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The debate on greenhouse gas emissions from freshwater reservoirs

Policy implications and opportunities for action

Kirsi Mäkinen

Supervisors

Philip Peck

Shahbaz Khan

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Published in 2009 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

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Disclaimer

While the work presented in this thesis benefitted greatly from the various contributions including interviewees, questionnaire respondents and the author's colleagues, the views expressed in it are solely the responsibility of the author, except where otherwise indicated. These views do not necessarily reflect the views of sponsors or other persons and organisations that facilitated this work.

Abstract

This paper explores freshwater reservoir greenhouse gas emissions from a policy perspective. Existing science on reservoir emissions indicates that reservoirs can emit significant amounts of greenhouse gases and this is of particular concern for tropical reservoirs. Current scientific knowledge has led to some precautionary policy measures, but, in general, policy development has been slow. At the same time, increasing demands for water, energy and food and the need to adapt to climate change signal significant increases in the number of large dams in many parts of the world. This research explores reasons for the slow uptake of policies addressing reservoir emissions and examines ways to facilitate policy development. The paper provides an overview of the existing debate on reservoir emissions, and analyses existing measures and future opportunities for action in three policy areas. Issues shaping the science-policy interface are described, and a number of barriers and contextual influences to policy development are identified.

Executive Summary

Background

Water and energy have traditionally been treated as separate policy areas; however, in recent years attention has been drawn to their interconnected relationship. Energy production requires substantial amounts of water (e.g. cooling water for thermal power plants, flow for hydroelectric power and irrigation for growing energy crops). Vice versa, water acquisition (e.g. from groundwater aquifers, surface water reservoirs, sea water through desalination or recycled water from wastewater) requires energy for treatment and transport. Climate change is affecting the availability of water and energy resources, and economic growth and population pressures such as growth and urbanisation are creating an ever-increasing need for both resources. As a result, interest in the water-energy nexus has grown and calls for integrated policymaking are emerging.

Freshwater reservoirs occupy a central position in the water-energy nexus through hydroelectric power production. In recent years, the climate neutrality of hydropower has been questioned as a result of unfolding science of the greenhouse gas (GHG) emissions from reservoirs (Fearnside, 2004; Giles, 2006; St. Louis, Kelly, Duchemin, Rudd, & Rosenberg, 2000). The science of reservoir emissions is continually expanding, but an emerging consensus has been reached on the processes by which methane and carbon dioxide are produced in reservoirs and the pathways through which they are released to the atmosphere. Figure 0-1 below presents some of the factors and pathways linked with reservoir emissions.

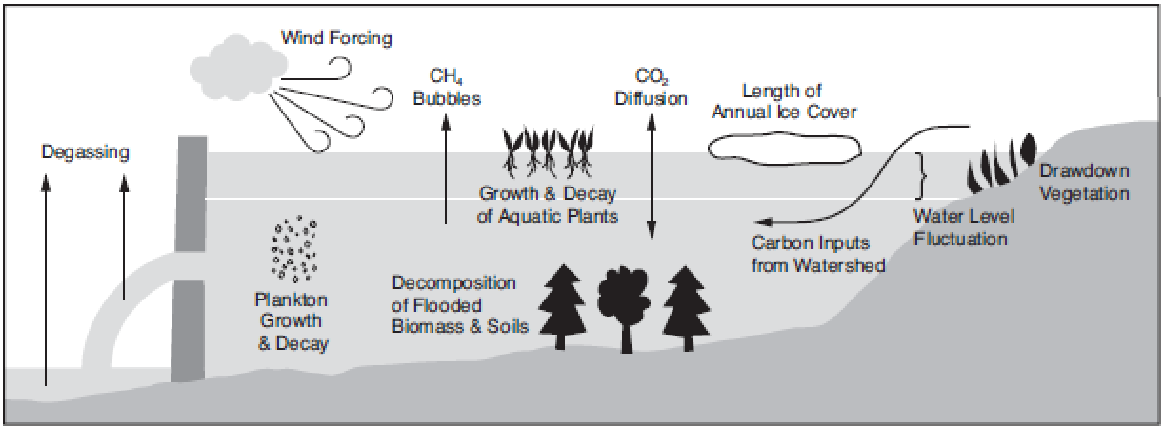

Figure 0-1 Some factors influencing the rate of GHG generation and release from reservoirs
Source: (McCully et al., 2006)

Current knowledge indicates that reservoirs in boreal and temperate ecological zones are associated with low to moderate emissions, whereas tropical reservoirs have higher emission levels (Soumis et al., 2005). Research also shows that the processes related to production and release of GHGs from water reservoirs are similar irrespective of the uses of a reservoir (Goldenfum, 2009b). This indicates that reservoir emissions are important to a range of sectors and activities beyond hydropower production including water supply for irrigation, domestic and industrial use, as well as flood control, inland navigation and recreation.

Human development is a key driver for dam construction; it is estimated that up to 60 per cent of the world's rivers have been dammed and diverted for human activities (Revenga, Brunner, Henninger, Kassem, & Payne, 2000). Today, dams affect the lives and livelihoods of billions of people through water supply for basic functions such as energy and food production. In the future, the role of dams will become even more important as countries respond to increasing demands for energy, food and water for their growing populations. Another major driver for future dam development is climate change – both its mitigation and adaptation to the changes. Renewable energy sources including hydropower are being promoted to developing countries as sources of energy, in the hope of leapfrogging more polluting energy production options. Other drivers for dam development include an increasing frequency of extreme weather events such as floods and droughts, and as a method of securing water supply by using storage reservoirs.

All the above-mentioned factors indicate that significant numbers of large dams will be built in the future. The impending climate crisis demands that all sources of emissions are included when considering human-induced climate impacts. The urgency to act on climate change combined with the pressing need to build more reservoirs in many parts of the world suggests that the time to overlook reservoir emissions has passed. Moreover, if or when mitigation measures are taken, there may be significant implications regarding how reservoirs are built and managed. Nevertheless, policy uptake of the issue of reservoir emissions has been generally slow and remains at an early stage despite international recognition in the Clean Development Mechanism (CDM) framework and by the Intergovernmental Panel for Climate Change (IPCC).

Research focus and methods

This study explored the science-policy interface of reservoir emissions by identifying policy areas relevant to the issue and reasons for the currently limited policy uptake. The research provides perspectives into the dynamics of the ongoing debate on reservoir emissions and the issues that stand in the way of policy development and planning for action. This study was guided by the following research questions:

1. *Why are policy-makers not yet acting upon the available scientific knowledge of reservoir GHG emissions?*
2. *How might the policy uptake of reservoir emissions be facilitated?*

The study was conducted in two stages. Stage one delineated the issues related to reservoir emissions and narrowing the research scope. In this stage, available literature resources were analysed and additional information was collected from water and energy practitioners using a simple survey. Stage two utilised an inductive approach to analysing specific policy areas, from which general observations of the science-policy interface and policy development related to reservoir emissions were drawn. In this stage, literature was used in conjunction with a series of qualitative interviews. Analysis was guided by approaches outlined by Moniz (2006) for using scenario-building tools in policy analysis. Some of these tools were adapted for this study to provide structure for interpreting the results.

Main findings

The findings of this study revealed that reservoir emissions are currently being addressed within the CDM framework and there are ongoing discussions regarding reservoir emission estimates and reporting within national GHG inventories. This research also identified that procedures for evaluating the environmental impacts and performance analysis of dams (e.g. life cycle analysis and environmental impact assessment) do not currently consider reservoir emissions. Such consideration should be undertaken in order to make these assessments more comprehensive and accurate evaluations of environmental impacts of reservoirs. Finally a number of issues were found to shape the science-policy interface and act as barriers to further policy development in the case of reservoir emissions.

Question 1: Why are policy-makers not yet acting upon the available scientific knowledge on reservoir GHG emissions?

Findings of this study indicate that the primary barrier to policy development is insufficient scientific knowledge regarding the measurement and upscaling of GHG emissions. An overview of the existing scientific knowledge and an analysis of the ongoing reservoir emissions debate revealed three significant knowledge gaps in the scientific understanding of reservoir emissions. These gaps relate to the quantification of reservoir emissions, the processes that contribute to their generation in and release from reservoirs, and the availability of tools and methodologies to estimate reservoir emissions including the level of uncertainty associated with such methods.

Another major barrier to policy uptake is the limited incentive for many stakeholders to raise the reservoir emissions issue on the national and international agenda. The reservoir emissions issue stands opposed to the mainstream agendas promoted by industrial actors, as well as many environmental groups engaged with freshwater issues. At the international level, national interests are a major political driver influencing if, how, and when the reservoir emissions issue enters the climate negotiation agenda.

A limited awareness of the problem, outside the small community of scientists working on reservoir emissions, is a further contributing factor to slow policy uptake. While water practitioners were aware of the issue at a general level, they had generally low levels of knowledge regarding the scale and impact of reservoir emissions. Some of the interviewed policy experts showed limited knowledge of the interconnections, complexity, and dynamics of the reservoir emissions issue. This limited awareness implies that the public demand for policy intervention is very low and there is little pressure on the policy-makers to act. Furthermore, minimal understanding of the issue within the policy community emerged as a reason for limited policy uptake.

Finally, rules and procedures within existing policy frameworks and dynamics of the broader climate debate were found to obstruct policy development. Uncertainties regarding international climate agreements in the post-2012 period affect climate policy areas and limit the incentive for different actors to introduce methodological improvements within regulatory frameworks. Changes to the rules and procedures of the existing frameworks require a number of years to implement thus acting as a significant structural barrier to policy development.

Question 2: How might the policy uptake of reservoir emissions be facilitated?

Just as insufficient scientific knowledge emerged as the main barrier to policy development, improving the existing knowledge base through research activities was identified as the main pathway to facilitate future policy development. Research is required to improve the existing data sets so that information is available for all ecological zones, and in particular to understand the temporal and spatial variations in emission levels. Specifically more research is required to better understand reservoir and catchment area processes contributing to reservoir emissions, establish standard measurement techniques, reduce the uncertainties associated with different methodologies, and develop modelling tools to enable accurate estimation of GHG emissions. These research activities should be carried out by both private and public actors in order to balance the current industry-led research dominance. Research by both actors would increase the cumulative research knowledge and improve the public-private balance of funding, thus improving the overall credibility of the research efforts.

Increased dialogue between the research and policy communities is required to improve information dissemination among policy-makers, and policy framework information requirements among researchers. Findings of this research highlighted a shallow level of awareness of reservoir emissions within the policy community. In particular, the findings indicate a lack of integrated knowledge and expertise of the different areas in which reservoir emissions are relevant for policy considerations. Such fragmentation of knowledge between, and also within stakeholder groups must be addressed if policy development is to move forward and the current piecemeal solutions are to be replaced with a holistic approach to addressing reservoir emissions.

National and regional initiatives may provide an avenue for accelerating the policy uptake of reservoir emissions. Leading research countries may have nationally representative data accessible before globally comprehensive results are available, which gives them the opportunity to act on the issue at a national level. National efforts can further support subsequent international initiatives by providing reference cases, lessons learned and pilot programs that can later be expanded into international programs.

General observations regarding policy development

This study found that scientific research has a seemingly dominant role in the science-policy interface of reservoir emissions. It acts both as an important driver for policy development and currently as a significant barrier due to uncertainties and gaps in scientific knowledge of reservoir emissions. Scientific research efforts are thus likely to shape the policy field significantly in the coming years, especially when results from currently ongoing research efforts begin to unfold. As the uncertainties are reduced and the scientific issues resolved, these new results need to be integrated into policy frameworks both in existing policies as well as in areas and processes where reservoir emissions are currently overlooked. It is also important to remember that policy development is not solely driven by science. The international nature of climate policy makes both national and international climate negotiations highly political, and in some cases national interest and other political drivers may overtake the influence of science. Any future treatment of reservoir emissions by international climate policy frameworks will be influenced by political motives as well as scientific facts.

Finally, the wider implications of reservoir emissions must be considered. Demand for water, food and energy especially in developing countries along with the need for climate change adaptation drive the development of dams and reservoirs. Such strong drivers necessitate looking beyond the immediate dynamics of the science-policy interface. It is necessary to recognize the risk of exacerbating GHG emission levels with the construction of more freshwater reservoirs and to take steps to avoid and minimise these emissions where possible. It is clear that a holistic view that includes both the adverse and beneficial impacts of freshwater reservoirs must be adopted to achieve sustainable development of water resources in the future.

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1 Introduction

1.1 Research background

Water and energy have traditionally been treated as separate policy areas, however in recent years attention has been drawn to their interconnected relationship. Energy production requires substantial amounts of water (e.g. cooling water for thermal power plants, flow for hydroelectric power and irrigation for growing energy crops). Vice versa, water acquisition (e.g. from groundwater aquifers, surface water reservoirs, sea water through desalination or recycled water from wastewater) requires energy for treatment and transport. For example, in water-constrained California, the largest single user of energy is the State Water Project that provides water to Southern California by pumping it over the mountains from northern parts of the state (U.S. Department of Energy, 2006). Economic growth and population pressure have resulted in an ever-increasing need for water and energy, and climate change affects the availability of both. As a result, interest in the dynamics of the water-energy nexus has grown and calls for integrated policymaking are emerging.

For a long time, hydropower has been the obvious link between water and energy as hydroelectric power plants produce electricity directly from water. Hydropower is widely regarded as a clean and renewable source of energy, both attributes that in today's changing climate conditions are highly desirable. However, in recent years the "climate neutrality" of hydropower has been questioned as knowledge of greenhouse gas (GHG) emissions from freshwater reservoirs increases (Fearnside, 2004; Giles, 2006; St. Louis et al., 2000). Decaying organic matter in water reservoirs produces carbon dioxide and methane which are released into the atmosphere through a variety of pathways. The exact amount of emissions is affected by various factors, including reservoir design, climate conditions and speed of the natural carbon cycle. For reservoirs in boreal and temperate ecological zones, research indicates low to moderate emissions. Tropical reservoirs, which are often characterised by fast natural carbon cycles, high levels of organic matter and designs that combine large surface areas with relatively shallow depths, have higher emission levels. (Soumis et al., 2005) In some cases, it has been shown that these tropical reservoir emissions are equal or even exceed the emission levels of equivalent electricity production from fossil fuels (Fearnside, 2002). However, the science is still very young and many aspects require further clarification. Significant research activities are currently underway and are expected to answer many questions regarding the detailed nature and extent of GHG emissions from reservoirs in the next two to three years time (Working Group on Greenhouse Gas Status of Freshwater Reservoirs, 2008).

Energy production is only one of many services provided by water reservoirs. Reservoirs can provide water supply for irrigation, domestic and industrial use, as well as flood control, inland navigation, and recreation. Increasingly many reservoirs combine a number of these functions and are classified as multi-purpose reservoirs. According to the International Commission On Large Dams (ICOLD), water supply for irrigation systems is by far the most common purpose among the 50 000 dams in the organisation's global database (2007). Irrespective of the uses of a reservoir, the processes related to production and release of GHGs from water reservoirs are similar (Goldenfum, 2009b). Thus reservoir emissions are relevant to a number of fields beyond energy production including urban water supply and food production, and emission mitigation has wide-ranging implications on where reservoirs are built and how they are designed and managed.

Economic development is a key driver for dam development and it is estimated that up to 60 per cent of the world's rivers have been dammed and diverted for development purposes

(Revenga et al., 2000). Dams and reservoirs have been instrumental in the development of many countries around the world, particularly in the post-war era. Today, dams affect the lives and livelihoods of billions of people through water supply for basic functions. Some countries such as Brazil and Canada rely heavily on hydropower for their electricity supply. It is estimated that 40 per cent of the world's population rely on irrigated land for their food supply, and 30-40 per cent of these agricultural areas depend on reservoirs for their water supply (Lempérière & Lafitte, 2006).

