DW Clow et al. 2015).
[13] Renewable and Sustainable Energy Reviews, "Getting Lost Tracking the Carbon Footprint of Hydropower" (H. Jager et al. 2022).

- Reservoirs with large water level fluctuations can lead to emissions from the drawdown zone, although hydropower reservoirs tend to have smaller drawdown zones than irrigation or flood control reservoirs, and hence tend to have lower levels of emissions.[14]
- Scientists are studying the phenomenon of methane degassing where methane can be indirectly released during water discharges from reservoirs. Degassing occurs if the reservoir becomes stratified and anoxic (lacking oxygen) at the depth of the discharge. Therefore, only a sub-class of all hydropower reservoirs have the potential for methane degassing[15], and the effect seems to be small relative to other carbon and methane emission pathways.[16] Degassing is more likely to occur in tropical and subtropical regions than in the temperate zones found across much of the U.S.[17]

Hydropower Generation Does Not Directly Emit Methane

- Unlike fossil fuel power plants, hydroelectric facilities do not emit greenhouse gases directly into the atmosphere. Emissions from hydro reservoirs do not increase along with increased energy production as they do for fossil fuels.

- Research has not distinguished between the pre-existing emissions of reservoirs and the impact of adding generation to a non-powered dam.

- Most published studies report gross emissions estimations, ignoring the baseline emissions that existed prior to reservoir inundation. Baseline emissions should be subtracted to estimate a reservoir's net carbon footprint.[18]

- The primary purpose of the vast majority of reservoirs equipped with hydropower is flood management, water supply storage, irrigation, and/or recreation, not hydropower generation.[19] In circumstances where hydropower is one of multiple services provided by a reservoir, reservoirs would be maintained even if hydropower generation stopped.

CONCLUSION

In sum, all freshwater ecosystems can produce greenhouse gas emissions which vary based on a wide variety of site-specific conditions. Studies have yet to synthesize all of these factors together beyond

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[14] Nature Geoscience, "Global carbon budget of reservoirs is overturned by the quantification of drawdown areas" (P.S. Keller et al. 2021)
[15] If a hydro turbine intake is not deep, or the reservoir does not stratify, or the anoxic conditions in the stratified lower layer are mitigated (e.g., by engineered oxygenation systems), then water drawn into turbines does not have high concentrations of methane, and the potential for methane to de-gas in tailwaters does not exist.
[16] Environmental Research Communications, "Variability in modelled reservoir greenhouse gas emissions: comparison of select US hydropower reservoirs against global estimates" (C. Hansen et al. 2022)
[17] Global Biogeochemical Cycles, "Year-2020 global distribution and pathways of reservoir methane and carbon dioxide emissions according to the greenhouse gas from reservoirs (G-res) model" (J.A. Harrison et al. 2021)
[18] Plos One, "Hydropower's Biogenic Carbon Footprint" (Scherer & Pfister, 2016)
[19] U.S. Army Corps of Engineers, National Inventory of Dams. According to the Inventory, 57,902 U.S. dams have a primary purpose of flood control, water supply, irrigation, and/or recreation. Of those, only 337 also have hydropower, or about one-half of one percent. There are 2,085 additional dams whose primary purpose is hydropower.

gross generalizations and studies result in widely varying emissions estimates from both natural systems and reservoirs. Studies have also shown that carbon and methane emissions can vary widely on a temporal and spatial basis within a single reservoir leading to even greater uncertainty in overall emissions estimates.[20]

Hydropower does not directly emit methane. It is critical to distinguish between reservoir emissions and hydropower operations. Reservoirs also positively impact the environment by sequestering greenhouse gases via carbon burial and storage. Currently, we have only a limited understanding of greenhouse emissions and their pathways from reservoirs in the U.S. We have an even more limited understanding of emissions from hydropower reservoirs. Most research has focused on reservoirs in general not hydropower specifically. Lastly, very few if any studies provide insight into how hydropower operations and patterns of hydropower production may or may not affect reservoir emissions. This would be very difficult to quantify given the multiple uses of most reservoirs, but also very important to future work in this area.

[20] Environmental Science and Technology, "Climate Impacts of Hydropower: Enormous Differences among Facilities and over Time" (I.B. Ocko and S.P. Hamburg. 2019)