**Scientific and Technical Advisory Panel**

The Scientific and Technical Advisory Panel, administered by UNEP, advises the Global Environment Facility

“Pilot project for methane mitigation and recovery from hydroelectric power reservoirs” – A GEF full sized proposal, submitted by the Inter-American Development Bank (GEF Project ID # 4144)

A review by a STAP targeted research committee

May 7, 2010

1. Introduction

The Scientific and Technical Advisory Panel (STAP) to the Global Environment Facility (GEF) formed a targeted research committee to review the full-sized proposal “Pilot project for methane mitigation and recovery from hydroelectric power reservoirs” submitted by the Inter-American Development Bank (IADB). The committee consisted of STAP, and three independent external reviewers, who agreed to provide their advice in writing. The resulting review papers provide broadly consistent findings and recommendations which STAP supports and from which STAP’s advice and recommendations are taken.

This report consists of a first section with STAP’s overall advice on how to strengthen the project’s scientific/technical viability, and a second section presenting the three independent review papers. The IADB and the proponents of the project are invited to consider STAP’s advice and to consult the review papers before proceeding further with project formulation.

2. STAP’s advice and recommendation

**Main Recommendations:** Because of the significant scientific and technology uncertainties and risks, STAP does not support further development of the project document according to the original project concept (PIF). STAP requests that the Targeted Research Committee have the opportunity to review an early draft of the project being developed for CEO endorsement to determine whether its concerns were addressed.

In particular, STAP strongly recommends that this project aims primarily at the development of a robust assessment of methane emissions including measurements of methane stock, sources and sinks in reservoirs chosen for demonstration. STAP is willing to assist the IADB in identifying any required scientific expertise to re-design the proposal.

STAP’s recommendation is based on its review of the following major scientific and technical deficiencies in the project proposal:

i. The project proposal does not provide convincing scientific arguments that global environmental benefits such as reduced release of methane to the atmosphere are to be delivered. The project’s working hypothesis that mitigation and recovery of methane from the reservoir is at least equivalent to the avoidance of methane release to the atmosphere is unjustified. Major factors influencing the fate of the methane include the dissolved oxygen availability in the water column, the elevation of the reservoir outlets in relation to the
anoxic zone, age of reservoir, hydrological regime and others. These factors are site-specific and do not justify any generalization. Scientific data are lacking to support the notion that hydroelectric power reservoirs globally or in Brazil particularly are a significant global source of atmospheric methane.

ii. In spite of the lack of scientific evidence for methane mitigation in reservoirs, STAP holds the opinion that this project, if re-designed, has the potential to provide globally important information by assessing methane stocks and fluxes in selected hydropower reservoirs in Brazil. One of the Committee members suggested that it might take at least one full hydrological cycle to construct a methane budget for reservoirs and considers the existing project duration of 18 months as unrealistic to test the efficiency of mitigation structures. The Review Committee provided initial guidance on how to set up this measurement process.

iii. Committee members questioned the feasibility of the two proposed options for methane mitigation. Their design has to depend on the spatial and temporal variability of methane sources and sinks in selected reservoirs. As such pre-selection of particular mitigation options proposed in the project is premature at this stage. STAP recommends considering several other mitigation alternatives in the project proposed, inter alia, in the reviews.

iv. STAP does not recommend pursuing a methane recovery option in this project due to the lack of any substantive evidence that methane recovery is feasible under the project conditions.

Further details on the priorities highlighted above can be found in the complete commentaries provided below.
3. Detailed comments provided by external reviewers

“Pilot Project for Methane Mitigation and Recovery from Hydroelectric Power Reservoirs”
Review by George W. Kling

Executive Summary of Comments and Recommendations

1. Overall this is an interesting concept, and potentially an interesting and useful project. The strongest part of the project and the one with the greatest chance of success is the engineering plan for mitigation of methane releases from reservoirs to the atmosphere. Channeling the water withdrawn from the methane-poor surface waters instead of the methane-rich bottom waters will have a definite mitigating effect on methane flux to the atmosphere, and can be applied to reservoirs around the world and be used in new reservoir design.

