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Recognizing that the state of the art needs improvement in the scientific basis in greenhouse gases emissions from reservoirs of hydroelectric to be considered in energetic policies, legislation and regulations

IEAHYDRO started in 2009 a new Annex "Managing the Carbon Balance in Freshwater Reservoirs"



- > Through a comprehensive program
 - *increase knowledge* on processes linked to reservoir GHG emissions
 - establish guidelines for planning studies on reservoir carbon balances
 - standardize GHG flux evaluation methods
 - develop an acceptable methodology to measure and manage the carbon balance in reservoirs





Since the kickoff meeting in August 2009 at CEPEL's offices in Rio de Janeiro, Brazil, 21 Annex meetings + 9 open workshops

HYDRO 2009, Lyon, FR; HYDRO 2010, Lisbon, PO; HYDRO 2011, Prague, CZ; HYDRO 2012, Bilbao, SP; HYDRO 2015, Bordeaux, FR ;

2014 Guidelines Volume 2 Scoping Workshop , Knoxville, TN, EUA;
2014 Guidelines Modeling Workshop, London, UK;
2015 Guidelines Modeling Workshop, Rio de Janeiro, Brazil;
2017 Guidelines Management Workshop, Rio de Janeiro, Brazil



> An international team of experts indicated by Annex country members has been working in the developing of a Guidelines on Quantitative Analysis of Net GHG Emissions from Reservoirs.

- Guidelines Volume 1: Measurement Programs and Data Analysis was launched in October 2012 at HYDRO 2012, Bilbao, Spain,.
- Guidelines Volume 2: Modelling was launched in October 2015 at HYDRO 2015, Bordeaux, France
- Guidelines Volume 3: Management the Carbon Balance in Freshwater Reservoirs was launched in October 2017 at HYDRO 2017, Seville, Spain





- **1. Literature Reviews of previous work on the topic**
- 2. Reviews of the work of institutions in Brazil, Norway, Finland, China, Japan, USA, Canada, Australia and France, as well as organizations, such as IHA and UNESCO as it relates to this subject matter
- 3. Workshops with Annex members and contributing parties, to discuss and draft the guidelines.
- 4. Identifying and communicating with sources that cover the range of industry practice and the experience of scientists and academics.
- 5. Gathering the collected knowledge of the authors and other contributors
- 6. A peer review from an independent group of experts





Guidelines Volume 1 Measurement Programs and Data Analysis.

General procedures for calculation of estimates of net
 GHG emissions from data obtained in measurement
 programs are provided.

➢Advice and procedures are given for planning and executing measurement programs for obtaining estimates of post-impoundment emissions for existing reservoirs. For estimating pre-impoundment emissions, the advice and procedures are given for both planned and existent reservoirs.





IEA Hydro Annex XII Project Guidelines - Volume 1



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- S **Burial Rates**
 - m unrelated anthropogenic sources
 - ity

erning GHG Fluxes and Permanent Carbon eas

t Techniques by Marco Aurelio dos Santos





> Guidelines Volume 2 Modeling.

➤Contain suggested requirements for models and modeling approaches, sourced from the experience of engineers, scientists and academics, and experts from the hydropower industry.

➢ Also provides a roadmap for communicating the science of modeling outcomes in terms that are both appropriate for use by the hydropower industry and acceptable by the broader scientific and engineering community.







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Guidelines Volume 3 : Management the Carbon Balance in Freshwater Reservoirs.

➢ Provides guidance on developing a GHG management strategy for a reservoir where there is a likelihood of significant net emissions, and if so, identifies appropriate mitigation measures to reduce these emissions and allocation approaches between the users of the water services.

Also provides guidance on reporting management procedures.