In the future, the role of dams will become even more important as countries respond to increasing demands for energy, food and water for their growing populations. Developing countries with underdeveloped water resources are particularly motivated to build more dams to utilise economically attractive water resources for energy production, irrigation and water supply. Another major driver for future dam development is climate change – both in regards to mitigation and adaptation to changes. Hydropower is one of the renewable energy technologies promoted to developing countries in the hope of leapfrogging more polluting energy production options. More recently, the role of reservoirs has been highlighted in relation to discussions on climate change adaptation in large international fora such as the 5th World Water Forum in Istanbul, Turkey in March 2009 and the World Water Week in Stockholm, Sweden in August 2009. An increasing frequency of extreme weather events such as floods and droughts also provides a driver for countries to build reservoirs as a means to increase their capacity to deal with climate variability. A secure water supply is another need that can be met with additional water storage reservoirs in many water-constrained areas.

All of the above-mentioned factors indicate that significant numbers of large dams will likely be built in the future. Existing knowledge of reservoir emissions suggests that the contribution of dams to climate change can be significant, particularly in tropical countries where much of future dam construction is expected. Dam emission contribution is expected to be high in developing countries with access to water resources such as Brazil, India and China. (Lima, Ramos, Bambace, & Rosa, 2008) The impending climate crisis demands that all sources of emissions are included when calculating the human-induced impacts on our climate. The urgency to act on climate change combined with the pressing need to build more reservoirs in many parts of the world suggests that the time to overlook reservoir emissions has passed.

The issue of reservoir emissions has been recognised at the international level by the Clean Development Mechanism (CDM) Executive Board (UNFCCC, 2006b) as well as the Intergovernmental Panel for Climate Change (IPCC, 2006). Beyond such preliminary developments, progress in the policy arena remains at a very early stage and is restrained by some scientific uncertainties. Scientific research in this area is time-consuming and relatively expensive. Moreover, much of the science to date has been produced by actors linked to the hydroelectric industry and this association has led other stakeholders to express concern over the transparency and objectivity of the emerging science (Cullenward & Victor, 2006; McCully et al., 2006). Even where public research funding is available, reservoirs are often owned and managed by private operators whose cooperation and support is required for research efforts to be carried out. While the scientific knowledge base is growing, calls to include reservoir emissions in climate policy frameworks are emerging from various stakeholders (Cullenward & Victor, 2006; McCully et al., 2006).

As significant research outcomes are expected in the relatively near future, an acceleration of policy discussions on the topic is warranted. In the past the policy-sphere has also been slow to embrace the issue of freshwater reservoir emissions thus the policy space is largely unexplored. Given the multitude of services provided by reservoirs and the consequent connection of reservoir emissions to a number of policy areas, it is not immediately clear in which policy areas and at what level policy interventions might occur. Figure 1-1 illustrates a simple schematic of some areas and levels at which reservoir emission policies may impinge and where implication management practices may arise as a result of policy interventions. Reservoir emissions touch upon areas such as energy, agriculture, land use, and water resource management. All, but the latter area are linked to climate policy frameworks which originate at the international level. Overlaps in the diagram represent loose connections that can be observed between different policy areas and levels.

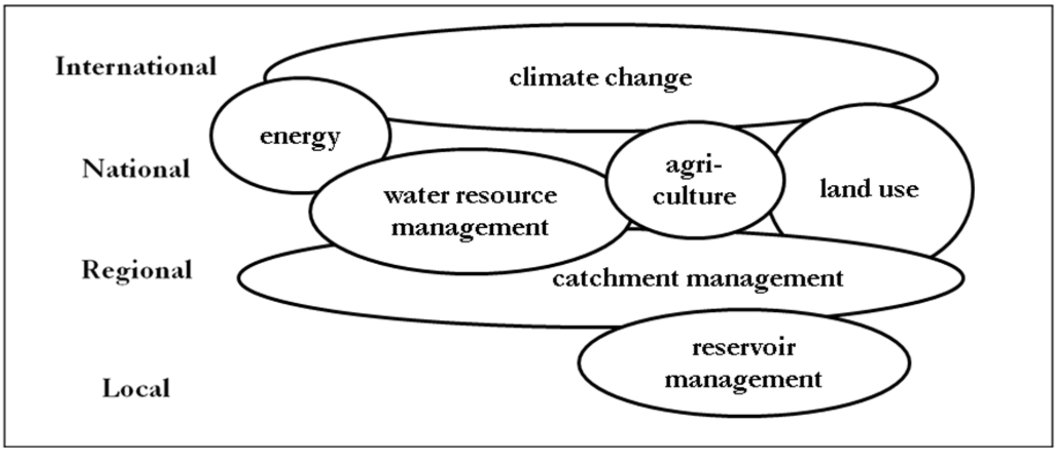

Figure 1-1 Policy and management areas and levels where reservoir emissions may have implications

This study aims to explore the science-policy interface of reservoir emissions and identify a number of policy areas relevant to the issue. In addition, the work analyses opportunities to include reservoir emissions in policy processes and further seeks to examine how future policy development might be facilitated. The research will provide perspectives into the dynamics of the ongoing debate on reservoir emissions and the issues that stand in the way of policy development and planning for action.

1.2 Problem definition

As indicated, reservoir emissions are important for the global climate debate, both in terms of efforts to reduce GHG emissions as well as in the establishment of emission baselines. Emission baselines form the foundation against which countries' emission reduction targets are established according to current rules of regulatory frameworks. Moreover, if or when measures are taken to act upon such emissions, the consideration of reservoir emissions could have significant implications for the manner in which reservoirs are built and managed. Scientific research has shown that reservoir emissions are of particular importance in tropical regions thus how reservoir emissions are addressed will potentially influence the role of many developing countries in global climate negotiations as well as development activities in these countries. With all these points in mind, one might expect that the need for action on climate change and multiple pressures to build more water reservoirs in the future would create a level of urgency in policy uptake of the reservoir emission issue. However, the preliminary discussions undertaken with high-level officials at the international level clearly indicated that such urgency is absent and the issue has barely entered the mainstream of climate policy discussions.

Policy development of reservoir emissions at the international level is dependent on both the state of the science and the related policy debate of reservoir emissions. The current knowledge of GHG emissions from reservoirs offers strong indications of the types of emissions and their potential impact (cf. Guérin et al., 2006; Soumis et al., 2005; Working Group on Greenhouse Gas Status of Freshwater Reservoirs, 2008). Despite being fairly limited, such scientific work has been sufficient for the CDM Executive Board to place precautionary restrictions on the eligibility of hydropower projects within the framework (UNFCCC, 2006b), a measure that has important implications for the availability of carbon financing for hydropower projects. Communication from the IPCC (2006) further indicates that GHG emissions from water reservoirs are likely to become integrated into national GHG inventories as scientific knowledge accumulates.

Based on this evidence, an important problem has been identified:

> *Despite the recognised importance of reservoir emissions, their impact on the global climate, and the pressing future desire to build more reservoirs, the issue or reservoir emissions has not achieved sufficient legitimacy among policymakers to drive a widespread uptake of the issue in the policy arena.*

1.3 Research question and objectives

Two research questions were formulated to address the research problem previously outlined:

> *Why are policy-makers not yet acting upon the available scientific knowledge of reservoir GHG emissions?*
>
> *How might the policy uptake of reservoir emissions be facilitated?*

In order to facilitate answering these questions, the following research objectives were defined for this study:

1. Provide an overview of existing knowledge on GHG emissions from water reservoirs and the degree of scientific consensus on the issue.
2. Identify a number of key policy areas and regulatory frameworks relevant to the issue of reservoir emissions.
3. Explore obligations set by these key policy areas and analyse how the current knowledge base responds to these demands.
4. Identify main drivers and barriers to policy development in relevant areas.

1.4 Scope and delimitations[1]

The research area is restricted to the role of anthropogenic freshwater reservoirs in climate change mitigation. As such, the focus is placed upon the implications of freshwater reservoirs' contribution to climate change through the generation and release of GHG emissions. Thus the study generally excludes the role of hydropower as a renewable energy source promoted in place of fossil fuel sources, as well as issues such as wetland restoration for climate change mitigation.. Likewise, the role of reservoirs as water storages in climate adaptation, while important to the context, falls outside the scope of the present study.

Greenhouse gas emissions are positioned within a range of environmental issues related to reservoirs (see section 3.1). The study does not attempt to address the variety of environmental externalities in depth, but aims to focus on the specific negative externality of

[1] Methodological limitations to the study are discussed in Chapter 2.

air emissions in the form of greenhouse gases from water reservoirs. Furthermore, issues of negative social externalities related to dams and reservoirs (such as the displacement of communities and impacts on indigenous peoples) are also not covered by this study.

The geographical scope of the study is not limited to any specific region or country as (i) the issue of climate change does not respect national boundaries, and (ii) information on the issue of reservoir emissions is comprised of pockets of knowledge scattered around the world. It is recognised that such a wide geographical scope will likely not produce an exhaustive account of the studied issues. However, the broad geographical scope was judged necessary due to the lack of an existing overview framework within which more focused and localised studies could be conducted. In addition, climate change is of concern to the global community and, as such, does not lend itself easily to a limited geographical scope.

The research assumes a distinctly policy-oriented perspective. It does not attempt to address details of scientific research on the topic beyond an overview of the existing knowledge base as reported in the literature and in statements of those engaged in research activities. The selected approach aims to contribute to the work of both the scientific and the research community by exposing issues and areas of uncertainty from both perspectives. It aims to facilitate a better understanding of the science-policy interface among both parties. It is recognised that the present enquiry is unable to address the full complexity of the issue at hand; however, it is hoped that the work can provide some perspectives into the existing obstacles to policy development in the area.

The primary audiences for this work are policy and research communities in the areas of climate change and reservoir emissions. For climate policy-makers at the international and national levels, the research offers an overview of the topic of reservoir emissions and a summary of the ongoing scientific debate on the issue. The research community may find the research useful in clarifying the science-policy interface, the variety of policy areas for which scientific research on reservoir emissions is required, and the requirements set by different frameworks. Additionally, the research may benefit organisations working on freshwater issues and water management by providing indications of how the policy field may develop, and; consequently, the implications to their respective operations. All the above-mentioned stakeholders are likely to benefit from a clearer idea of the issue of reservoir emissions and the context that will be affected by the unfolding science.

1.5 Outline

The report is organised in seven chapters. This introductory chapter outlines the research background, presents the focal problem and the research questions that guide the study, and discusses the scope of the research. The second chapter focuses on research methodology and presents the research design and methods selected for data collection and analysis. Limitations of the chosen approach are also considered. Chapters three and four present findings derived from the literature analysis. These set the stage for the main body of analysis, which is presented in chapter five and commences with an evaluation of existing of policy responses to reservoir emissions, followed by an analysis of future opportunities for policy development. Chapter six presents a discussion of possible implications for different stakeholders, and the final chapter offers conclusions and recommendations for further research.

2 Research Methodology

2.1 Project initiation and research design

The idea and motivation for this project emerged from discussions with a high-level representative of UNESCO[2] Division of Water Sciences at an international conference on the water-energy nexus in November 2008 in Paris. It was further developed in the first half of 2009, and during a four month internship in the Division of Water Sciences at UNESCO headquarters in Paris in 2009. This affiliation provided the author privileged access to high level meetings addressing the topic and two conferences in Australia. Moreover, the position provided access to UNESCO library resources as well as some interviewees within UNESCO and some of its partner organisations. Although the conducted study was linked to activities within the seventh phase of the International Hydrological Programme (IHP) coordinated by UNESCO, the study was not commissioned or funded by UNESCO and as such remained independent of the organisation.

The research was carried out in two stages. The initial stage sought to delineate and establish an understanding of the nature of GHG emissions from freshwater reservoirs and the debate surrounding the topic. This stage also focused on mapping policy areas where there is evidence that reservoir emissions have or are likely to have an impact in the future. Data from literary sources was utilised in combination with a short questionnaire delivered at two international water events. The questionnaire collected information on the general awareness and views of practitioners in the area of energy and water management. For this stage, an exploratory approach was selected due to its flexible nature. Such exploration allows a researcher to seek out new aspects and gain an understanding of an unknown area (Robson, 2002). This stage helped to refine the research problem and identify the relevant issues and policy areas suitable for further investigation in the second stage of the work.

The second stage focused on the issues and policy areas identified in stage one. Existing policy developments in international climate change frameworks were analysed. Policy interventions were considered in the area of climate change as well as areas such as assessment procedures linked to dam development (e.g. environmental impact assessments). The main data sources in the second stage were existing literature, and qualitative, semi-structured interviews. The approach adopted in this stage was largely inductive, in which specific observations were used to inform the generation of wider patterns and principles. (cf. Hesse-Biber & Leavy, 2005) The main data analysis occurred during this stage of the research and was guided by approaches, outlined by Moniz (2006), for using scenarios-building tools in policy analysis. Methods for data collection and analysis are elaborated in later sections of this report.

Secondary data was collected from a variety of literary sources, websites and legal documents. Academic publications related to reservoir GHG emissions were searched in Lund University library catalogues (Lovisa and ELIN), UNESCO library database, CSIRO Library Network Database[3] and through internet search engines such as Google Scholar. Further searches were conducted in the publication databases of universities and research institutes engaged in climate change and freshwater issues. Publications by intergovernmental and non-governmental organisations (NGO) were identified primarily through internet searches and

[2] United Nations Educational, Scientific and Cultural Organisation

[3] CSIRO is the Australian Commonwealth Scientific and Industrial Research Organisation. Access to the database was facilitated by one of the author's supervisors.

other publications. Policy information was accessed primarily through the websites of relevant intergovernmental and governmental agencies. Overall, a significant amount of material was discovered from the references flagged by interviewees or found in materials identified by initial searches. Materials from the following areas were consulted:

- basic information about dams and reservoirs and related environmental impacts;
- existing research findings on GHG emissions from water reservoirs;
- ongoing research activities on reservoir emissions;
- current status of reservoir emissions in climate policy frameworks and indications of future developments;
- environmental policy principles, particularly in areas of climate change, water and natural resource management.

These sources were chosen with the aim of covering the scientific evidence available on the topic and to support the policy focus selected for the study.

Primary data was collected in stage one using a questionnaire and a series of qualitative interviews. As indicated, a short survey questionnaire was given to energy and water management professionals and practitioners to ascertain their level of awareness of the issue and to solicit a list of policy areas they deemed relevant. The questionnaire was distributed to participants at the beginning of two international meetings in Brisbane, Australia, which the author attended in July 2009.[4] In total, the questionnaire was returned by 31 of 60 people to whom it was distributed. A sample of the questionnaire applied is provided in Appendix 2. The results were used to identify relevant policy areas within the broader fields of climate change and water policy.

The key source of primary data in the second research stage was qualitative interviews with informed individuals in the field. Potential interviewees were initially identified through literature and professional contacts, and further subjects emerged through a sampling technique called snowballing, in which informants are asked to refer individuals who could provide additional information or alternative perspectives on the topic (O'Leary, 2005). Some interviewees were also identified from among questionnaire respondents and their professional networks. Throughout the interviews, a wide range of perspectives were sought from different stakeholders and areas in order to achieve sufficient coverage of different aspects of the research problem and to ensure a balanced research outcome. Interviewees represented a range of backgrounds and positions including academic research institutions in both policy and GHG emission areas, industry associations, environmental groups and experts involved in international climate change negotiations. The interviews were open and semi-structured in format due to the exploratory approach demanded by a lack of published information on policy links. The interviews aimed to facilitate:

- an understanding the dynamics of relevant policy developments and in different policy areas;
- a mapping of the broader context of potential policy interventions;
- a better comprehension of the issues affecting the science-policy interface of reservoir emissions; and
- a discovery of scientific and political drivers and barriers to policy development in the specific context of reservoir emissions.

In total 13 interviews were conducted. Three interviews were carried out in person, nine by telephone and one by email. Notes were taken during interviews and written up as interview summaries immediately following the interaction. Most interviews were recorded, but

[4] AMSI/MASCOS/UNESCO international workshop on Future Models for Water and Energy Management in Brisbane, Australia on 20-22 July 2009 and UNESCO-HELP workshop on Integrated Water Resources Management in Brisbane, Australia on 24 July 2009

recordings were primarily used as reference to ensure consistency of notes made during the interview rather than as detailed transcription. Clarifications and follow-up questions were sent via email after the interview to four interviewees. Anonymity of information was promised to all interviewees who expressed a wish that their name would not be published. A list of interviewees is provided in Appendix 1.