2. The project relies heavily on measurement of methane concentrations in the water (for feasibility of methane extraction), total amounts in the reservoir(s) (for estimating mitigation and methane recover potential), rates of generation of methane (for evaluating long-term sustainability of methane extraction), and the flux of methane to the atmosphere (for estimating mitigation). At present the methods and sampling descriptions for these measurements are inadequately described or are inappropriate. I understand that there are space limitations in the proposal, and that part of this work is funded from outside GEF, but before proceeding a more detailed technical description and research plan should be produced and reviewed that indicates how, when, and where the methane measurements required will be made.

3. The most intriguing and potentially valuable contribution of this project is the generation of electricity from reservoir methane extraction. As with all energy extraction plans, the concentration of the source is key. It is possible that more potential energy (in the form of methane) can be extracted from the water than is used in the extraction itself, depending on the methane concentrations. However, what is lacking is an integrated and comprehensive assessment or even a plan for assessment of the full energy costs involved in methane extraction from water, methane transportation, and methane combustion to produce electricity. If the goal of the project is to produce such an assessment that is fine, but because this represents the largest funding component of the project there should be at least a detailed plan of how this assessment will be made and what components it will include.

4. I see no evidence that the group involved in project implementation is unable to perform the above tasks and recommendations – in other words, they appear to be technically capable, but the project as written does not yet demonstrate that capability.

Detailed Comments

1. METHANE MEASUREMENTS

There are three key pieces of information that are needed for this project:

(a) the concentration of methane in the water, which is critical for determining whether the energy gained from CH4 extraction will be greater than the energy used for the extraction process itself;
(b) the total amount of methane in the reservoir, which is critical for determining the extent and impact of mitigation (reduction of methane releases to the atmosphere) and for the global impact when considering multiple reservoirs; and

(c) the rates of methane generation in the reservoirs, which is critical for the long-term sustainability of such methane recovery projects.

For measurements of the methane concentration, on page 5 of the proposal, it says “Van Dorn bottles collect the water on site and are maintained pressurized until measures are made on lab.” That is not feasible especially if you are sampling many depths or many locations, plus, the Van Dorn bottles would leak as they are returned to the lab. Typically a headspace equilibration of the sample directly from the water in the Van Dorn is done in the field, and this gas sample is then either analyzed shipboard or transported back to the laboratory to be measured on a gas chromatograph. You could have separate, pressurized cylinders that are leak-proof that can be returned to the laboratory (this is the method mainly used in the work on the Cameroon lakes Nyos and Monoun), but it would be extremely expensive and time consuming to measure methane concentrations in this way.

As noted you can also measure the methane with a sensor, and there are commercial systems available. In these methods the gas can be detected in situ in liquid phase using a probe lowered into the water, or the CH4 can be detected in gas phase after automatic pumping from depth and equilibration with the atmosphere or an inert gas. There are currently many arguments about what the liquid phase detector is actually measuring, but the gas phase detectors seem to work fairly well and have been around for a long time in commercial applications (I have used these on lake studies to measure CH4 and CO2 in the water continuously). With both methods, however, you need to be careful that the sensor is properly calibrated. In the proposal it says “These sensors (hardware and software) are still being developed by the project team” – however, because the measurement of CH4 concentrations is a critical part of this project, it seems appropriate to see the results of this development before the project begins. As I mentioned on the phone, a group of scientists working at Hydro-Quebec (led initially by Alain Tremblay) and at the Experimental Lakes Area (led by Ray Hesslein at the University of Winnipeg) have constructed several different floating systems to measure CO2 and CH4 gases in real time and installed them in reservoirs. Further development of these technologies for reservoirs has been conducted by Julie Bastien (jhantryk@access.com, phone 1-250-655-5868), and you may wish to contact them for further information.