HYDROPOWER AND THE ENVIRONMENT:

Managing the Carbon Balance in Freshwater Reservoirs

Guidelines for Quantitative Analysis of Net GHG Emissions from Reservoirs

Volume 3 – Management, Mitigation and Allocation

IEA Hydro Technical Report

January 2018







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4.3 ALLOCATION OF GHG EMMISSIONS TO SERVICES PROVIDED BY THE

RESERVOIR





4.0 FAIR ALLOCATION

4.1 PRINCIPLES OF ALLOCATION

4.2 IDENTIFICATION OF SERVICES PROVIDED BY THE RESERVOIR

4.3 ALLOCATION OF GHG EMMISSIONS TO SERVICES PROVIDED BY THE RESERVOIR

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HYDROPOWER AND THE ENVIRONMENT:

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> Volumes 1, 2 and 3 are now available to download at IEAHydro web site

http://www.ieahydro.org/annex-xii-hydropower-and-the-environment



➢ Working in close cooperation with IEAHydro Annex XII, the Brazilian R&D project sponsored by three ELETROBRAS utilities (ELETRONORTE, CHESF and FURNAS) planned a broad program of field measurement campaigns in hydro plant sites in Brazil.

Eleven sites where chosen,

DEA

- eight of hydro plants already in operation and
- three under the construction phase with their reservoir not already filled

Field campaigns from March, 2011 to December, 2012. Four field campaigns per site with intervals of two months were schedule so that one complete hydrological year was monitored for each plant.



Field Campaigns in Brazil



- •8 hydro plants in operation
- •Tucuruí in Amazon River Basin
- •Balbina in Amazon River Basin;
- •Serra da Mesa in Tocantins River Basin;
- •Xingó in Sao Francisco River Basin ;
- •Três Marias in Sao Francisco River Basin
- •Funil in Paraiba do Sul River Basin;
- •Segredo in Parana River Basin
- •Itaipu in Parana River Basin
- •3 hydro plants under construction
 •Santo Antônio in Amazon River Basin
 •Belo Monte in Amazon River Basin;
 •Batalha in Parana River Basin





Field Campaigns in Brazil



Measurements of gases fluxes at the water-air interface with diffusion chambers

-upstream, downstream and in different depth compartments







Field Campaigns in Brazil



Energy 133 (2017) 99-107

| | Contents lists available at ScienceDirect | |
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| ELSEVIER | journal homepage: www.elsevier.com/locate/energy | Additional of Table Science Development and additional of the Science Scienc |

Estimates of GHG emissions by hydroelectric reservoirs: The Brazilian case



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ARTICLE INFO

Article history: Received 23 November 2016 Received in revised form 11 May 2017 Accepted 13 May 2017 Available online 17 May 2017

ABSTRACT

This article reports and discusses the application of an analysis of reservoir greenhouse gas (GHG) emission using the net emission approach (difference between post-impoundment and preimpoundment emissions) to assessments of GHG emissions from hydropower reservoirs compared with GHG emissions from thermal plants producing electrical energy. Reservoirs were chosen from a representative set of different Brazilian biomes and climatic regimes. A field campaign program was performed between 2011 and 2013 to estimate net GHGs emissions from 8 Brazilian representative bydropower plants. Four field campaigns to each bydropower plant were scheduled within two-month



Field Measurements







The SINOP Project on GHG Fluxes Balance for Pre-impoundment and Filling Conditions





The Teles Pires runs through 1,431 Km inside the Mato Grosso state in the SE-NW direction from the Azul and Finca Faca mountain chains until its confluence with the river Juruena, forming the Tapajós river.

It drains a total área of 142,660 km², in a transition zone between the Brazilians biomes of Cerrado and Amazônia.



One hydrological year completed at SINOP with 4 fields campaigns (DEC 2017, MAR 2018, JUN 2018, SEP 2018)

| Compartment | Stratum | Area (ha) | | |
|--------------|-------------|-----------|--|--|
| | Depht 0m-6m | 2.070,89* | | |
| Water Bodies | Depth >6m | 3.641,10* | | |
| | Total | 5.711,99 | | |
| Dry land | Forest | 23.655,65 | | |
| | Bare soil | 154,22 | | |
| | Culture | 1.131,33 | | |
| | Pasture | 3.620,14 | | |
| | Total | 28.561,34 | | |