As indicated, triangulation of data sources was sought throughout the data collection period with the aim of ensuring data authenticity and credibility of the study (O'Leary, 2005). This was deemed particularly important due to the existing concerns over the involvement of interiewees with vested interests in the topic and the consequent objectivity of some published resources. Triangulation was pursued by combining different sources of secondary and primary data. Within the secondary data, triangulation was pursued by collecting publications from a variety of sources (academic, governmental, industry-related and NGO) and also by seeking broad representativeness within the source categories e.g. by explicitly seeking academic papers published in different journals and by various publishers. For primary data collected through interviews, similar approaches were applied. Views were sought from various stakeholder groups including scientific researchers, policy-makers, academics involved in policy research and environmental advocacy groups. Within the scientific research community, researchers from both private and public spheres were approached.

2.2 Methods for data analysis

Analysis of questionnaire data

Data from questionnaires was analysed in a simple grouping exercise, first according to self-indicated levels of awareness on the topic, and then according to how the respondents viewed the importance of policy consideration of reservoir emissions. Finally, responses were grouped by the main issues raised by respondents in support of their views. These last grouping categories emerged from the responses themselves as they were prompted in the questionnaire. Throughout the analysis, attention was paid to the position and area of expertise of the respondents. This added attention helped to identify different groups of practitioners who might be expected to have certain level of awareness due to their position or field of expertise (such as those working with reservoir management or environmental issues).

Analytical framework

The main analysis used data from interviews along with supplementary literary sources, presentation materials and legal documents recommended by interview informants. This analysis was guided by approaches developed for the use of scenario-building in policy analysis, which are briefly discussed below.

Policy analysis can focus either on evaluating existing policies and their outcomes (*ex-post* analysis) or impacts of planned policy measures (*ex-ante* analysis). In the area of environmental policy analysis, the focus is on environmental improvements delivered by implemented policies or anticipated from new policy measures. (European Parliament, 2002) Although policy development in the area of reservoir emissions has not progressed to a state of explicit proposals that could enable the use of methods of ex-ante policy analysis, some of the tools used in such endeavours can be helpful in more preliminary future-oriented policy studies. Scenario-building is an often used tool when exploring prospective policy futures (see e.g. Bradfield et al. (2005) for an overview of scenario-building techniques).

Scenario-building has been offered as a useful tool for policymaking to help policy-makers grasp problems more easily and to better identify challenges and opportunities in an overall framework (Moniz, 2006). Scenarios can be either quantitative or qualitative, exploratory or normative, complex or simple, and offer a snapshot of a single point in time or a projection from a given time (usually the present) into the future. Despite a variety of definitions for scenarios and the processes of planning and building scenarios, most scenarios have some common characteristics: (i) they are hypothetical and describe possible future pathways; (ii) they account for dynamic processes, driving forces and key events; and (iii) they expose areas of uncertainty and inevitability (Strupeit & Peck, 2008). Scenarios can be used for a variety of purposes:

1. decision-support in public policy-making;
2. managing risk and uncertainty;
3. establishing a common understanding and a vision for the future among different stakeholders; or
4. facilitating learning and understanding among the actors involved in the process of scenario-building.

In the field of environmental policy-making, scenarios have been used by governments and bodies such as the European Environment Agency (EEA) for policy evaluation in a number of areas including air pollution and transport. Although not policy scenarios *per se*, other well-known applications of scenario techniques in the environmental field are the global GHG emission scenarios produced by the IPCC.

From the above, the third objective for using scenarios i.e. facilitating understanding and creating a common vision among stakeholders was deemed most applicable for this work on reservoir emissions. The unexplored nature of the policy field and the multitude of relevant yet unconnected stakeholders suggest that at this preliminary stage establishing common ground among the different actors would be highly beneficial. Alcamo (2001) has pointed out that perhaps the most important value of using scenarios comes from their ability to bridge environmental science and policy through synthesising complex knowledge into a form that helps policy-makers grasp the different aspects, connections, and spatial and temporal scales of an environmental problem. Scenarios could thus prove useful in bringing clarity to the science-policy interface.

Some of the defining features of scenario-building exercises are that they engage a large number of stakeholders from different fields of expertise, and consequently they are rather time-consuming tasks. The time taken to develop most scenarios is measured in years rather than months and one author described 18 months as a short time for scenario-building (Moniz, 2006). Therefore, the direct use of scenario-building methods as such was deemed too ambitious for this study. Many of the questions that guide scenario development were, however, considered applicable and useful for the task at hand and thus selected to provide structure to the analysis. The analytical framework was synthesised from selected ideas presented in Moniz (2006), which are summarised in Table 2-1 below.

Table 2-1 Aspects of scenario-building theory selected to guide analysis in this study

Selected idea	Adaptation of the ideas for this study
General types of questions that guide scenario-building: - what is uncertain? - what is inevitable? - what are driving forces of trends and developments?	These questions were selected to frame the general interpretation of data. Answers to the questions were sought for each of the studied policy areas as well as the overarching science-policy interface in order to facilitate the process of inductive inquiry selected for the study.
Elements of scenario development: - identification of focal issue and key elements of the system being studied; - identification of driving forces towards change or maintaining stability; - assessment of the force and direction of these trends;	The first three elements of a scenario-building exercise were deemed applicable for this type of preliminary exploration of policy aspects. The elements were applied at the general science-policy interface level as significant overlaps were expected among the separate policy areas. Furthermore, the aim of an inductive approach is to draw overarching themes from individual observations and hence consolidation of the analysis was aimed at this more general level.
- development of alternative futures including preferable visions; - consideration of "wild-cards"; - identification of appropriate actions.	The last three elements were deemed to require more time and complex resources than what was available for the present study and were thus excluded.

Source: Adapted from Moniz (2006)

Using the ideas in table 2-1, a framework for analysis was constructed for this study. For the separate policy aspects and areas, the general questions guided the interpretation of data. This process was expected to yield sufficient observations that could be used to analyse the more general level trends shaping the science-policy interface. At this higher level, the analysis was framed around three categories. These categories capture: (i) areas of inevitability and uncertainty; (ii) main drivers and barriers for policy development; and (iii) key events that are likely to shape the policy space.

While time scales are central to scenario-building exercises, this preliminary work does not attempt to temporally define the future policy space for reservoir emissions. Due to significant uncertainties regarding future developments in the area, this analysis takes the present time as a point of departure into a temporally undefined future policy space. Removing the time dimension from the analysis has some drawbacks by increasing the level of abstraction and thus risking the usefulness of the results. Thus, an attempt was made to address this limitation by constructing a parallel timeline of political and scientific key events that are expected to shape the science-policy interface in the next 5-10 years using available information for anticipated events. It is intended that the parallel observation of these illustrations will help the reader understand some of the challenges in the science-policy interface as related to the topic of reservoir emissions.

Application of the analytical framework to interview data

Data from interviews was analysed in two stages. In the first stage, information was loosely organised in a temporal sequence from previous developments to ongoing issues and finally to views on future possibilities for each of the identified issues and policy areas. This was done primarily to facilitate analysis of the current policy status of different areas and immediate issues that define the debate today. In the second stage, a more abstract analysis was performed in which the framework adapted from scenario-building was applied to prospective policy developments. The inductive process was consolidated through the exposition of overarching themes and issues that arose from the separate aspects and areas that were studied.

Scientific knowledge was identified as a prerequisite to forming policies, thus a range of environmental policy principles were drawn on as guidelines for policy development. These were combined to create a continuum of policy development that encompasses three loose stages: no policy intervention, limited policy intervention and advanced policy intervention. Elements of the policy development continuum are described in more detail in section 5.2.1.

Results of the analysis were organised along a continuum of policy development stages which was constructed to facilitate the conceptualisation of the science-policy interface. The current situation was analysed by placing the identified policy areas on the continuum based on existing policies. This provided a starting point for further analysis regarding future opportunities. The idea of a policy continuum emerged from a discussion on aspects of policy-making with a colleague.

2.3 Limitations

Data collection

Limitations were experienced regarding both the data collection and analysis. The relative limit

novelty of the topic and the emerging nature of the research area placed clear limitations on the secondary data collection. Moreover, a lack of established terminology in the research area hampered literature searches. Published resources were available in limited quantities, and in particular, the lack of previous studies related to the policy aspects of reservoir emissions was a significant limitation. Some key journal articles were not readily available through the library resources and efforts to acquire access to these resources proved unsuccessful. Other recent material on the topic was only been published in Brazil and had to be excluded due to the author's limited language skills in Portuguese. Overall, the secondary resources available did not allow this study to be positioned in relation to existing work.

Primary data collection was restricted by limited access to interviewees. Only a relatively modest number of people are actively working on the issue of reservoir emissions which reduced the total number of potential interviewees. Moreover, informed individuals and experts on the issue are scattered both geographically and across policy areas thus hampering the process of identifying potential interviewees. Observations in meetings and discussions with high-level officials indicated that access to some actors and organisations could be restricted due to highly political nature of the reservoir emission issue. This was in fact experienced with some individuals who were approached for an interview. Moreover, the data collection process revealed that the issue of reservoir emissions is relatively unknown outside the immediate group of individuals engaged on the topic. Consequently, a number of individuals who were approached based upon their positions or accountability areas, judged themselves too uninformed to provide information.

Some limitations also emerged within the interview process. Most interviewees were able to answer questions only on some of the areas that had been identified for studying. On some occasions, informants were keen on learning more about the areas in which their knowledge turned out to be limited, which diverted their attention away from the purpose of the interview. In this light, some difficulties were experienced when informants repeatedly sought information on the issue from the interviewer. Although these events curtailed the amount of information that could be extracted from the interviewees, they also implicitly revealed important findings for this study. The apparent knowledge gaps among the experts as well as their explicit interest to learn more about aspects of the study reinforced the need for this type of work.

Data analysis

Limitations in data analysis were encountered with both primary data sources. Questionnaire data collected in first research stage did not return the expected results and thus reduced the analysis. Some responses were incomplete or illegible, consequently some information was missing or could not be fully analysed. The questionnaire data provided some indication of the level of awareness among practitioners, but the vast majority of respondents were completely uninformed or indicated very shallow levels of knowledge. These results are briefly discussed in section 4.5. This limited awareness among the practitioners was unexpected, since preliminary discussions with experts indicated that these practitioners would be expected to be aware and knowledgeable of the issue of reservoir emissions. Despite the surprising findings, the questionnaire was able to identify individuals with suitable backgrounds and sufficient levels of information who would be good candidates for follow-up detailed interviews.

Analysis of interview data was restricted due to both the limited number, and availability of representativeness of different stakeholder groups. Experts were not available to comment on all of the studied policy areas, which led to some of the research aspects enjoying significantly richer data than others. Additionally, most experts were not able to offer views on more than one of the policy areas and issues being studied. Consequently, aggregate data consisted of pieces from individual respondents with little overlap among the various interviewees. This gave rise to higher uncertainty in particular areas with limited triangulation and data validation opportunities. Overall these data limitations affected reliability of the analysis and the results inferred from the data.

By definition, exploratory research returns a mix of outcomes that reflect the different dimensions of a problem. When the outcomes do not fit together well, it can be challenging for the researcher to group and interpret information in a logically coherent way. The outcomes of the data collection phase and the analysis presented such challenges. As the research progress the opportunities offered by other stakeholder and policy process theoretical frameworks intrigued the author; nevertheless, their application was left outside the current study and reserved for future efforts to understand different aspects of the problem in more detail.

3 Overview of dams and reservoirs

Reservoirs are defined as natural or man-made water bodies which are used for the storage, regulation and control of water resources, whilst dams are barriers built for the purpose of creating a reservoir (UNESCO & WMO, 1992). A reservoir created by the construction of a dam is by default man-made and this definition of reservoir is used in this work. The history of modern reservoirs began at the end of the 19th century when the first dams were built for hydropower generation. Since then, their construction has increased steadily with two peaks in the 1950s and 1980s. (World Commission on Dams [WCD], 2000) Today, there are some 33 000 large dams (height > 15 m) and thousands more that are not reported in official statistics (International Commission On Large Dams [ICOLD], 2003).

Even before reservoirs began to be built for hydropower generation, they were used for a multitude of purposes including water supply, irrigation, flood and drought control, navigation and recreation. Most currently operational dams are used for a single purpose (71.7%) but the number of multi-purpose dams (28.3%) is growing. The most common use of single-purpose dams is irrigation (48.6%), followed by hydropower (17.4%), water supply for domestic and industrial purposes (12.7%) and flood control (10%) (ICOLD, 2007). Multi-purpose dams can serve any combination of these purposes. It is also commonplace that the purposes of a reservoir can change during its lifetime. For example in Queensland, Australia, the Wivenhoe dam which was originally built for flood control now supplies 2/3 of the drinking water supply for the city of Brisbane (S. Hoverman, Brisbane City Council, personal communication, 21 July 2009). In Central Asia, various dams that were originally built for irrigation purposes were rehabilitated to include a hydroelectric element after the collapse of the central Soviet energy system (GTZ policy advisor, personal communication, 31 July 2009).

As defined above, reservoirs are used to store water and regulate the flow of water for different purposes. The total amount of water stored by reservoirs was recently estimated at 10,800 km^3 (Chao, Wu, & Li, 2008), which is almost the amount of water in Lake Superior in North America, the world's third largest lake. Since these estimates were made, the world's largest reservoir in China (connected to the Three Gorges dam) has been filled which adds hundreds of cubic kilometres to global impounded water resources. In terms of surface area, global estimates range from 0.26 million km^2 (Downing et al., 2006) to 1.5 million km^2 (St. Louis et al., 2000). The global surface area of all water resources, natural and artificial, is estimated at 4.6 million km^2, which indicates a minimum share of 5% for reservoirs (Downing et al., 2006).

Geographically, most dams are situated in Asia (39%), North America (32%) and Europe (19%). Africa, South America and Australasia have five, three and two percent of the world's large dams, respectively. (ICOLD, 2007) Currently, approximately 1,600 dams are under construction and the top five builders (China, Iran, Turkey, Japan and India) account for 2/3 of ongoing construction projects (WWF, 2005). Future dam construction is expected to focus on Asia, Africa and South America where construction potential is highest and population pressure and economic growth will increase the demand for water storage for irrigation, water supply and energy. For hydropower reservoirs alone, the construction potential is enormous for the three continents, with less than 1/3 of economically and technically feasible potential currently developed. (International Hydropower Association [IHA], 2008) As most dams are built for irrigation rather than energy purposes, this figure is likely to represent only a part of the total potential for dam development in the world.

3.1 Environmental issues related to dams and reservoirs

Dams provide water for agriculture and human needs, act as safeguards against floods and buffers during droughts, and create opportunities for recreation and pathways for inland navigation. Despite the benefits, the diversion of natural rivers can have a variety of negative environmental impacts or externalities on the surrounding ecosystems and downstream users. As part of its comprehensive review of the world's large dams, the World Commission on Dams (WCD) undertook an evaluation of the range of environmental issues that can undermine the sustainability of dam projects if left unaddressed (2000).

Impacts on terrestrial ecosystems and biodiversity include destruction of forests and plant species in the inundated area, and destruction of habitats for animals which leads to their displacement and possible extinction in the case of unique wildlife habitats. Flooding an area can lead to occupation and clearing of upstream areas as displaced communities search for replacements for the land lost to flooding. The loss of vegetative cover can accelerate erosion and increase sedimentation, decrease water quality and alter seasonal variations in flows. Altering natural river flows affects the distribution and timing of flow, which compromises the health of aquatic ecosystems downstream of the dam, which in turn affects biodiversity. Significant flow variations following water releases from a dam change the quantity, quality and temperature of water, which can be detrimental for the riverine ecosystems in downstream areas. For example, natural fish species are often sensitive to water temperatures as signals for migration and spawning. Ecosystem alterations create opportunistic conditions for non-native species which can outcompete natural species and further disrupt the natural balance of ecosystems. Furthermore, the building of a dam creates a physical barrier that prevents fish and other aquatic species from migrating into upstream areas. Dams also intercept the natural flow of sediments in the river by trapping them in the reservoir. This affects ecosystems in downstream floodplains, river deltas and coastal areas and can significantly reduce productivity of land and fisheries in downstream areas and increase erosion in delta areas.