There is also little or no information about the research plan for measuring the total amounts of methane in the reservoir. At a minimum there needs to be a plan developed which includes information on which depths will be measured, how many spatial locations (stations) in the lake will be visited, the frequency of sampling throughout an annual cycle, and a brief reference to the availability of data on lake bathymetry in order to calculate the total amounts of methane and its distribution over time.

Measuring the rates of production of methane is not mentioned in this proposal, but the rate of new methane produced is critical for determining whether there would be enough methane at any time to make feasible a methane extraction and recovery program for the ultimate purpose of combusting the methane to generate electrical power. It is possible for the rates of production to be measured in situ in the reservoir water column and sediments, and it is also possible to calculate the net production rates by comparing the vertical and horizontal survey data on methane concentrations between two different time points. Neither of these methods are described in the proposal at present.
2. MITIGATION OF METHANE RELEASE

Page 5, section ii. **Test different technologies and devices for mitigation of CH4 and identification of the most adequate one to be used in the selected hydropower:**

Installing the barriers (membranes) is an engineering project, basically a refitting of reservoir intake placement designed to eliminate CH4 rich bottom water from leaving the reservoir. It is too bad that the standard design in temperate zones for different depths of water withdrawal to manage outflow temperature isn’t used in the tropics (where the temperature range top to bottom is very small). While this refitting of the structures will certainly reduce CH4 release to the atmosphere, it seems to be an engineering project and I don’t see what this has to do with science or research. There are other aspects of this mitigation plan that need to be developed, or considered. For example, if any of the reservoirs are monomictic (the water column completely mixes from top to bottom once each year, a typical pattern in tropical lakes) then most if not all of the methane being stored in the bottom waters is released to the atmosphere anyway. If this is occurring, the level of mitigation impact by channeling withdrawal water will be reduced.

3. RECOVERY OF RESERVOIR METHANE

Page 6. iii. **Develop a pilot project for CH4 recovery:**

There was some misunderstanding of the degassing systems in Cameroon as referenced in the proposal. Although in our conference phone conversation it appears that Fernando and the others recognize these misunderstandings, I will describe them in some detail here just to make sure that there is no future assumption that the high gas pressure systems of the African lakes can be used as models for methane extraction in reservoirs.

First, in the Cameroonian systems there is no collection vessel at the surface as stated, and there is no pressurized container at the surface in the pumping facilities in Lakes Nyos and Monoun in Cameroon. In these facilities the extracted CO2 and CH4 gas is released directly to the atmosphere. There is a collection vessel at the surface in the Lake Kivu methane extraction plant which is currently operating (producing about 2.5 MW as of January 2010).

Second, it appears that there is the idea that two-phase fluid will be generated and used to enhance upward flow in the pipe as stated in the proposal by “...two phase flows causes a reduction in column density that enhances the upward flow”. It is very unlikely that the bottom water gas pressures in these reservoirs are high enough for this to work. For example, in Lakes Nyos and Monoun the total gas pressures are ~18 bar and 8 bar at the pipe inlet, and in Lake Kivu the total gas pressure is 19 bar at the bottom of the lake. These gas pressures provide tremendous lift and driving force, but the useable energy from initiation of two-phase flow in a pipe drops off dramatically as the pressure drops – for example, you probably need a total gas pressure of 3-5 bar at the bottom of the lake in order to drive an upward flow without added energy, and there is no indication that these high gas pressures exist in reservoirs anywhere (e.g., see the book by Tremblay, A. et al. (eds). 2005. Greenhouse Gas Emissions – Fluxes and Processes, Hydroelectric Reservoirs and Natural Environments. Springer, 732 pp.). In fact, only in Lake Kivu is the CH4 gas pressure very high (~14 bar), which translates to about 350 g CH4 per m3, and in Cameroon only Lake Monoun has substantial methane, and it is less than 1 bar pressure at the bottom (~25 g/m3). In other words, even if you had 2 bar total gas pressure at the bottom of the reservoir, 0.8 bar of that would be N2 gas,
and if the remaining amount was CH4 there still isn’t enough pressure to drive a flow. The maximum levels of CH4 in tropical reservoirs seem to be about 20 g/m³ and the typical values are much lower. Without using the self-sustaining fountain generated by high gas pressure at depth, it will require a lot of energy to pump the water vertically toward the surface where it can be degassed (point taken up again below).