The SINOP Project Pre-impoundment



Balances of GHG Emissions (values in tCO2eq per day)

| Stratum | gas | CAMP1 | CAMP2 | CAMP3 | CAMP4 | MEAN |
|--------------------------------------------------------------------------------------|------------------|-----------------|----------------|---------------|---------------|--------------|
| Water Bodies (diffusive) | CH_4 | 43.5 ± 12.1 | 42.5 ± 5.4 | 24.2±3.6 | 28.1±4.6 | 34.6±3.6 |
| | CO2 | 229.5 ± 30.5 | 338.6 ± 30.3 | 68.9±33.0 | 115.1±27.9 | 188.0±15.3 |
| | N ₂ O | 9.5 ± 2.3 | 7.0 ± 2,4 | 0.0±0.0 | -1.2±0.5 | 3.6±0.9 |
| Water Bodies (ebullitive) | CH ₄ | 41.6 ± 14.3 | 37.1 ± 21.0 | 55.9±24.6 | 39.0±16.3 | 43.4±9.7 |
| | CO ₂ | 0.4 ± 0.1 | 1.0 ± 0.3 | 0.6±0.3 | 0.6±0.3 | 0.6±0.1 |
| | N ₂ O | 0.002 ± 0,0001 | 0,004 ± 0,0001 | 0.002±0.001 | 0.018±0.0 | 0.006±0.001 |
| Dry Land (difusive) | CH_4 | 7.1 ± 3.2 | 9.2 ± 24.4 | -10.8±9.1 | -4.5±1.4 | 0.3±2.9 |
| | CO2 | 1,060.8±161.5 | 985.5±125.2 | 282.4±112.6 | 728.2±98.5 | 764.2±63.3 |
| | N ₂ O | 72.8 ± 15.6 | 77.3 ± 30,4 | 87.6±42.0 | 166.3±17.5 | 101.0±12.8 |
| Total | | 1,465.1 ± 165.8 | 1,498.1±132.5 | 507.9 ± 127.4 | 1,071.7±105.3 | 1,135.7±67.2 |
| Total Annual Emission (tCO ₂ e.year ⁻¹): 414,525.7 ± 24,545.4 | | | | | | |





- Reservoir filling.
- (a) organic carbon, dissolved GHG, and other water quality variables in the water column of the reservoir;
- (b) GHG diffusive and ebulitive fluxes at the air-water interface of the reservoir;
- (c) GHG diffusive fluxes at the sediment-water interface of the reservoir;
- (d) GHG diffusive fluxes at the air-soil interface for each type of use of soil.
- (e) permanent carbon burial rate
- (f) degassing fluxes





Dissemination of Guidelines Volume 3

Guidelines Volume 3 describes a road map for best practices in the management of net GHG emissions from reservoirs through the processes of mitigation and allocation.

A report is being prepared reporting cases collected from Annex members of mitigation measures that reduce GHG emissions and relevant allocation.



Position papers on "Status of the GHG debate"

Since 2009 (start of Annex XII and IHA/UNESCO project on reservoir GHG status) substantial improvement of the knowledge on processes linked to reservoir GHG emissions has been achieved.

The concept of net emissions and acceptable methodologies to measure and manage the carbon balance in reservoirs are now available for assessing net GHG emissions from reservoirs.

More recent meta-analysis assessments of global emissions from reservoirs are providing estimation emissions significantly below estimates of the beginning of the century.

The publication and dissemination of the work done in Annex XII (Guidelines Volume 1, 2 and 3 and the results of the Brazilian extensive field measurements campaigns) has successfully achieved its objective.

It is time to Annex XII consolidated this achievements by producing a position paper on "Status of the GHG debate".

2018-2019 Annex XII



Support to IPCC Working Group on Refinement to the 2016 IPCC Guidelines for National Greenhouse Gas Inventories

The 26th Meeting of Task Force Bureau of IPCC (28 - 29 August 2014, Ottawa) concluded that to maintain the scientific validity of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories certain refinements may be required, taking into account scientific and other technical advances that have matured sufficiently since 2006.