The WCD's report addresses the issue of GHG emissions from large dams as one category of environmental impacts (2000). The section on reservoir emissions concludes that greenhouse gases are produced by the rotting of biomass and carbon inflows into the reservoir, questioning the conventional wisdom that hydropower has only positive impacts on climate. The report further emphasises that GHGs are produced by reservoirs created for any purpose and that there is a need to investigate the issue further.

Many of these environmental effects are created in a complex and interdependent processes and are often mutually reinforcing. Furthermore, when multiple dams are built on a single river system, the cumulative impacts can easily multiply the negative effects to detrimental levels. Over 60% of the world's rivers have been dammed or diverted and in many corners of the world, diversions are causing rivers to run dry near coastal areas (Revenga et al., 2000). Most of the environmental impacts associated with dams and reservoirs are primarily felt by local communities and ecosystems and can be addressed through mitigation measures at the local level. In the case of GHG emissions, any applicable mitigation measures will be taken at the local level at which the water resource is managed. The benefit, however, is felt at the level of the global climate, which sets it apart from the other environmental effects of reservoirs. This leads to an inherent mismatch between the level at which costs of mitigation will accrue and the level at which the benefits will be credited. This concern for the global commons sits at the heart of the problem addressed in the remainder of this paper.

Figure 3-1 Lake Argyle reservoir in Western Australia. Photo credit: Justin Story

Figure 3-2 Petit Saut reservoir in French Guiana. Photo credit: Compagnie des Guides, Panoramio

4 Greenhouse gas emissions from reservoirs

The issue of greenhouse gas emissions from reservoirs was first discussed in academic literature in the early 1990s (Rudd, Harris, Kelly, & Hecky, 1993). Despite increasing interest in the topic, the issue remains relatively unknown outside the scientific community. Research has been ongoing for some 15 years with the aims of identifying the processes by which reservoirs produce greenhouse gas emissions and quantifying the emissions. Geographically, most research has been carried out in boreal regions (primarily in Canada and Scandinavia), whilst Brazilian researchers have also published widely on the topic of greenhouse gas emissions from tropical reservoirs primarily in the Amazonian basin. To date, reservoirs in arid and semi-arid regions have been have not been studied comprehensively.

Reports indicate that reservoirs can be significant sources of emissions. Especially methane emissions from tropical reservoirs have attracted attention due to reports of alarming emission levels. Highest estimates suggest that global GHG emissions could increase by 3-4% if reservoir emissions were accounted for (St. Louis et al., 2000), while other estimates offer more modest figures in the range of 0.5% of total global emissions (Varis, Kummu, Härkönen, & Huttunen, n.d.). In the case of methane emissions, which appear to form the dominant part of reservoir emissions due to the relatively high global warming potential of methane, reservoirs have recently been estimated to contribute an additional 30% to existing global methane emissions from anthropogenic sources (Lima et al., 2008).[5]

For individual countries, estimates vary greatly due to different climatic conditions and reservoir surface areas. Although disagreement on emission quantities remains to be resolved, the scientific community has largely reached a consensus on the processes by which GHG emissions are formed in reservoirs and the different ways in which they are released to the atmosphere. The following sections summarise the existing knowledge on the processes and pathways of reservoir emissions, the issues that continue to be contested among scientists and the ongoing research efforts that aim to solve these controversies.

4.1 Processes and pathways of GHG emissions from reservoirs

Reservoirs generate GHG emissions through aerobic and anaerobic decomposition of organic material. This includes the soils and biomass initially flooded by the creation of the reservoir, nutrient inflows from watershed, aquatic plants and plankton that grow and decay in the reservoir as well as drawdown vegetation that grows seasonally as a result of water-level fluctuations. Aerobic decomposition occurs in oxygen-rich conditions and produces carbon dioxide, whilst anaerobic decomposition takes place in oxygen-poor (anoxic) conditions and produces carbon dioxide and methane. (dos Santos, Rosa, Sikar, Sikar, & dos Santos, 2006) This distinction is significant because the conversion of carbon into methane, which has 25 times the global warming potential of carbon dioxide over a 100-year period (IPCC, 2007a), has a potentially magnifying effect on the overall climate impact of a reservoir.

Figure 4-1 below illustrates the main processes by which GHG emissions are generated and pathways through which they are released to the atmosphere. Empirical measurements of reservoir emissions have recorded significant variations, which is a direct result of the multitude of factors affecting the rate of GHG generation and release from reservoirs. The figure illustrates three factors that affect the rate of emissions: wind forcing, water level

[5] Anthropogenic methane emissions currently include coal mining and combustion, oil and gas related emissions, biomass burning, waste disposal and rice paddies.

fluctuations and length of annual ice cover, which is important for boreal reservoirs. Additional factors include temperature and sunlight, physical and chemical parameters of the water body, and biosphere composition. All these factors influence the speed of the carbon cycle in a reservoir. (Rosa, dos Santos, Matvienko, dos Santos, & Sikar, 2004)

Greenhouse gases are released from reservoirs through three main pathways: diffusive, bubbling and degassing emissions. Molecular diffusion occurs at the air-water interface and is two-directional: gases are both released into the atmosphere and absorbed by the water body. Bubbling emissions are the result of gas bubbles that are formed in sediments at the bottom of a reservoir and consequently travel up the water column. Although some methane bubbles can be oxidised into carbon dioxide during this movement, significant amounts are released directly to the atmosphere as the bubbles reach the water surface especially in shallow areas of a reservoir. Height of the water column and water pressure are two factors that determine the rate at which methane is released to the atmosphere. The deeper the reservoir, the more time there is for methane bubbles to be oxidised as they move up the water column. Decreases in water pressure, for instance as a result of water release from the dam, increase the rate at which bubbles are released from the sediments and begin their way up to the reservoir surface. (T. del Sontro, research scientist, personal communication, 12 August 2009) Degassing emissions occur when water is released through hydroelectric turbines and spillways. Turbine outlets are often at low levels of the water column, which means that the water passing through them is pressurised and contains relatively high amounts of gases. As water is released though turbines and spillways, the instant drop in pressure releases the concentrated gases to the atmosphere (Fearnside, 2004). These emissions were controversial for a number of years, but recently their significance has been recognised by the scientific community at large (Goldenfum, 2009a). Along with bubbling emissions, degassing has been identified as a particularly important pathway for methane emissions from reservoirs. (Guérin et al., 2006; IPCC, 2006) The three pathways are illustrated by vertical arrows in Figure 4-1.

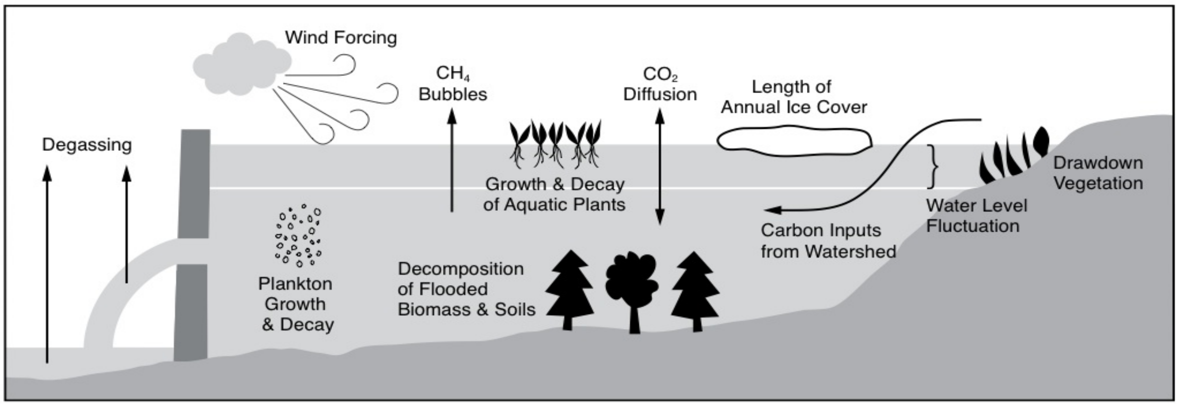

Figure 4-1 Processes and pathways of GHG emissions from reservoirs
Source: (McCully, Pottinger, & International Rivers Network, 2006)

Greenhouse gas generation and emission levels are of particular importance for tropical reservoirs, which are often characterised by high temperatures, high levels of organic material, and naturally productive carbon cycles. Especially shallow, plateau-type tropical reservoirs have been shown to generate and emit significant amounts of methane. Deeper reservoirs with smaller surface areas relative to storage capacity have tended to show lower emissions. (IPCC, 2007b)

4.2 Knowledge gaps and ongoing research efforts

In addition to the emerging consensus on processes and pathways described above, the scientific community continues to debate a number of issues surrounding reservoir emissions. The first of these is the issue of gross vs. net emissions. In order to accurately estimate the climate impact of building and operating a dam, it is necessary to deduct pre-dam emissions from those measured after impoundment. Some natural ecosystems such as forests and grasslands are an important carbon sink, in which case the net impact of impoundment should combine the removal of carbon sink capacity as well as additional emissions from the reservoir. For other ecosystems such as lakes and other wetlands, the net impact is likely to be smaller but nonetheless important. (Svensson, 2005; WCD, 2000) Linked to the question of gross vs. net emissions is the issue of anthropogenic vs. natural emissions, which makes a distinction between those reservoir emissions that result from human activities and those that have a natural source. This introduces immediate complications as for some processes, such as erosion of upstream areas which increases the inflow of carbon into a reservoir and thus contributes to reservoir emissions, it may not be easy to determine the causal link to human activities in a complex system. A related distinction is made between direct and indirect human-induced emissions, which aims to single out those emissions that result directly from human activities specific to a reservoir from those that result from other, unrelated human activities such as agriculture or wastewater from upstream areas. All three comparisons imply slightly different system boundaries for the study of reservoir emissions. They are all important considerations in a comprehensive assessment of a reservoir's emission profile, in terms of focusing attention on the human impact on the environment and avoiding double-counting as emissions related to horizontal transfers of carbon can be accounted for in the initial source activity. As discussed later in section 5.2.3, this is one of the key questions in policy debates on the issue of reservoir emissions.

Significant controversies surround methodologies for measuring and quantifying reservoir GHG emissions. A variety of methods have been applied in previous research efforts and there is currently no universally applicable measurement methodology available. Different methods are associated with varying uncertainty levels, which makes the comparability of research results difficult. Furthermore, the full picture of reservoir emissions includes different emission pathways which require the application of different measurement techniques. In order to arrive at a full picture of the emissions from a reservoir, a variety of techniques thus needs to be applied. Most studies to date have considered only some aspects of reservoir emissions, often excluding degassing emissions. Comprehensive studies that include all aspects of reservoir emissions are important, as it has been demonstrated that total emission levels increase as more parts of a reservoir are included in a study (D. Cullenward, Stanford University, personal communication, 11 July 2009).

A further aspect of quantification methodologies is related to the extrapolation of measurements from limited field measurements to cover the area of a whole reservoir that can reach thousands of square kilometres. Within such a vast area, emission generation and release rates are likely to vary. A related area where controversies arise is temporal extrapolation as reservoir emissions vary according to seasons and according to the age of a reservoir. (Rosa et al., 2004) Both of these aspects make it challenging to arrive at emission factors comparable to other sources of greenhouse gases. For instance, exercises that have attempted to compare emissions from a hydroelectric reservoir with emissions from fossil fuel sources that result from uniform combustion have often had limited success. Furthermore, given the increasingly common multi-purpose nature of reservoirs, such approaches are likely to prove insufficient in future efforts to compare reservoir emissions with other known sources of GHGs.

The relative importance of different processes and parameters that influence the rate of GHG generation and emission from reservoirs constitutes another important knowledge gap. One scientist working on the issue stressed that this problem presupposes that all relevant factors have been identified, which may not yet be the case. Of the range of factors outlined in section 4.1 above, there is no consensus which factors are most important determinants of the emission profile of a reservoir. Svensson (2005) studied the influence of reservoir depth, latitude, carbon content, surface area and energy output on reservoir emission levels and suggested that surface area is the most influential variable. The study, however, considered a relatively small number of reservoirs and again concluded that further investigations are needed. Solving this question is likely to be instrumental in the development of modelling tools for reservoir emissions, as the multitude of contributing factors hinders the deployment of modelling efforts. According to one informant, modelling presupposes the identification of all contributing factors and processes and their consequent grouping into classes of major, minor and unknown significance.

Significant research efforts are currently ongoing which aim to clarify many of these issues. The largest research initiative is lead by the International Hydropower Association (IHA) with the International Hydrological Programme (IHP) of UNESCO. The project grew out of two workshops organised under auspices of UNESCO-IHP in 2006 and 2007 which focused on discussing the state of research on the topic and identifying knowledge gaps for further research. The three-year project aims to evaluate the net GHG effect of creating a reservoir through developing tools and methodologies for comprehensive data collection and predictive modelling. The other main objective is to develop mitigation guidance for existing and future reservoirs. (Working Group on Greenhouse Gas Status of Freshwater Reservoirs, 2008) The main focus in the first stages of the project has been to develop a standardised methodology for measuring reservoir emissions, the first version of which was released in June 2009 (Goldenfum, 2009b). Following the Measurement Specification Guidance document, a field manual for measurement campaigns is currently being developed and expected to be released later in 2009. Another deliverable that is under construction is a screening tool to be used for preliminary assessment of the vulnerability of existing and future reservoirs for GHG emissions. Data collection will focus on filling data gaps through the investigation of a representative sample of reservoirs around the world covering all climatic zones and data will be collected in a central database. In later stages the project will focus on developing more detailed modelling tools and mitigation measures. These deliverables are expected in 2010-2011. (IHA, 2009)

Another international research project that will begin shortly is part of the International Energy Agency's Hydropower Implementing Agreement (IEA Hydro), Annex XII on Hydropower and the Environment. This research will be coordinated by Brazil with additional inputs from other IEA Hydro members including Japan, Norway and Finland. (IEA Hydro, 2009) Additional research activities are ongoing at least in Canada, Switzerland and Australia. In Canada, the EM1-Project focuses specifically on determining net emissions of a reservoir in northern Québec by conducting a series of measurements before and after impoundment.[6] In Switzerland, researchers are working on methane emissions from small reservoirs connected to run-of-river hydropower stations[7], which is an area that has been largely overlooked by research efforts to date as most research has focused on large storage reservoirs (T. del

[6] www.eastmain1.org

[7] Run-of-river hydropower utilises the gravitational flow of water for power production and thus does not require a reservoir with large storage capacity. The area impounded by a run-of-river reservoir is usually small, often not much larger than the area naturally occupied by the river it is connected to and the residence time of the water is usually some days compared to multiple years in the case of large storage reservoirs.

Sontro, research scientist, personal communication, 12 August 2009). Like the Swiss research activities, the Australian project run by CSIRO Land and Water is funded by public research grants. These are some of the first research projects on reservoir emissions that are not funded by the hydropower industry. The Australian research efforts are also pioneering in that their scope reaches beyond hydroelectric reservoirs into reservoirs used primarily for water supply and irrigation. (B. Sherman, senior research scientist, personal communication, 20 August 2009) Overall, it is expected that as these research activities progress, scientific publications will follow and add to the existing body of knowledge in the area. These outputs will be of direct interest to bodies of the United Nations Framework Convention on Climate Change (UNFCCC) and the IPCC, which depend on scientific publications for their data sources.

4.3 The debate on reservoir emissions

"It is politically incorrect to observe hydroenergy may not be 'green', so you'll be lucky to find much published on it."