4. POWER GENERATION FROM RECOVERED METHANE

On p. 6, in part iv. **Conduct a technical and financial feasibility study for electricity generation using recovered CH4:**

There are two main parts of this process – first is extracting the methane from the water, and second is transporting the methane from the lake and to a facility where the methane can be combusted to produce electricity. This second part of the process is not described in the proposal, but it is critical for the ultimate success of this “methane for electricity” promise being made for tropical reservoirs. The first part of the process is described, but, I found some errors in the presentation of this work. These errors are not large or fatal, but they are worrisome and as with the methane measurements, may indicate the need for additional expertise in the project. For example, the proposal states “Recent studies have shown that if the water is collected at depths greater than 50 meters within the CH4 saturation zone, the gas recovered will have a partial CH4 pressure in the range of 36 to 80% (the rest being mainly N2 and CO2), suitable for stationary applications.”

Perhaps this was just a typographic error, but if not it illustrates a fundamental misunderstanding of the gas dynamics involved. The values of 36 to 80% are mole fractions, not pressure (pressure is measured in Pascal, bar, atmosphere, torr, etc. – I noticed that this same error is in a publication on the topic in the journal *Climate Change*). In addition, it is strange to see ratios of gases (presented in the next sentence) as given in units of parts per million (ppm) – such ratios should have no units. While this may not by itself be considered an important issue, combined with the earlier comment on the apparent lack of understanding or experience in measuring CH4 in natural waters, I would be uncomfortable recommending this work to go forward until the project employs a real gas chemist with field experience, and demonstrates that the required measurements can be made.

I understand that the “Graph of Extraction Efficiency” is supposed to indicate that the energy from burning methane contained in the water could drive the gas extraction. I have not made these calculations myself, but I have reviewed their explanation in the article published in the journal *Energy* 32 (2007), pp. 1038-1046. Although the data presented in this article indicate that this extraction method has potential, there is no discussion or analysis of other energy costs or potential difficulties in the entire “supply chain” of methane from the lake to the power generation plant. For example, there are many assumptions that must be made – the depth of the water column from which the extraction takes place doesn’t matter much, but the energy required to lift the water mass once you are above the lake surface becomes substantial. In addition, if I read it right there will be pressure nozzles or some other means to help degas the water (which will be necessary at such low total gas pressures) which will require additional energy. The extraction efficiency seems to be a poorly constrained quantity in this calculation, and yet it is critical for determining whether there is enough heat to electricity conversion to have a net energy gain from the CH4 extraction. And, where is this energy generated? If diesel engines on the raft are driving the many m³ flow of water required, then is the later burning of the methane in a power plant that recoups this energy used? That is fine, but, what are the assumptions of the energy losses or inefficiencies in compressing the methane shipboard to be transported to shore, and then the further transport of the methane to power
plants and other supply train problems? Perhaps all of this is “hidden” behind the Extraction Efficiency graph, and that would alleviate some of my concerns, but otherwise these issues (see also additional points made in the next section) need to be described in sufficient detail initially for there to be an evaluation rigorous enough to proceed with this part of the project.

5. ENVIRONMENTAL CONCERNS

In the IADB replies to STAP comments document, there is the statement “Moreover, our technology integrates the knowledge of reservoir limnology and hydrology to avoid undesirable environmental impacts as the rupture of the vertical thermal stratification. Hypolimnetic waters of tropical dams are colder and richer in nutrients and methane. Therefore, after gas extraction in our prototype, the processed water is returned back to the reservoir in thermal equilibrium and below the euphotic zone, around the metalimnion.”