As this Guidelines include good practices guidance for estimating and reporting anthropogenic GHG emissions and removals from land converted to flooded land (filling of reservorirs) and Flooded land remaining flooded land (operation of reservoirs) the work of Annex XII is of interest and we are supporting the IPCC working group.

Their first order draft showed the incorporation of the net emissions concept.

For the CO2 emissions, only the initial effects of flooding could cause extra CO2 emissions and for old impoundments (more than 20 years) it would be assumed that CO2 emissions that are occurring result from C losses in the watershed that are already covered by methodologies in other land use sectors.





Collaboration with IHA on Screening modeling

Application of hydraulic & water quality models to simulate GHG emissions with high fidelity (Brazilian project)





- 1- Four field campaigns in Jirau, Batalha and Belo Monte.
- 2- Four field campaigns in São Luiz do Tapajós and Jamanxim.
- **3 Four field campaigns in cascaded reservoirs at River Teles Pires**

4. Twelve field campaigns in Funil and SINOP to collect data aiming calibration and validation of physical-biogeochemical models including collect lake limnological data, sediment samples, acoustical geochemical characterization of sediment and eddy-covariance fluxes measurements in a tower.

6. **Development, calibration and validation of biogeochemical models for Funil** and **SINOP (ex: 2D- laterally averaged based on CE-QUAL-W2)**

Next Phase of Annex XII



Theme: Climate Change Influence in Fresh Water Reservoirs

- Fresh water reservoirs multi-purpose benefits include water supply for agriculture and domestic consumption, electric energy generation, flood control, fluvial transport and recreation.
- Disadvantages are related to environmental and social implications of damming natural watercourse and inundation of part of the river valley.
- The balance between benefits and negative socio-environmental impacts of artificial reservoirs has motivated plentiful research and studies efforts all over the world. Most of these work were performed based on the assumption of the persistence of past observed climate regimes.
- Prognostics of changes for the next decades in climatological and hydrological regimes at hydrograph basins pose new problems and opportunities to the manage of fresh water reservoirs.



Theme: Climate Change Influence in Fresh Water Reservoirs

With this background, future activities in Annex XII will include undertaking research on "Climate Change Influence in Fresh Water Reservoirs" covering knowledge on climate change influence on main process affecting benefits/negative impacts of hydropower reservoirs.

Scope:

Annex XII activities on the subject will focus two themes:

Carbon Balance and Evaporation



Climate Change Influence in Fresh Water Reservoirs

Carbon Balance

The hydrological flows changes related to climate changes will influence transport of carbon, nutrients and contaminants as well as erosion, therefore affecting aquatic ecosystems (lakes, rivers or reservoirs) functions and productivity, possibly biodiversity, as well as GHG emissions.

Knowing how carbon or contaminant are affected by climate change will allow a better understanding of the role of reservoirs and help separate the environmental impacts related to the impoundment than those related to climate change.

Evaporation

Changes in air temperature or wind will affect water evaporation.

Knowing more about this issue will help industry improve water footprint methodology and the overall life cycle analyses used to compare energy sources. Actually, hydropower is negatively perceived on this issue as many theoretical articles have considered that evaporation was consumed water.



Theme: Hydropower Adaptation and Resiliency to Climatic Changes

Despite the well known benefits of hydropower, including the mitigation of climate change through low greenhouse gases emissions, its inherited dependency on future climatic conditions and hydrological regimes at hydrographic basins imposes risks to its associated benefits that should be evaluated from the view point of business, energy security and socioeconomic issues.

With this background, future activities in Annex XII will include undertaking research on "Hydropower Adaptation and Resiliency to Climatic Changes" covering knowledge on methodologies for assessment the level of adaptation and resilience of hydropower projects.



Theme: Hydropower Adaptation and Resiliency to Climatic Changes

Scope

There is a growing trend that access to funding for the development of new hydropower plants or for investiments in existent plants will require demonstration that the project meets specific criteria for resilience and adaptability to current and future climate change scenarios.

The developing of a framework for assessment of hydropower projects' status in terms of adaptation and resilience to climate change is a key element to promote or even enable the implementation and operation of the vast global hydropower potential.