(senior water management professional)

Publication of the World Commission on Dams (WCD) report in 2000 was an important milestone in the debate on reservoir emissions. Before that, the issue had only been discussed by individual research papers and the issue had not been addressed at the international level. The report concluded that reservoirs emit greenhouse gases, thus challenging the conventional wisdom that hydropower is a clean, carbon-neutral form of electricity. (WCD, 2000) The report called for further investigation into reservoir and catchment characteristics in order to quantify the level of emissions.

Coinciding with the WCD report, the first attempt to estimate reservoir emissions at global level was published by a group of researchers from Canada (St. Louis et al., 2000). Their estimates are uncertain due to lack of data regarding the global surface area of reservoirs as well as uncertainties in the data regarding the emissions themselves. Despite the uncertainties, the research concluded that reservoirs are a source of greenhouse gas emissions to the atmosphere. Since 2000, a number of articles presenting research on measurements and estimates of reservoir emissions primarily from boreal and tropical have been published (Abril et al., 2005; dos Santos et al., 2006; Duchemin, Lucotte, St-Louis, & Canuel, 2002; Fearnside, 2002, 2004; Rosa et al., 2004). The most recent peak in the debate on reservoir emissions occurred in 2006 when a series of articles was published in the journal *Climatic Change*. (Cullenward & Victor, 2006; Fearnside, 2006; Rosa, Santos, Matvienko, Sikar, & Santos, 2006) Outside the realm of peer-reviewed journals, the issue has been touched upon only on isolated occasions (Giles, 2006; the Economist, 2003; Tremblay, Varfalvy, Roehm, & Garneau, 2004).

Overall, the issue has been discussed in two main contexts over the years. The dominant focus has been on debating hydropower's climate-friendliness and comparing the emissions from hydroelectric reservoirs to other energy sources, primarily fossil fuels. This debate was initiated by research from Brazil which indicated that tropical reservoir emissions can equal or even exceed emissions from equivalent fossil fuel power plants (Fearnside & Postal, 1995). The debate has since continued in a number of publications over the years. These considerations are important at the strategic level where national energy policies are developed and the future sustainability of different energy sources is considered. The other context has been the comparison of reservoir emissions with emissions from natural ecosystems such as peatlands, lakes and river systems. Very little attention has been given to emissions from reservoirs built for other purposes such as agriculture, flood control or drinking water supply and so far no study has considered the full complexity of the issue in an integrated manner.

Much of the research published to date has been produced by researchers connected to the hydropower industry, which has raised questions regarding objectivity of the research (Cullenward & Victor, 2006). In order to remove doubts of industry influence on research outcomes, independent bodies such as the IPCC have been called upon to take the lead in clarifying the research. Some argue that the IPCC is the only forum with the capacity to integrate technically advanced and politically sensitive research material whilst maintaining transparency and scientific integrity. (Cullenward & Victor, 2006; McCully et al., 2006) Hence, a much anticipated addition to the debate is a Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) currently being prepared by the IPCC. The report was commissioned in the 28th session of the IPCC in April 2009 and will include a section on hydropower and its environmental and social impacts. (IPCC, 2008a) Although detailed procedural information is not available on the report, work is progressing according to schedule and the special report is to be published in late 2010 (M. Görner, IPCC Technical Support Unit, personal communication, 5 June 2009).

Whilst the SRREN is expected to touch upon the issue of reservoir emissions, there is concern that it will be of limited use in moving the debate on reservoir emissions forward (D. Cullenward, Stanford University, personal communication, 11 July 2009). Firstly, the report will consider a wide variety of renewable technologies and its focus on hydropower will be limited. Consequently, the issue of reservoir emissions is unlikely to gain much attention. Secondly, although the IPCC enjoys a significant level of authority among scientists and policy makers alike, its role is limited by some of the fundamentals of its mandate (UNEP, 2000). On the one hand, the IPCC's role is to assess scientific information available through published literature. On the topic of reservoir emissions, the Panel's work is thus constrained by the limited availability of scientific publications on the topic. The ongoing research efforts are likely to be of assistance in the future, but there is a significant time delay from current research activities through published results to possible IPCC treatment of the material. On the other hand, as part of an intergovernmental process the IPCC can only launch investigations into issues upon requests from the Conference of the Parties (COP) and other subsidiary bodies of the UNFCCC. This process is complicated, highly political and national interests play an important role in determining negotiation outcomes. The issue of reservoir emissions is part of a larger debate on Land Use, Land-Use Change and Forestry (LULUCF) emissions in national GHG inventories, which is one of the most contested areas in international climate policy.

4.4 Calls for policy consideration

The paper by St Louis et al. (2000) marked the beginning of calls to include reservoir GHG emissions in policy frameworks. They concluded that due to the significant surface area occupied by reservoirs at the global level, these emissions should be included in global inventories of anthropogenic sources of greenhouse gas emissions. The current exclusion of reservoir emissions from national greenhouse gas inventories has been noted by both the scientific community (Soumis et al., 2005) and environmental advocacy groups. Among the latter, the most vocal calls have been voiced by International Rivers Network (IRN), a US-based environmental advocacy group working to protect river ecosystems and the communities that depend on them (McCully et al., 2006). There is, however, relatively little awareness of the issue and it has not entered mainstream discussions of GHG emissions and climate change.

Two factors make the issue controversial and as such potentially challenging to address through policy development. The first is national interest on part of countries that rely on hydropower for large proportions of their electricity supply, such as Brazil, Canada or Norway. Large natural resources are at stake along with significant financial resources. The second is industry's conflict of interest. Many of the researchers in the field are directly associated with large hydropower companies such as Electrobràs, Hydro-Québec or Statkraft. These aspects cannot be completely separated from the policy negotiations nor the auxiliary processes that contribute to the policy arena.

4.5 Awareness of the issue among practitioners in the field

In order to map the level of awareness of the issue among professionals and practitioners in the area of energy and water management, a simple questionnaire was distributed at two meetings in Brisbane, Australia in July 2009. The first meeting convened 50 international participants in a workshop on Future Models for Energy and Water Management and the second meeting on Integrated Water Resources Management (IWRM) engaged 20 participants primarily from Australia and New Zealand along with some international participants. The total number of professionals present in the meetings was 60 as ten people took part in both meetings.

Of the 31 respondents who returned the questionnaire, only one third indicated any previous awareness of the issue. The majority of these respondents had a background in water management. Most expressed having heard about the issue in general discussions but being unsure of the scale of the problem. Almost all expressed a lack of available information on the topic. None of the respondents was aware of any policy areas where the topic would be currently included.

When asked for their opinions on whether the issue should be addressed by policy frameworks, the vast majority thought that reservoir emissions should be included in climate change policies. Some were unsure and expressed an interest to wait until more detailed knowledge became available and a few did not think the issue is significant and thus necessary to be addressed by regulatory frameworks. There were no significant differences in the opinions of those who had previous awareness of the issue and those who had recently learned about it in association with the questionnaire. On the question of whether the issue should be considered by water policies, a similar pattern of responses emerged. The majority felt that GHG emissions should form a part of IWRM plans, few expressed practical concerns of how this could be done whilst some thought that the issue is not of importance.

The questionnaire results provided limited scope for analysis and thus contributed less to the research objectives than what had been anticipated. Some general observations can, however, be inferred from the responses. Firstly, the level of awareness on reservoir emissions among respondents was very low which provides some indication that the issue has not reached a sufficient level of awareness among practitioners in the field. Secondly, responses indicated that the issue is generally felt to be of importance among practitioners and the need for further research was reinforced. Lastly, the responses offered no information about policy developments in the area of reservoir emissions, which provided some support to the preliminary findings in the first part of the project that policy developments are only beginning to emerge. The sample was, however, small and only a few of the respondents worked directly in policy-related areas. Consequently, the responses were of limited value to the research task.

5 Analysis of policy implications

"Don't expect too much from politicians – there is a huge gap between cutting-edge science and policymaking."
- Dr. Anders Wijkman, Vice President, Club of Rome and Vice Chairman, Tällberg Foundation
Opening session on Climate Change and Water at the World Water Week, 19 August 2009

From a policy perspective, there are various areas where reservoir emissions could be considered. In the area of climate policy, this study found that the issue has been considered in the Clean Development Mechanism (CDM) framework. It was also found that the issue is deemed relevant for national GHG inventories, although its current treatment in this area is limited. Additionally, assessment procedures were discovered as an area where regulatory demands are currently nonexistent but considered important for the future.

The first part of this chapter presents an evaluation of the current treatment of reservoir emissions in national GHG inventories and the CDM framework. Policy development to date, current status and ongoing issues are described for both areas. The second section discusses pathways for further policy intervention, either through enhancements in currently relevant frameworks or introduction of the issue to additional policy areas. For this analysis, a continuum of policy development stages is constructed by combining different levels of knowledge with a set of environmental policy principles. This idea is elaborated further in section 5.2.1 below. The identified policy areas are placed on this continuum based on an evaluation of their current policy development status and possibilities for further policy development are discussed in detail for the three areas. Common issues affecting policy development around the issue of reservoir emissions are identified and discussed with the help of categories commonly used for scenario-building in policy analysis research. These categories focus on exposing contextual influences, drivers and barriers for policy development along with key events and uncertainty areas that shape the policy field (Moniz, 2006). The chapter concludes with a summary of the current statuses of relevant policy areas and key factors that are likely to shape further policy development.

5.1 Evaluation of current policies related to reservoir emissions

5.1.1 Greenhouse gas inventories

The United Nations Framework Convention on Climate Change (UNFCCC) was signed in 1992 and has currently been ratified by some 192 countries. The objective of the convention is to stabilise GHG concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system. It requires all parties to establish national inventories of GHG emissions and report their national emissions according to IPCC Guidelines,[8] however emissions from reservoirs are currently not part of mandatory reporting categories. Emissions from existing reservoirs fall under a reporting category "Flooded Land

[8] Annex I countries currently follow the 1996 Revised IPCC Guidelines for National Greenhouse Gas Inventories, the Good Practice Guidance (GPG) and Uncertainty Management in GHG Inventories, and the GPG for LULUCF; whereas non-Annex I countries follow the 1996 Revised Guidelines for their reporting under the UNFCCC.

Remaining Flooded Land"[9] which is included in the Good Practice Guidance (GPG) on Land Use, Land-Use Change and Forestry (LULUCF) as an appendix to indicate future methodological development in the area. This essentially means that reservoirs have been identified as a source of GHG emissions, but there is a lack of globally accepted standard methodologies for measuring reservoir emissions. Until such a methodology is available, the emissions category will remain voluntary for reporting purposes.

In 2006, the IPCC published an updated version of its guidelines for national GHG inventories, which provides methodological guidance for limited estimation of carbon dioxide (CO_2) emissions from reservoirs. These guidelines have not yet been approved by the UNFCCC for reporting purposes, which entails that their adoption by parties is voluntary at this stage (IPCC WGIII co-chair, personal communication, 6 August 2009). In the process of debating the new guidelines in the 25th session of the IPCC, Brazil (supported by Austria and Norway) was against including flooded lands in the guidelines based on a concern for double-counting of emissions, whilst Canada and USA were against further changes to the compromise that had been achieved in the drafting of the guidelines. In the accepted guidelines, only one of proposed methods for calculating reservoir emissions was included in the official guidelines whilst other methods were relegated to appendices. (Earth Negotiations Bulletin, 1 May 2006)

Guidance on estimating reservoir emissions in the 2006 guidelines is provided as part of Volume 4 on the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC, 2006). CO_2 emissions in the category 'Wetlands Remaining Wetlands' are excluded on the basis that these emissions are included in estimates of emissions from land use and land use change in upstream areas. Measurement guidance is provided for CO_2 emissions in the category 'Land Converted to Wetlands' in section 7.3.2.1, based on a carbon stock change method which estimates the amount of biomass in the flooded area, which is assumed to be emitted immediately. This excludes carbon in the flooded soils as well as any carbon inputs from upstream areas or biomass generation within the reservoir. Further guidance on establishing country-specific emission factors for flux CO_2 emissions is provided in appendix 2 to Volume 4 of the 2006 guidelines, which includes guidance for developing future methodologies for estimating diffusive, bubbling and degassing emissions. Methane emissions from reservoirs are covered in appendix 3 of the 2006 guidelines, which makes their inclusion in national GHG inventories voluntary, even when the 2006 guidelines are eventually approved for official reporting purposes. As one respondent put it, the IPCC is cognisant of the need to address reservoir emissions in its guidelines, but this is a task for the future when more data and information are available. The difficulties related to compiling inventories from wetland emissions were discussed at an IPCC expert meeting in Helsinki in May 2008, which concluded that while the 2006 guidelines are not comprehensive and do not cover all emissions, they are the best that can be achieved using the scientific information available at the time. The meeting decided to wait two to three years before moving forward on the issue, pending scientific clarification on reservoir emissions. (IPCC, 2008b)

Environmental groups have argued that the current exclusion of reservoir emissions from mandatory GHG inventory reporting can lead to incomplete inventories and underestimation of the climate impact of certain countries with large reservoir areas. Consequently, they have called for the IPCC to make all reservoir emissions mandatory in the next guidelines. They have also called upon countries with sufficient scientific capacity to develop national emission

[9] Flooded Lands are defined as "water bodies where human activities have caused changes in the amount of surface area covered by water, typically through water level regulation" (IPCC, 2006, p. 7.19). Reservoirs built for the production of hydroelectricity, irrigation, or navigation fall under this category.

factors for reservoir emissions to take lead and voluntarily include the emissions in their national inventories. (McCully et al., 2006)

So far, the only country to have taken the initiative of including any reservoir emissions in its national GHG inventory is Canada. In the 2009 Canadian National Inventory Report CO_2 emissions from the creation of reservoirs (flooding land) are included. Rather than adopting the default carbon stock change method provided by the IPCC, the approach taken by the inventory compilers involve the development of a national emissions methodology. The approach takes into account the slow decomposition of flooded biomass in the prevalent conditions in Canadian reservoirs. (Environment Canada, 2009) This pioneering effort to include reservoir emissions in national greenhouse gas inventories has potential to develop into a more comprehensive treatment of reservoir emissions as scientific research efforts both in Canada and internationally deliver more accurate results of emission levels. It can also serve as an example for other countries in the estimation of reservoir emissions and thus facilitate future reporting of reservoir emissions by other Parties to the UNFCCC.

Another pioneering effort in this area was recently advanced at the regional level by The Climate Registry, a non-profit collaboration among North American states, provinces, territories and National Sovereign Nations that provides standards for the calculation and reporting of GHG emissions into a single registry. The organisation adopted a protocol for calculating emissions from the Electric Power Sector (EPS) in June 2009, which will guide reporting by its members (some 240 corporations, government agencies and non-profit organisations in North America) from the beginning of 2011. A draft of the EPS Protocol required that fugitive emissions from hydroelectric reservoirs be reported using two methodologies based on the IPCC 2006 guidelines. During the public consultation period, the issue of reservoir emissions received most attention of all aspects of the Protocol with 15 out of 47 organisations that provided comments specifically focusing on the issue. These comments were nearly unanimous about postponing the proposed reporting requirements. Reasons given ranged from high variability of emissions from reservoirs in both space and time, scientific uncertainty regarding influencing parameters to a lack of representative data from North American reservoirs. The comments also pointed to the costly and time-consuming nature of conducting measurements and the dissimilarity of reservoir emissions from other emission categories normally included in corporate inventories. It was stressed that separating out anthropogenic emissions is a complex process, which is better suited to analysis at watershed or regional level and over multiple year time scales – neither of which is consistent with corporate reporting that normally takes place annually. (The Climate Registry, 2009a) Following the consideration of public comments to the draft, the Registry's board decided to make reporting of reservoir emissions optional in the final EPS Protocol, pending the outcome of international research efforts in the area. (The Climate Registry, 2009b) Meanwhile, The Climate Registry encourages its members to report these emissions whenever feasible and emphasises that the overall objective of the reporting is to be comprehensive and consequently emissions from hydroelectric reservoirs will be included when further clarification is provided by scientific research (S. Hitz, The Climate Registry, personal communication, 14 August 2009). Although opposition to include reservoir emissions in the EPS Protocol outweighed the proponents for the initiative at this early stage, the initiative taken by the organisation and its attempt to enter a new area of calculating and reporting GHG emissions from reservoirs is notable in itself. It illustrates the potential of national or regional efforts to advance the treatment of reservoir emissions, which is likely to support global efforts in the area. Given the ongoing research efforts in North America, regional efforts might also be able to move forward faster than global initiatives, which are dependent on the production of globally representative science and data.