I am very glad to see that the project is considering these important issues, and that they have given them some thought. However, with regard to the return of surface degassed water to the depth of neutral buoyancy, this requires energy to achieve this return flow against gravity - I wonder if this energy cost has been appropriately considered in the Extraction Efficiency analysis. After reading the proposal I get the sense that this is fundamentally an engineering project, and on a massive scale. Although I do not know the proposers, my sense is that they are researchers who have worked at smaller scales. One might think that it’s best to have a large engineering company undertake such a project, or, if this is truly just a small scale demonstration project then there are many more details that need to be provided and examined.

Final Comments. In the end, and somewhat unrelated to this proposal, it seems to me that if you want to mitigate methane releases from reservoirs worldwide and collect the CH4 for power generation, then the best option would be to collect the methane in gas phase as it exsolves from water passing through the turbines or spillways. Perhaps this will require a new design of future hydroelectric dams and plants, or perhaps you can fit plastic covers over certain parts of existing systems to trap the CH4 as it naturally degasses from the water. This option also removes the need for redirecting the inflow water as well, and in fact for this purpose a bottom-draining dam would be preferable and essentially the hydroelectric reservoir operations would be doing all of the work for you except for collecting the gas and distributing it to an electric-generating power station.

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“Pilot Project for Methane Mitigation and Recovery from Hydroelectric Power Reservoirs”
Review by Frederic Guérin

Greenhouse gas (GHG) and particularly methane (CH4) emissions from hydroelectric reservoirs are thought to be significant at the global scale (St Louis et al., 2000; Lima et al., 2008). Even if these global estimates suffer from large uncertainties (total reservoir surface, emissions downstream of the dams…), they both show that most of the CH4 emissions from these man-made lakes occur in the tropical region. More specifically, for the two reservoirs for which emissions were extensively quantified, the main CH4 pathway was located downstream of the dams (Abril et al., 2005; Kemenes et al., 2007). In addition to this specific environmental issue, the building of dams leads to (1) a loss of diversity by flooding specific biomes and (2) to the social disruptions and dislocations (Sathaye et al., 2007). A project aiming at (1) mitigating emissions from hydroelectric reservoirs by reducing emissions from the main pathway and (2) using the CH4 produced during the decomposition of organic matter within the reservoir for additional energy production that can reduce the creation of new dam sounds very timely in the framework of global change.

MITIGATION EFFICIENCY

One of the main objectives of the project is to mitigate CH4 emissions and to quantify to what extent the proposed methodology will reduce emissions. It is not clear how this part of the project will be performed; some clarifications about measurements that will be performed are needed (methodology, spatial and temporal resolutions) since all emission pathways cannot be assessed by measuring only vertical profiles of CH4 in the water column of the reservoir.

CH4 emissions from hydroelectric reservoirs occur from four main pathways: bubbling, diffusive fluxes from the reservoir itself and from the river downstream and just below the dam when water comes out of the turbines due to a pressure drop (Abril et al., 2005; Guérin et al., 2006). In some cases, for reservoir with a very large drawdown area, emissions from the littoral zone can also be very significant, especially when the littoral zones are vegetated (Chen et al., 2009). As shown by (Abril et al., 2005; Guérin and Abril, 2007; Kemenes et al., 2007), concentrations and emissions exhibit seasonal variations by several order of magnitude, depending on the hydrology. Estimations based on 1 to 2 surveys per year should be taken with caution.

If one of the objectives of the project is to identify the best mitigation options, emissions must be measured before and after the installation of one of the two proposed technologies in order to quantify their efficiency.