5.1.2 Clean Development Mechanism (CDM)

The Kyoto Protocol (KP) to the UNFCCC sets binding emission reduction targets for Parties listed in Annex I of the Protocol, on average 5.5% reductions by 2012 against a 1990 baseline of emission levels. Countries are at liberty to pursue emission reductions through a combination of domestic measures and trading of carbon credits with other countries. The CDM is one of three market-based flexible mechanisms built into the KP, which countries can use to acquire credits to use towards meeting their national reduction targets.

CDM is a project-based mechanism that allows the generation of emission-reduction credits (Certified Emission Reductions, CERs) by projects in developing countries and their consequent selling to developed countries facing commitments under the KP (Annex-I countries). The main ideas behind the CDM are threefold: (i) to include non-Annex I countries in the active work towards achieving the overall aims of the UNFCCC; (ii) to assist developing countries to achieve sustainable development; and (iii) to help Annex I countries to achieve their commitments. The main enabling principle of the CDM is that the marginal costs of reducing GHG emissions are significantly lower in developing than developed countries, and thus implementing emission-reduction projects in developing countries results in overall cost efficiency (Wara, 2008). The incentive for developed countries to take part in CDM projects is that they can acquire emission reduction credits that they can use to meet their Kyoto targets at a lower cost than they would with purely domestic measures. For developing countries, the main incentives are access to additional project financing by selling carbon credits and access to new forms of technology as technology transfer is often perceived a desired side-effect of CDM projects. Project activities commonly include renewable energy, energy efficiency, fuel switch and reduction of GHGs such as methane (CH_4) and hydrofluorocarbons (HFCs).

Article 12(5) of the KP defines three conditions that must be met by project activities to be accepted under CDM rules. Firstly, all emissions reductions must have the voluntary consent of all involved parties. Secondly, they must be associated with verifiable long-term benefits that contribute to mitigating climate change. Lastly, they must comply with the condition of additionality, i.e. emission reductions must be additional to any that would have happened in the absence of a CDM activity. Additionality can be considered either as 'financial additionality' which entails that the project is financially less feasible than realistic alternatives, thus implying that the project could not go ahead unless accepted under the CDM, or 'environmental additionality' which means that the project brings about additional emission reductions in comparison to the baseline 'business-as-usual' scenario. An overarching requirement of the CDM is that project activities must help host countries to achieve sustainable development and contribute to the overall objective of the UNFCCC of reducing GHG concentrations in the atmosphere.

Hydropower is currently the largest project category under the CDM with over 25% share of all registered projects as of 1 June 2009 (IGES, 2009). In the CDM pipeline, 1242 hydro projects occupy top position with 27% share of all projects applying for CDM credits. The vast majority of projects are located in China, followed by India and Brazil who together host four out of every five hydro projects in the CDM pipeline. (UNEP Risoe Centre, 2009, August 1)

Renewable energy projects can be classified as large or small-scale under the CDM. A hydro project is classified as small-scale if the maximum output capacity is below 15MW, otherwise is falls into the large-scale category.[10] In February 2006, the CDM Executive Board (EB) ruled that hydropower projects in the large-scale category must satisfy certain power density conditions in order to be eligible as CDM project activities. Table 5-1 below summarises the power density thresholds put forward as a precautionary measure whilst clarification on the magnitude of reservoir emissions is pending:

Table 5-1 Restrictions on hydropower projects under the CDM

Power density of hydroelectric reservoir (installed generation capacity divided by flooded surface area), W/m²	**Eligibility to use approved methodologies under CDM rules**
<4	excluded from using currently approved methodologies (ACM0002, AM0019 and AM0026)
4-10	allowed to use approved methodologies but project emissions must be included at 90 gCO2-eq/kWh
>10	allowed to use approved methodologies and project emissions can be neglected

Source: (UNFCCC, 2006b)

While there was no awareness among the interviewed experts of specific hydropower projects that would have been rejected by the CDM EB on basis of the power density restrictions, one informant pointed out an observed shift towards run-of-river projects among hydro projects in the CDM pipeline after the power density thresholds were put in place. One industry representative stressed that the imposed thresholds effectively exclude hydropower projects with generation capacity above 20MW from the CDM. Some industry actors feel that the thresholds are quite high and above international power density averages for hydro projects linked to storage reservoirs. Environmental groups, however, push for even stronger precautionary measures and have proposed that all projects with power density below 10W/m² should be excluded from the framework under its current rules (McCully et al., 2006).

The CDM EB notes that its decision does not prevent the submission of revisions to existing methodologies, especially in relation to project activities related to reservoirs that have no significant biomass in their catchment area nor does it prevent the submission of new methodologies for consideration in the CDM Meth Panel (UNFCCC, 2006a). However, as one respondent noted, it is likely to take between two and three years to revise or approve a new methodology from the date it is submitted to consideration by the CDM administration and its validation processes. Thus, it seems unlikely that new methodologies for large hydro projects with reservoir storage would be approved by the CDM EB before the end of the first commitment period in 2012.

Another respondent who works in an advisory role in relation to CDM hydro projects noted that there is significant confusion among Designated National Authorities (DNAs) in Europe regarding the use of the power density parameter as a basis for eligibility of large hydro under CDM. The method itself is relatively straightforward in being based on a simple calculation of

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[10] The effective difference between the two categories is that small-scale projects benefit from simpler application modalities which may have e.g. lower transaction costs. There are two additional conditions under which projects can be classified as small-scale but these are not relevant for hydro projects. See Decision 1/CMP.2, Paragraph 28 at http://unfccc.int/resource/docs/2006/cmp2/eng/10a01.pdf#page=3.

installed generation capacity divided by surface area flooded by the reservoir so it is unlikely to be the source of confusion. The mere adoption of the decision raised further questions of the environmental sustainability of large hydro projects, which in Europe has been under scrutiny for a number of years. In some countries like Sweden, the level of concern has reached a stage where companies are reluctant to purchase large hydro credits towards meeting their emission reduction commitments (L. Hansson, personal communication, February 2009).

In 2004, the European Union (EU) introduced Directive 2004/101/EC, which links the CDM with the European Union Emissions Trading Scheme (EU-ETS). Article 11b(6) of this so-called Linking Directive places an additional criterion for carbon credits from large hydro projects within the EU-ETS. CDM hydro projects with generating capacity exceeding 20MW must demonstrate compliance with relevant international criteria and guidelines for considering whether hydro projects have negative environmental or social consequences. The Directive offers the WCD report 'Dams and Development' published in 2000 as the primary source for these criteria and guidelines. The WCD report includes 26 criteria for assessing the sustainability of large hydro projects, but does not go into detail how these criteria should be implemented or assessed at a practical level. Ongoing difficulties with assessing the compliance of hydro projects with the WCD guidelines might benefit from a German initiative to harmonise the assessment procedure within Europe. The initiative produced common guidelines for the assessment of project compliance with the seven priority areas WCD (German Emissions Trading Authority, 2009).[11] The guidelines and the associated report template were adopted by Member States in the first quarter of 2009, and consequently practical experiences of their use are currently limited. A second initiative with potential to assist in the assessment of WCD compliance is a Hydropower Sustainability Assessment Protocol (HSAP) developed under the auspices of IHA. The HSAP is currently undergoing review in a multi-stakeholder process and possible adoption of its revised version as an administrative tool is being discussed by IHA and relevant EU bodies linked to CDM activities (IHA representative, personal communication, 6 August 2009).

5.2 Opportunities and further pathways for policy intervention

"It's a bit of a chicken and egg type of thing"

(expert on water and energy policy)

The relationship between environmental science and policy is seldom linear or straightforward. Environmental problems are widely recognised as having some features that make them particularly difficult to solve and address through policy interventions. Mickwitz (2003) offers an overview of such characteristics. Cause-effect relationships may be difficult to establish due to the complex and interdependent nature of ecological systems. The problem may connect geographically remote areas or there might be a significant time delay that complicates the evaluation process. The environmental problem itself might defined by a detrimental future impact that we are trying to prevent. The science is often young and continually evolving, and yet plays a prominent role in policy discussions. Policy-making in the field of climate change is one area where all these complications and uncertainties are relevant.

[11] The seven priority areas are Gaining Public Acceptance, Comprehensive Options Assessment, Addressing Existing Dams, Sustaining Rivers and Livelihoods, Recognising Entitlements and Sharing Benefits, Ensuring Compliance and Sharing Rivers for Peace, Development and Security. The priority areas are specified in 26 guidelines. (WCD, 2000)

In the case of reservoir emissions, the science is particularly emerging and comprehensive data sets are not currently available. As one respondent put it, the current relationship between science and policy in the area of reservoir emissions can be described idiomatically as a "chicken and egg" problem. On the one hand, policy-making is constrained by the availability of scientific information that is translated into usable form, but on the other hand it is difficult to know if the science is far enough to allow this.

One of the central tenets of the UNFCCC is that if climate policy is to stabilise GHG emissions, all sources of emissions must be accounted for. The issue of reservoir emissions does not exist in an isolated vacuum but is instead part of this broader context on emissions and climate change. Consequently, it is not prudent to sideline the issue until perfect scientific information may be available to inform policy. Moreover, climate policy-making will always include an element of uncertainty due to its fundamental nature of attempting to prevent negative future impacts on the climate system. The remainder of this chapter will explore possibilities for further ways in which reservoir emissions could be addressed through policy interventions.

5.2.1 Different stages of policy development

As described above, policy development is to an extent a function of available information on an issue. The first prerequisite is that an issue is recognised and there is some level of public awareness. As more knowledge is accumulated and the level of public awareness increases, policy interventions can be put in place based on sufficient knowledge on the issue and in response to increasing demands by a variety of actors. Ultimately, as the knowledge base develops further, more elaborate and targeted policy responses are possible.

Environmental policy principles provide commonly agreed and widely applicable guidelines for policy-making. Most principles have originated in international forums such as the 1972 UN Conference on the Human Environment (UNCHE) in Stockholm or the 1992 UN Conference on Environment and Development (UNCED) in Rio de Janeiro. Principles that are specific to certain areas of environmental policy (e.g. biodiversity or air pollution) are often sub-sets of a wider set of principles embodied by the concept of sustainable development. The Brundtland Report defines sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987). This concept of sustainability was institutionalised in 1992 in the Rio Declaration and Agenda 21 that resulted from the Rio Earth Summit. The principles provided in these documents have since been embedded in various international agreements on the environment, which has led to the mainstreaming of sustainable development principles in national legislations.

The main principles that guide climate policy are embodied in the UNFCCC and reflect the global nature of our concern for climate change. Among the principles are the principle of intergenerational equity, the principle of common but differentiated responsibilities, and the precautionary principle. The latter is of particular relevance for the issue on reservoir emissions. According to the precautionary principle, the lack of scientific certainty shall not be used as a reason for postponing action where there are threats of serious or irreversible damage to the environment (Principle 15 of the Rio Declaration). Application of the precautionary principle thus warrants policy intervention in the face of scientific uncertainty that currently reflects the limited knowledge on reservoir emissions.

Another well-known environmental policy principle is the polluter pays principle. Principle 16 of the Rio Declaration promotes internalisation of negative environmental externalities and the use of economic instruments with the notion that the polluter should bear the cost of pollution. The polluter pays principle has been implemented in areas such air pollution and transport through emission and fuel taxes. Application of the polluter pays principle entails the use of specific economic instruments, which requires a significant level of knowledge in design and implementation. For the current case of reservoir emissions, this represents a future state in terms of the complexity of policy development.

By combining different levels of information and the precautionary and polluter pays principles, a continuum of policy development was constructed for this study to conceptualise the existing and future policy space for reservoir emissions.[12] Stage I has severely limited or no knowledge and there is a consequent lack of policies. This stage can be described as a "tragedy of the commons" world. Stage II has some but limited knowledge which allows for the application of the precautionary principle. Stage III is most advanced in terms of both knowledge and policy development and the polluter pays principles is applied. Figure 5-1 illustrates the three stages in the form of a continuum of policy development, as it is not possible to draw strict lines between the different stages.

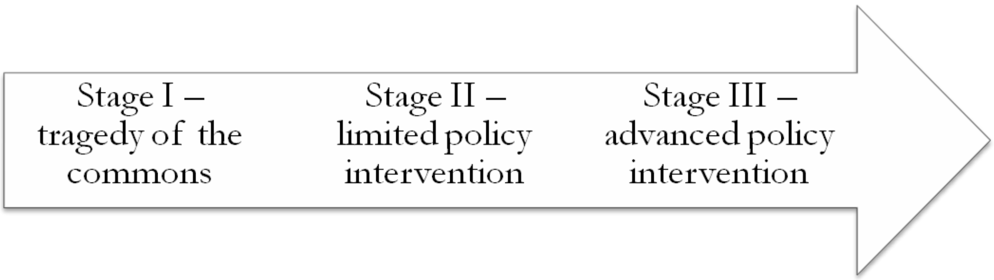

Figure 5-1 Continuum of policy development

The next sections place the three areas that were identified as having possibilities for enhanced policy intervention on this continuum and discuss possibilities for moving these areas further along the continuum. Assessment procedures are discussed first due to their least developed status in relation to reservoir emissions, which is followed by national GHG inventories. Finally, the CDM framework, which is currently the most advanced area in terms of policy consideration of reservoir emissions, is discussed.

5.2.2 Assessment procedures

Dams are subject to a variety of assessment procedures in different stages of their life cycle. These include the commissioning and decommissioning of dams, as well as other assessments during their operational period. Different assessment procedures are employed to evaluate risks and performance of dams, which commonly include both environmental and financial aspects. In addition to such regulatory demands for assessment procedures, various economic feasibility assessments are carried out before construction and during operation. This study found that reservoir emissions are not explicitly included in any current processes that assess the environmental performance or impacts of dams and reservoirs. This area can thus be placed in Stage I of the policy development continuum in terms of its current status.

Strategic Environmental Assessment (SEA) is an environmental assessment procedure applied to policies, plans and programmes at a strategic level, before any decisions of specific adoption are made. They are comprehensively used in the EU where the use of SEA is

[12] Idea for the continuum arose initially from discussions with one of the author's supervisors and was further developed by the author.

regulated by Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment. Other countries where the use of SEA is a regulatory demand include the United States and New Zealand. In international environmental law, SEA is covered by the 2003 Kiev Protocol to the 1991 UNECE[13] Convention on transboundary Environmental Impact Assessment (EIA). The Protocol is currently not in force due to an insufficient number of ratifications by UNECE member states, but once it enters into force it will be open to all UN member states. The use of SEA is spreading through the work of organisations such as the World Bank which has integrated SEA into its operations as well as the Organization for Economic Cooperation and Development (OECD), which promotes the use of SEA in development cooperation. Climate impacts are one of the focus areas in an SEA. The issue of GHG emissions from reservoirs could be integrated into this assessment process even with the currently limited knowledge on the topic as the nature of SEA does not require detailed calculations.

Another pre-development assessment process is Environmental Impact Assessment (EIA), which is performed for individual projects prior to decision-making. EIAs tend to be wider in their scope than SEAs, including not only environmental but also social and economic aspects. Principle 17 of the Rio Declaration includes a commitment to use EIA as a national instrument to assess proposed activities that may have adverse impacts on the environment. Consequently, the use of EIAs is relatively widespread, with EIA legislation in force across Europe, North America and Australia as well as many countries in the Asia-Pacific region. This includes 55 developing countries with EIA provisions in framework environmental legislation, of which 22 have specific regulations for EIA procedures (Mathur, 2006). Despite the generally comprehensive nature of EIAs to consider all possible impacts a development project might have on the environment, the assessment of GHG emissions from a reservoir project is not standard EIA practice anywhere in the world. In Australia, a supplementary study to the Traveston dam EIA sought to include reservoir emissions, however the resulting environmental impact statement (EIS) concluded that it was not feasible to assess emissions from the planned reservoir due to the limited availability of scientific publications on the topic (Queensland Water Infrastructure, 2008). One informant noted that the US might be in a process of introducing reservoir emissions into EIA procedures, however it is unclear whether this would be at the federal or state level and it was emphasised that this information is speculative.

The EIA process generally consists of several steps which are cyclically connected. The main steps include:

1. *Screening* to determine whether an EIA is required for a project;
2. *Scoping* to determine key issues and concerns for the coming assessment process, determine an environmental baseline and consider suitable alternatives;
3. *Impact analysis and mitigation* to predict potential impacts, determine their relative significance and evaluate options to avoid and reduce significant environmental impacts;
4. *Production and review of an EIS* which presents the collected information and submits it for public review and consideration by the relevant authority;
5. *Decision-making* where the results of the EIS along with comments from the public consultation are considered by the authorities in a process to reach a decision of the proposed development activity; and
6. *Post-decision monitoring and audit* which compare actual impacts to those predicted in the EIS, evaluate the effectiveness of mitigation measures and provide general feedback

[13] United Nations Economic Commission for Europe

on the quality of the EIA process that can be used to improve future assessments. (EVALSED, 2007)

Within this process there are several possible entry points for introducing the consideration of reservoir emissions. In many jurisdictions, most large dam projects are automatically subjected to EIA procedures due to their scale and importance at regional and national levels. For example within the EU, the EIA Directive includes dams with storage capacity exceeding 10 million m^3 in the class of projects that always require an EIA (Directive 97/11/EC). Smaller dam projects can also be of risk of significant GHG emissions. Screening should thus be the first stage at which reservoir emissions are included in EIA procedures as proposed dam projects can be at risk of having significant GHG emissions. At this early stage in the EIA process, the required level of information is not particularly specific and current knowledge might already be sufficient for such an evaluation. One of the deliverables of the ongoing UNESCO-IHA research project is a screening tool for the preliminary assessment of the vulnerability of a hydropower project to gross GHG emissions. Given the equal vulnerability of all-purpose reservoirs to significant GHG emissions, such a tool could have wider application in the assessment of all types of water storage projects. A similar tool could also be utilised in the scoping phase of an EIA. Reservoirs at risk of high GHG emissions should have the issue thoroughly assessed in an EIA, which requires that the issue is identified as a priority area in the scoping phase. Further on the issue should be given due attention in the impact analysis and mitigation phase. Existing knowledge places limitations on the level of detail to which these impacts could be currently evaluated, but it is expected that ongoing research efforts will deliver outcomes that can assist in this task relatively soon.

Mitigation measures is an area that is largely missing from the current debate on reservoir emissions. They are, however, one of the key elements of an EIA that aims to ensure that development projects that are given the go ahead have minimal impacts on the environment. Current knowledge offers indications of the main factors that affect the emission profile of a reservoir, which could be used to prescribe mitigation measures. For example, it is known that tropical reservoirs are highly vulnerable to significant GHG emissions as they tend to develop anaerobic conditions and have ample supplies of biomass. Minimising the amount of initial biomass to be flooded, flowing in and growing in the reservoir itself are thus important measures which can be taken to reduce reservoir GHG emissions. Land management upstream in the catchment as well as the areas around the reservoir has an important role in reducing the level of nutrients and other organic material flowing into the reservoir. Dam operation in terms of water-level regulation can affect the amount of vegetation growing in the reservoir through affecting vegetation growth in drawdown areas. Finally, clearing the biomass in the reservoir area before flooding can significantly lower the amount of carbon that can contribute to reservoir emissions. However, any pre-impoundment logging measures must be supplemented with reasonable plans for biomass utilisation e.g. for energy purposes, otherwise a good intention of removing biomass in the hope of avoiding reservoir emissions might merely relocate the emissions. Reservoir topography is another identified determinant of reservoir emissions, which makes careful site selection an important mitigation option. Shallow reservoirs tend to be connected with large surface areas and generally give rise to higher emissions than deep reservoirs, which is a relatively straightforward consideration that can be applied even with today's limited scientific information. Anoxic areas in the water body give rise to significant methane generation by bacteria. Current knowledge indicates that this is affected by a number of factors including aforementioned nutrient loading which affects oxygen content in the water body, and can be controlled through mechanic oxygenation methods in the reservoir. Methane generated in anoxic sediments tends to form bubbles, which are sensitive to the level of pressure in the surrounding water column. When pressure drops as a result of water release through the dam, methane bubbles travel up the water column and release the gas to the atmosphere. Dam operation can thus affect the rate at which emissions are being released. Other mitigation options prescribed by current knowledge include regulating water residence time in reservoirs and offsetting emissions through sequestration measures. Although the option to offset reservoir emissions through sequestration such as planting forest is not in fact a measure to reduce reservoir emissions themselves but to influence the net balance of emissions, it has been proposed as a measure for tackling GHG emissions from the Traveston Crossing Dam in Queensland, Australia (Queensland Water Infrastructure, 2008). Although current information is unable to provide exhaustive guidance on mitigating reservoir emissions, adopting a precautionary approach calls for the utilisation of mitigation efforts wherever feasible.

SEA and EIA are used to inform decision-making at strategic and specific project levels, respectively. In addition to such environmental assessments, GHG emissions could be considered by financial assessments of dam projects. Tools such as Cost-Benefit Analysis (CBA) are used to evaluate the economic viability of projects, and have the ability to account for environmental externalities through assigning them a monetary value. Monetary value could be placed on reservoir GHG emissions already today, using prices found in global carbon markets which have recently ranged between $15-30 per ton of CO_2-eq. Such calculations would, however, require more detailed and accurate information about emission levels from reservoirs than what is currently available. In addition to better information which would make such calculations technically feasible, certain policy developments (e.g. related to emission allowances) might also be required to create appropriate incentives for project developers to include such costs in their deliberations. Quantitative considerations of reservoir GHG emissions CBA calculations are thus more of a future prospect than an actual step to be taken today. In terms of costs and benefits, there is a further development on the front of mitigation measures that could affect the financial performance of an existing dam. An additional mitigation option that provides an end-of-pipe solution to reservoir emissions is methane capture. Researchers in Brazil are currently developing technologies to harvest reservoir methane and use the recovered gas as biofuel. Researchers from the National Institute for Space Research in Sao Paulo have estimated that large dams in Brazil, China and India could emit somewhere in the order of 100 million tons of methane to the atmosphere annually, approximately two thirds of which could be recoverable for fuel production with current technical knowledge (Lima et al., 2008).[14] With current gas prices there are multiple different technologies that could be economically viable to use to tap into reservoir methane, and several equipment for methane-capture have patents pending (Ramos et al., 2009).

Further to commissioning and operational performance evaluation, assessments are required when dams are rehabilitated and decommissioned. Dam rehabilitation to change or add functions to a reservoir often includes assessment procedures where GHG emissions could be included. Decommissioning of dams involves environmental assessments for which GHG emissions are of particular importance. The role of sediments is one aspect of the reservoir GHG cycle that has not received much focus in the academic literature, although it is known that sediments can lock significant quantities of carbon and temporarily remove it from the carbon cycle until the dam is decommissioned and the sediments become exposed. One of the few studies on this aspect looked at six large hydroelectric reservoirs in the US and found notable emissions from decommissioning (Pacca, 2007).

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[14] The paper provides a figure of 104 ± 7.2 million tons for the three countries' combined annual methane emissions (Lima et al., 2008). However, in light of general uncertainties related to emission levels found in literature and a number of assumptions employed in the study, such a figure is unlikely to be highly accurate, but may be used to indicate a rough level of magnitude, which in turn signals importance.

For hydroelectric reservoirs, this points to a need to reassess how hydropower is covered in life cycle assessments (LCA) which are a common tool for comparing different energy options. So far, such assessments have considered emissions from building the dam (energy use and construction materials such as steel and cement) and in some cases emissions from decommissioning (Denholm & Kulcinski, 2004; Gagnon, Belanger, & Uchiyama, 2002; Pacca, 2007). Most research that has been published strictly on reservoir emissions has focused on measuring gross emissions from dam surfaces and in fewer cases also degassing emissions from dam operation. The "cradle-to-grave" approach of LCA warrants that all emissions including those from constructing a dam, reservoir emissions during operation and emissions resulting from decommissioning are included. It has been noted that most LCA studies to date have been incomplete and exclude one or more of these aspects (Pacca, 2007). There are thus no comprehensive studies that consider the full life cycle of a reservoir including emissions from construction and decommissioning along with net emissions from operation. Consequently, the full picture of reservoir emissions is currently not captured by such assessment processes.

Different stages in a reservoirs lifetime are thus linked to a variety of environmental and financial assessments, none of which currently have GHG emissions as an integral part of their procedures. Different levels of information can suffice for different assessments, and current knowledge already allows for certain assessments to be carried out with due consideration for reservoir GHG emissions. To improve the accuracy and comprehensiveness of existing assessment tools currently feasible measures should be incorporated as soon as possible. More quantitative measures should be recognised as future improvements to applicable instruments and as such, implemented when better information becomes available. The key issues that currently need to be solved from the perspective of assessment procedures relate to improved scientific knowledge and consequent issues of estimating emissions at project-level.

5.2.3 GHG inventories

As discussed in section 5.1.1 above, reservoir emissions are currently not part of mandatory reporting of national GHG inventories. Some developments are in sight but not yet enforced, which currently places the area of GHG inventories between stages I and II on the policy development continuum. Latest IPCC guidelines provide limited guidance on measuring reservoir emissions, but the 2006 guidelines have not yet been approved by the UNFCCC for official reporting purposes. Their current adoption is thus voluntary and fully at the discretion of Parties to the convention. The new guidelines provide general guidance based on a carbon stock change method, which accounts for only some aspects of reservoir emissions. Technical limitations are primarily caused by limited scientific knowledge on the issue and a lack of consensus on universally applicable methodologies for quantifying reservoir emissions. Although research efforts are ongoing to address the scientific uncertainties, any future development of the guidelines is likely to take years. Figure 5-2 below presents an illustration of how IPCC methodological guidelines are developed and estimates of minimum timescales of the different steps. The figure was constructed based on reviews of IPCC documentation and confirmed by informants, one of which noted that the next IPCC review of methodological guidance is likely to take place in 2013-2015.

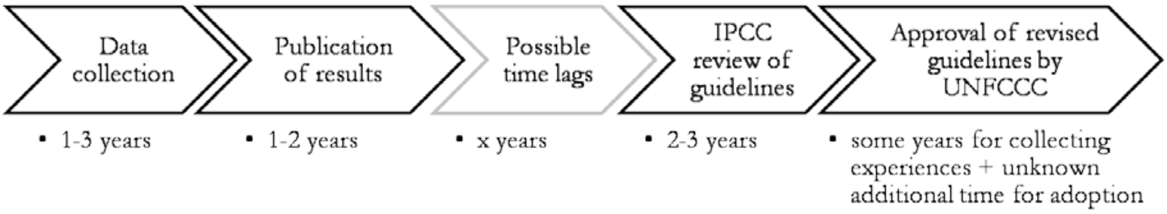

Figure 5-2 Possible future development of IPCC's methodological guidance on reservoir emissions.

In the area of national GHG inventories, technical issues are only one aspect that influences policy development. Inventories are at the heart of international climate policy frameworks, which are primarily driven by political issues. In this respect, reservoir emissions are part of a broader context, the dynamics of which are important determinants of any future treatment of reservoir emissions in the area of emissions reporting.

Emissions from reservoirs are considered under the area of wetland emissions, which is one of many reporting categories in the current LULUCF sector.[15] There was a consensus among respondents that while there are pockets of interest in reservoir emissions, wetlands are not on the agenda in any meaningful way. Furthermore, the limited discussions on wetlands are primarily driven by the issue of peatlands, which are a significant source of GHG emissions especially in tropical areas. Future treatment of reservoir emissions will thus depend on the role defined for LULUCF in ongoing negotiations.

The issue of LULUCF itself is one of many issues being debated in international climate negotiations. The current ambition is to arrive at a new agreement in COP-15 in Copenhagen in December 2009 that would follow the Kyoto Protocol, which provides the first set of targets to achieve the overall goals of the UNFCCC in the period 2008-2012. In addition to the future role to be assigned for LULUCF, there are three other major issues that drive current climate negotiations: (i) emission reduction levels to be assigned to Annex I Parties in the second commitment period post-2012; (ii) whether non-Annex I parties should also have binding emission reduction targets; and (iii) future market-based mechanisms to facilitate efforts to reduce emissions, especially sectoral crediting mechanisms such as REDD[16] and NAMA[17] (senior expert on LULUCF, personal communication, 1 August 2009).

The role of LULUCF within the larger context of climate negotiations is focused on the extent to which the sector can be used by Parties to offset emissions from other sectors. At the aggregate level, the LULUCF sector is different from other sectors as it can be a source of emissions or function as an overall sink due to emission removals by the sector. The latter is often the case for countries with large forestry sectors such as Canada or Scandinavian countries. Current accounting rules under the Kyoto Protocol assign that emissions and removals from afforestation, deforestation and reforestation activities shall be used towards meeting commitments by Annex I parties (Article 3.3). Other activities such as forest management can be used by countries, but their decision to include or exclude these emissions is fixed for the first commitment period (Article 3.4). Overall, countries are likely to include

[15] The 2006 IPCC Guidelines combine Agriculture, Forestry and Other Land Use categories into one sector (AFOLU). Current practices are still based on a distinction between agriculture and LULUCF as are ongoing negotiations regarding post-2012 climate agreements.

[16] REDD = Reducing Emissions from Deforestation and Degradation

[17] NAMA = Nationally Appropriate Mitigation Actions

only those activities that contribute emission removals that benefit their overall national carbon budgets. One respondent noted that the sector has a role in ensuring flexibility of commitments under the Kyoto Protocol. The future of LULUCF in the next agreement is largely undecided but it possible that a similar role will be assigned to it.

In the context of national GHG inventories, one of the main methodological issues for estimating reservoir emissions is related to the use of managed land as a proxy for anthropogenic emissions and removals. The proxy was adopted in the 2006 IPCC guidelines due to the complexity of estimating emissions from land use activities. Managed land includes all lands that have been altered by human interventions and consequently all emissions and removals from such lands are treated as anthropogenic and as such are subject to estimation. In the specific case of reservoir emissions, this makes the separation of natural and human-induced emissions from reservoirs irrelevant as all emissions are assumed to be anthropogenic. Moreover, the issue of double-counting of emissions from upstream catchment areas has been raised in relation to the proxy. According to one respondent, the issue of separating direct and indirect human-induced emissions has been recognised at a general level in the negotiations and there are parties who hold strong positions on addressing the issue. At this stage, however, there is no consensus of how it might be resolved. Concerns on this issue have mainly focused on pointing out various sources of organic material which originate in upstream areas and as such should not be attributed to reservoirs. While the sources originate upstream from the reservoir, it is exactly the existence of a dam that traps this organic material in a reservoir. Without this man-made barrier in a river, the organic material would under natural conditions flow towards the sea and be deposited in delta areas and the seabed which are relatively stable and long-term carbon stocks. The issue is thus largely a question of where the limits on human intervention in the environment are drawn.

Some issues with the managed land proxy are related to larger negotiations on what aspects of LULUCF will be included in a future agreement. Some countries with significant emissions from land use and land use change are pushing for emissions from the LULUCF sector to be excluded, whilst some other parties are concerned about excluding the removals from the sector. The latter position would seem counter-intuitive to many at first encounter. The reasons for a country to promote the exclusion of removals can be linked to provisions found in Article 3.7 of the Kyoto Protocol. The paragraph details that for any country for which emissions from the LULUCF sector were net positive in the year 1990, these emissions can be included in the calculation of that country's emission allowance. To date, the provision has been applied to a handful of countries including Australia, the United Kingdom, Portugal and the Netherlands. Non-Annex I countries that have large emissions from the sector may want to have these emissions included in their baseline emission allowance. However, in certain cases the removals from the sector could be significant enough to make the net effect of the LULUCF sector negative in which case any emissions from the sector would not be included in the country's assigned amount. This logic could be driving countries such as Brazil or Indonesia, both of which have significant forest resources but currently no binding emission reduction targets. Any movement by such countries towards Annex I type commitments for emission reductions for the next commitment period is likely to be accompanied by such negotiation tactics.