RECOMMENDATIONS

1. Measurements of vertical profiles of CH4 concentration in the reservoir at a least two types of stations: littoral stations and stations located on the former river bed. This will allow the estimate of the CH4 storage in the hypolimnion

2. Measurements of vertical profiles of CH4 concentration in front of the turbines or if possible, a better option is to gather samples from the turbines

3. Measurements of CH4 concentrations in the river downstream of the dam
4. Concentrations must be determined by classical headspace techniques (see for instance (Bastviken et al., 2002; Guérin and Abril, 2007)). The proposed technique with Van Dorn bottles will not be successful since they are not water and gas tight during transport. In addition, as mentioned in the two above cited papers, water needs to be poisoned. Another option is the use of “Automated systems” developed by Environnement Illimité (Demarty et al., 2009) as mentioned by G Kling. Although it gives reliable results for CO2, as mentioned p 8914 of the manuscript, the sensitivity of the CH4 sensor might not be sufficient, so comparison with the headspace technique is needed.

5. Results from actions 2 and 3 using techniques mentioned in 4 allow the calculation of the so-called “degassing” term which is (1) the main CH4 pathway in tropical reservoirs (Abril et al., 2005; Kemenes et al., 2007) and (2) the emission pathway that will be mitigated by the proposed technology.

6. Diffusive fluxes must be either measured or calculated at the stations in the reservoir upstream of the dam and in the river downstream of the dam, see for instance (Guérin et al., 2007), (DelSontro et al., 2010) and reference therein for the techniques and the design of the chambers.

7. Bubbling fluxes must be determined by the classical funnel technique (Keller and Stallard, 1994; Galy-Lacaux et al., 1999; Abril et al., 2005) in the reservoir upstream of the dam.

8. All the proposed measurements must be performed on a monthly basis (Abril et al., 2005; Guérin and Abril, 2007; Kemenes et al., 2007).

9. Measurements should be performed during one full hydrological cycle before the installation of mitigation structure and during one year after the installation of this structure.

**ISSUE:** The project lasts only 18 months and at least 24 months are needed to test the efficiency of the mitigation structure.

**CHOICE OF THE MITIGATION TECHNIQUES**

Two mitigation options are proposed: (1) the membrane technique and (2) the self-guided plate. How will the efficiency of these two options be tested within a period of 18 months (which should also include the quantification of CH4 emissions from the reservoir in its basic configuration, see above)?

**RECOMMENDATIONS**

Models can be good and inexpensive tools to test the impact of the two different technologies. The potential storage of CH4 in the hypolimnion of the reservoir depends on the hydrodynamics in the reservoir water body which will be impacted by the proposed structures. Physical models that allow the injection of passive tracers should be used for this test.

Anyway, since both technologies will direct mainly surface “CH4-depleted” water to the turbines, downstream emissions will be significantly mitigated. If CH4 emissions from the selected reservoir occur mostly downstream of the dam as observed at Balbina (Kemenes et al., 2007) and at Petit Saut
Reservoirs, this could reduce total CH4 emissions from the reservoir by more than 50%.

ISSUES

Again, the time frame of the project will not allow comprehensive tests on the efficiency of the two options to be performed.

Since we can expect a highest residence time of hypolimnic waters due to the proposed structures, the CH4 storage in the reservoir will increase. With highest CH4 concentration at the bottom, there is a risk to increase oxygen demand for aerobic CH4 oxidation which under particular circumstances could lead to complete anoxia of the system. In case of lake overturn, the stored CH4 will be emitted at once. This has to be taken into account in the CH4 budget of the reservoir.

CH4 RECOVERY

I wonder about the efficiency of the CH4 recovery. Based on the 15-year Petit Saut Reservoir database, maximum CH4 concentrations at the bottom of the reservoir were about 20 g m-3 during the first 4 years but due to the very high seasonal variability the yearly concentration in the hypolimnnion was close to or below 6 g m-3 with concentrations ranging from 0.5 to 20 g m-3 (median = 3.5 g m-3). Ten years after flooding, maximum CH4 concentrations are close to 10 g m-3 but these high concentration events last only one or two month a year and the yearly average and median concentrations are 3 and 2 g m-3, respectively. In the literature (Galy-Lacaux et al., 1996; Galy-Lacaux et al., 1997; Galy-Lacaux et al., 1999; Abril et al., 2005; Guérin et al., 2006; Rosa et al., 2006; Guérin and Abril, 2007; Kemenes et al., 2007), maximum CH4 concentrations in 10 years old (or more) tropical reservoirs are often around 6 g m-3 and the average concentration in the hypolimnion is often close to 3 g m-3 which is the limit for the operation of the CH4 extraction. From this, two questions arise:

- What is the range of concentrations in the hypolimnnion of the selected site?
- Is the system really applicable to most of the tropical reservoirs considering the high concentrations needed?

RECOMMENDATIONS

Again the use of physical modelling would allow the following question to be answered: Will the mitigation systems lead to an increase of CH4 concentrations in the hypolimnion allowing efficient CH4 recovery? Without being quite sure that the CH4 concentration will increase and reach the needed level to extract CH4, I will not recommend the proponents to develop this part of the project.

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References


Project 4144 title: Pilot Project for Methane Mitigation and Recovery from Hydroelectric Power Reservoirs
Review by Richard M Taylor

Comments presented here draw largely from the scientific knowledgebase derived from the ongoing UNESCO/IHA Project – GHG Status of Freshwater Reservoirs. This international research, involving some 100 institutes and organizations, aims to improve understanding on the impact of reservoirs on natural GHG emissions in a river basin, with a view to obtaining a better comprehension on current methodologies and helping to overcome knowledge gaps. A major component of this work is to reach a scientific consensus on how freshwater reservoirs should be measured. This component is nearing completion with comprehensive guidelines due for publication in July 2010. Contribution from the UNESCO/IHA GHG Project Manager, Dr Joel Goldenfum, to the review of Project 4144 is acknowledged.

Overview
The Project 4144 proposal, insofar as it considers the potential for methane emission mitigation and capture from reservoirs, raises novel approaches to the current situation. However, the proposal includes fundamental assumptions, generalisation and extrapolation that require attention.

The project title infers that methane accumulation is exclusive to hydroelectric impoundments. Long standing scientific research (see, for example: Cole et al., 2007) has identified that methane has the propensity to accumulate in anoxic zones of all water bodies, including, soil- and groundwater, wetlands, peat-lands, lakes, ponds and reservoirs. With regard to the latter, all reservoirs, irrespective of the services they provide (energy, irrigation, drinking water, flood mitigation, etc.), have the potential to accumulate methane under certain conditions. The motivation/message of the Project 4144 title, referring exclusively to hydroelectric reservoirs, is therefore of some concern. The key parameters leading to the accumulation of methane in some reservoirs has been the subject of the last three years of work relating to the international UNESCO/IHA project referenced above. One of the categorical findings of this research is that there is no single parameter that determines the accumulation of methane; for example, it is incorrect to assume that the reservoirs in the same region would have similar methane profiles.

The second important finding of contemporary research is that methane accumulation, or ‘stock’, in a reservoir is not directly proportional to the release of methane from the reservoir. That is, the fate of the methane stock in the (lower) anoxic zone of a reservoir is not necessarily that of emission to atmosphere. Major factors influencing the fate of the methane include the oxygen availability in the water column (leading to methane oxidization) and the elevation of the reservoir outlets in relation to the anoxic zone. Therefore it would be erroneous to assume that the harvesting and conversion of methane stock in a reservoir could not be considered equivalent to an avoidance of atmospheric methane accumulation.

Project 4144 main elements

1. Exploration of technologies and devices to be used for the mitigation of methane emission from hydropower reservoirs, and identification of an appropriate technology for use to do so (mitigation); and,
2. Development of a project for methane recovery from lower anoxic zones, with the intention that the methane is captured for use as an energy source (recovery).
Each of these is addressed below:

1. Mitigation

(i) The levels of methane emission downstream as used in the Project 4144 proposal are based on data from three reservoirs in Brazil. The uncertainty in this area should be reflected as a serious component of this evaluation. There is scientific consensus that generalisations or extrapolations are not appropriate at this stage:

- Project 4144 estimates total production of 8.6 Tg/y of methane for the three reservoirs mentioned. By comparison, according to data from the First Brazilian Inventory on Anthropogenic GHG Emissions (Rosa et al., 2006), these figures are of 0.8 Tg/y. This indicates the range of findings at the same reservoirs through research campaigns, and re-confirms the need for greater scientific rigour in field measurement.

- Project 4144 assumes that methane released from “water passing through turbines or spillways accounts for up to 70% of the total reservoir emissions”. For reasons explained above, this generalization is not sound and is extremely misleading. Further, Project 4144 assumes that this maximum is always the case and extrapolates the results to the entire Brazilian hydropower system. Clearly, these assumptions are deeply flawed.

(ii) Project 4144 proposes a system where a portion of the methane that might be degassed at the turbines or spillways could, instead, be oxidized by methanotrophic bacteria before reaching the atmosphere. To achieve these objectives, the Project promotes use of a barrier method for capturing methane upstream of an off-take. However the Project does not appear to address fundamental general questions surrounding use of the barrier method, especially assumptions surrounding the offtake and where it is situated. Only low-level outlets would be vulnerable to drawing on methane saturated zones. A barrier in front of such outlet structures could lead to mixing of zones and increase downstream emissions, so care should be taken on this matter.

(iii) A proposal that might have more merit in relation to climate mitigation might be to look at the oxidation of methane emitted downstream of reservoirs, if significant levels are present. It would be interesting to know if the authors have considered this. With regard to other mitigation options, the common good practice is to design modern facilities with off-takes at their highest level, or better still, with multi-level off-takes. Other mitigation possibilities could be aeration weirs in the upstream areas of the reservoir.

2. Recovery

(i) As mentioned above, even when methane might be present in sufficient quantities in situ within the reservoir, the fate of this stock is, at best, uncertain. Rather, it is the case that the majority of the methane might not be released into the atmosphere. In this regard, data from several studies (Bastviken et al., 2002; Bastviken et al., 2008; Fallon et al., 1980; Frenzel et al., 1990; Kankaala et al., 2006; Kuivila et al., 1988; Liikanen et al., 2002; Rudd and Taylor, 1980; Utsumi et al., 1998) indicate that the proportion of the methane that is oxidized can be large (30–99%), through methanotrophic bacteria in oxic water or sediment interfaces.

(ii) Removal of methane stock that would not otherwise be released into the atmosphere might have to be considered as hydrocarbon mining more than climate mitigation. If in fact this removal were to
be operationalized, this aspect would be scrutinized with some rigour in relation to potential Clean Development Mechanism opportunities.

(iii) Implicit in this part of the proposal is recovery of sufficient amounts of methane to render it financially feasible as an energy source. However there are real issues around this assumption, when in fact the concentrations in most reservoirs are such that this is not actually the case. Beyond noting that reservoirs that are known to have significant anoxia do not achieve concentrations above 10 g/m3, it appears likely that the energy-payback ratio will not be favourable. It appears from current dialogue in the energy sector that shale gas abstraction is considerably more viable to those that wish to exploit such reserves. In relation to the experience gained through the UNESCO/IHA GHG project in exploring GHG levels in reservoirs, Project 4144 is believed to be of relevance in that it is looking at mitigation. The main issue is that the quantification of the problem is far from resolved, and the reviewer believes this to have been potentially exaggerated by the Project 4144 authors. Notwithstanding this, there will be reservoirs that have significant methane releases, particularly young reservoirs with low-level outlets that display a pulse in emissions in the first years of impoundment, where some form of mitigation might be considered. Research to consider methane capture may be of relevance in extreme cases. However, we are of the belief that the proposal as it stands raises a number of fundamental issues that require attention and possible project re-direction, prior to inception.

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References