Overall, scientific and technical issues seem to assume a subsidiary role in the area of national GHG inventories. Reservoir emissions occupy a small space in larger contexts, where other issues such as emissions and reductions from forestry activities occupy centre stage and developments are driven by primarily political motives of negotiating parties. Even if the scientific uncertainties surrounding reservoir emissions were resolved, the position of the issue in a bundle of complex issues related to emissions and removals from LULUCF activities is likely to block or at least significantly stall policy interventions addressing reservoir emissions. Intergovernmental climate negotiations are based on consensus-building, trade-offs, compromises and finding the lowest common denominator. If all the politics was removed from the picture, what would be left is a need to develop methodologies for national accounting of reservoir emissions. Such aggregate data could be produced using sufficient average emission data and national reservoir data, neither of which are comprehensively available. Development of both aspects of data and models to support their utilisation in national accounting are thus key priorities.

5.2.4 Clean Development Mechanism

Of the policy areas relevant for the issue of reservoir emissions, policy intervention to date has been most advanced in the CDM framework. As described in section 5.1.2 above, the CDM Executive Board placed power density thresholds on hydro CDM projects in 2006 as a precautionary measure, pending clarification of scientific uncertainties. This policy area can thus be placed in stage II on the policy development continuum.

The imposed restrictions are based on strong indications offered by current scientific knowledge that reservoirs can be significant sources of GHG emissions. In absence of a methodology that can be used to estimate emissions at project-level, projects judged to be at high risk based on a power density parameter were excluded altogether. As the mechanism's main purpose is to achieve emission reductions, it is necessary to ensure that project activities that generate carbon credits are in reality resulting in emission reductions if the framework is to be used successfully for the mitigation of climate change. For hydro projects, this requires that reservoir GHG emissions are assessed and taken into account. This calls for detailed information of processes at reservoir level as well as tools to measure them.

From the perspective of CDM, one of the key issues that require scientific clarification is how emissions from a reservoir change with time. It is known at a general level that young reservoirs have relatively higher emission levels due to decomposition of initially flooded biomass and these emissions normally level off after the first 5-10 years. The level at which this happens and the resulting longer term emissions depend on the continued supply of organic matter into a reservoir. Better knowledge of the dynamics of this process along with practical tools for modelling this change in emissions are required in order to allow for accurate prediction of emission reductions available from a CDM hydro project. Additionally, tools are required for the verification of actual emission reductions. The latter aspect is particularly important as the final number of credits awarded to a project depends on a verification of emission reductions that actually took place, which for a reservoir depends on continuous measurements and monitoring of emissions which could be costly. Improved knowledge on aspects such as site selection, reservoir design and mitigation measures are also of interest for the CDM, as these are key elements that influence the amount of reservoir emissions and thus have knock-on effects on the number of carbon credits a project could generate.

Assuming that such improved scientific information was available today, policy development within the CDM framework is constrained by aspects of the framework itself as well as wider issues surrounding the market mechanism. Within the CDM itself, the way forward from the current situation is through introducing a new methodology that hydro projects can use to estimate emissions or to amend one of the existing methodologies. Both processes are relatively complex and time-consuming. The introduction of new or revised methodologies happens through a new project that is used to demonstrate the applicability of a methodology. This requires identification of a suitable vehicle project, application of a new methodology in the project and sufficient data sets to support it. Once a project is submitted to the CDM process, it normally takes 2-3 years to complete the process after which a new methodology can be approved by the CDM Executive Board if it is assessed to be globally applicable. This effectively means that such developments are unlikely to happen during the current commitment period leading up to 2012. According to one respondent, the condition of global applicability makes the introduction of new methodologies into the CDM framework particularly challenging. Outcomes of the ongoing UNESCO-IHA research project are hoped to be useful in developing a new methodology for storage hydro projects within the CDM. This requires global involvement and input into research efforts, if the outcomes are to be representative enough and enjoy sufficient international support to be accepted by the CDM Executive Board. While the project seems set up to achieve this, continued support from all major hydro countries is required to guarantee the desired outcome. Some actors have raised concerns that as new research initiatives in the field are springing up both internationally and in individual countries, global consensus-building efforts might be undermined if efforts to collaborate between the different initiatives are not made.

In the broader context, overarching uncertainties surrounding the post-2012 period influence the CDM. One of the big issues that are currently debated is the future of market mechanisms in the second commitment period. One respondent suggested that the emphasis on sectoral crediting mechanisms might imply a smaller role for the CDM in the future or significant changes to the framework. This is a major factor that increases uncertainty for project parties. Another important influence is the future of the EU-ETS. The European carbon market is the largest trading system for carbon credits and as such any developments within it are likely to have wider implications to other carbon market frameworks. Future modifications to the EU-ETS have been laid out in a new directive that places strong emphasis on credits generated by project activities in Least Developed Countries (LDCs). This effectively excludes large countries such as Brazil, India and China that have seen significant growth rates in recent years. If there is no agreement on the next commitment period in Copenhagen or any time before 2012, CDM credits eligible for trading in the EU-ETS are restricted to those from the poorest countries. If an agreement is achieved, emphasis will still be placed on carbon credits from LDCs. (Directive 2009/29/EC) It is likely that such high uncertainties regarding the future of CDM in any post-2012 climate agreement and the future of carbon credits in trading schemes such as the EU-ETS have a negative influence on policy development within the CDM framework. Uncertainty of the benefits of developing new methodologies is likely discourage such activities among project parties and limit new projects to those that can get registered under current rules. This is a typical phenomenon in the face of future uncertainty, and it is already visible in the CDM pipeline where there has been a shift among hydro projects towards run-of-river projects which are generally unaffected by power density thresholds as they are connected to very small reservoirs if at all (GTZ policy advisor, personal communication, 31 July 2009).

Future development of the CDM framework as it concerns emissions from hydroelectric reservoirs is thus likely to be defined by a combination of political and scientific factors. Methodological development is time-consuming and thus unlikely to take place during the first commitment period. It is further hindered by large uncertainties regarding the future role of the mechanism, which reduces incentives for project developers to drive methodological development. Movement from the current status of applying the precautionary principle forward is thus unlikely to occur before the future fate of the CDM is determined by political processes in climate change negotiations and related movements in the European carbon market.

5.3 Overarching issues shaping policy development

> *"It's an uphill battle in many ways"*
>
> *(policy analyst, environmental organisation)*

The previous sections discussed three areas where regulatory frameworks could be modified to incorporate the issue of reservoir emissions, and specific issues that are likely to shape policy development in these areas. This section will consolidate these inductive findings and discuss general issues affecting the policy space surrounding the issue of reservoir emissions. The analytical framework presented in section 2.2 served as a basis for the analysis and is used to structure the following discussion.

5.3.1 Uncertainties and inevitabilities

Two main groups of uncertainties emerged from the findings: scientific and political. **Uncertainties in science** exist at the level of individual aspects of the problem as well as at a more general level. Specific uncertainties relate to areas such as the relative importance of contributing factors and processes related to the generation and release of greenhouse gases from reservoirs, degrees of uncertainty associated with different measurement methodologies as well as spatial and temporal variations in emission levels. The latter is an issue both at reservoir level as well as more generically. For example, existing research indicates that the issue is a relatively small problem for boreal regions but of high relevance for tropical reservoirs. However, one informant noted that ongoing research in a boreal reservoir is showing preliminary results that indicate methane emission levels on the same order of magnitude as currently known averages for tropical reservoirs and an order of magnitude higher than known averages for temperate reservoirs. As comprehensive data sets covering all types of reservoirs in different climate zones are not yet available, the full extent to which the issue could be relevant remains to be discovered. Other generic uncertainties in the science dimension include the eventual size and importance of reservoir emissions, which is dependent on improved methods to quantify reservoir emissions. During the study it was found that a lack of knowledge of the likely scale of the issue and the size of reservoir emissions relative to other emission sources was one of the primary reasons that impedes the issue from entering the agenda in the area of climate change policy. As the science unfolds, the widespread uncertainty surrounding the relative importance of the issue is likely to be cleared. However, there are significant uncertainties regarding when this might happen. Ongoing research efforts are expected to fill many of the existing knowledge gaps in the relatively near future, but many of these research projects have only recently begun or will commence in the next 6-12 months and spread over the coming years. It is quite conceivable that research efforts will be prolonged as currently ongoing and planned projects might not be able to answer all the required questions. During the study it was indicated that in addition to answering some of the currently pressing questions, such research efforts are likely to expose further areas and aspects of the problem that require additional research. One of the larger scientific uncertainties is thus linked to the question when scientific knowledge will become sufficient to enable the policy-makers to act on the science. Due to the inherently uncertain nature of climate science, exact science is unlikely to ever be available for policy-makers. The critical level in terms of the quantity and coverage of scientific research that would facilitate policy uptake of the issue is one of the great unknowns in the area.

Uncertainties in the political dimension focus on ongoing climate negotiations and the future of regulatory frameworks in the climate area. This was demonstrated by the uncertain role of wetland emissions in future climate agreements, which is largely dependent on the role assigned to the LULUCF sector in the ongoing negotiations. Although these are implications that the sector will continue to play a similar role in the reporting of national GHG inventories, nothing can be said with certainty as the history of climate negotiations has shown that concessions are made and compromises can be found in unexpected areas during final stages of negotiations. Furthermore, the issue of reservoir emissions is positioned within a complex web of issues that are being debated. Other issues and influences quite removed from the issue of reservoir emissions may end up defining their treatment in future climate agreements. Likewise, political uncertainties were found to be major determinants of the policy development in within the CDM framework. While scientific uncertainties relating to measurement methodologies need to be resolved before methodological development can take place within the CDM structure, uncertainties regarding the future of the framework in the post-2012 period inhibit the resolution of such issues themselves. Prevailing uncertainty regarding the potential future benefits of developing new methodologies that could be submitted for review by the CDM administration is currently so high that many project developers are discouraged from investing in such efforts. Such structural uncertainties can create significant delays in policy development.

Inevitabilities were observed to significantly lesser extent. The science and policy areas related to reservoir emissions are dominated by uncertainties. Some examples emerged that could be interpreted as representing very strong indications of future developments, for instance the North American Climate Registry's desire to include emissions from hydroelectric reservoirs in their reporting protocols. They are nonetheless dependent on scientific developments that are characterised by significant uncertainties, and consequently cannot be taken as inevitabilities. There are, however, **some trends** that **cannot be avoided in the future**. Growing populations and increased urbanisation have created an ever-increasing demand for water, food and electricity that implies an increasing need to build more reservoirs to support the supply of these basic functions through water storage, water supply for irrigation and generation of hydroelectricity. Furthermore, pressures related to both climate change mitigation and adaptation will require that more reservoirs are built in the future. Whilst this implies that total emissions from reservoirs will increase in the future as more are built, it also offers opportunities to develop our understanding of the issue and reduce the negative climate impact reservoirs. New reservoir projects can be studied to improve the knowledge of reservoir net emissions as a result of pre- and post-impoundment measurements. Existing knowledge on mitigation measures can be applied to minimise or reduce the emissions. The sooner these techniques and management practices begin to be adopted the better are our chances to ensure that future dam development goes ahead with due considerations for the global climate.

5.3.2 Drivers and barriers to policy development

Few drivers

A prominent feature of environmental problems and policy is that scientific knowledge and discourse play a central role in policy development (Carter, 2007; Mickwitz, 2003). Science occupies a particularly important position in climate policy debates and is thus of central importance for the issue of reservoir emissions. The role of **science was highlighted** on a number of occasions during the research and it emerged **as the main driver for policy development**. The slow pace of policy uptake of the issue, however, indicates that this driver has not been particularly strong. This could be explained by the relatively small volume of independent research done in the area to date. It may also be related to the apparent phenomenon that industry-related research can be biased. Private interest may have fewer incentives to promote active policy development on an issue if it has potential to reduce their operational freedom. On the other hand, private actors may have an opposite interest if it provides them with an opportunity to affect the outcome of a policy process. The latter is, however, likely to happen when an issue has gathered sufficient momentum and policy development is progressing regardless of the efforts of industry actors. For reservoir emissions, such momentum is yet to be achieved in terms of public awareness and concern.

In addition to the scientific community, environmental advocacy groups might be expected to act as a driving force in policy development on the issue. Their role, however, has been limited to date. Although it was found that agents within large environmental groups such as WWF, Wetlands International and Conservation International are aware of the issue, it has not achieved a prominent place on their promotional agendas. The only environmental NGO actively promoting the issue and its inclusion in climate policy frameworks appears to be International Rivers, a relatively small group focused on the negative social and environmental impacts associated with dams. One informant noted that the issue is highly complex and requires specialist expertise that environmental groups may not have, which has discouraged some groups from engaging in it. Such **caution on the side of environmental groups** highlights the important position of science in the debate. Furthermore, it was suggested that promoting the issue could work against some environmental groups, especially those working on a wider range of freshwater issues as their main interest in relation to climate change is to promote issues such as wetlands restoration as an option for climate change mitigation. Observations in international meetings confirmed that this motivation is also relevant for some research organisations working with water issues, as they are primarily interested in promoting the role of water resources in climate change adaptation.

Despite the weakness of active policy drivers on the issue of reservoir emissions, policy development is driven forward to some extent as part of the **overall debate on climate policy**. The dynamics of climate policy negotiations are not and will not be defined by the issue of reservoir emissions, but any broader developments in climate policy frameworks are likely to shape the treatment of reservoir emissions. This will depend on the role assigned to the LULUCF sector in future climate agreements and more specifically the treatment of wetland emissions within the sector.

Multiple barriers

The above discussion on drivers touched upon some issues that might be better described as barriers. Carter (2007) describes agenda-setting as a critical stage in the policy process which is instrumental in achieving policy change. The apparent lack of incentives among various stakeholder groups to raise the profile of reservoir emissions in policy debates is holding back policy development. The small number of agents who have an interest to raise the issue on the agenda are likely to experience difficulty in doing so, as the issue is opposed to many mainstream policy agendas related to water reservoirs. This was confirmed during the study by informants, who noted that reservoir emissions are not on the climate policy agenda "in any meaningful way". The **lack of high-level recognition** and the issue's **position outside the negotiation agenda** are thus leading barriers to policy development.

Due to the prominence of science in policy development, the current **lack of scientific knowledge** on the issue emerges as another important barrier. As long as scientific knowledge is perceived to be incomplete or is associated with unacceptable levels of uncertainty, policy development is likely to hinge on the availability of comprehensive, good quality science. So far, lobby groups have been able to water down progressive initiatives in the climate policy arena to include reservoir emissions on grounds of insufficient scientific knowledge. It is difficult to determine when the science might reach a critical level of sufficiency that enables policy uptake. It is, however, clear that it will depend on two variables. One is quantity of science and the amount of knowledge accumulated through research activities. Increased quantity of science is likely to reduce levels of uncertainty associated with measuring methodologies and emission levels and thus improve its usability by policy-makers. The other is quality of science in terms of objectivity and transparency. Existing concerns over the **influence of vested interests** on research activities and related biases need to be cleared through the application of rigorous scientific methods and transparent reporting and sharing of findings. Instrumental to this process is a balance between public and private funding of research activities. One reason for the relative **lack of publicly funded research** in the area is the above-mentioned lack of high-level recognition of the issue. For example, one interviewed researcher noted that since the publication of the WCD report in 2000 where the issue was first raised at the international level, it took eight years to gain public funding for a research project on reservoir emissions. Instrumental to getting the grant was recognition of the issue by the IPCC in its latest assessment report in 2007. More independent research may thus emerge as a result of the topic's recognition by high-level organisations such as the IPCC. A much-awaited development in this respect is the upcoming SRREN in late 2010.

While public research activities may require high-level recognition to justify public spending on research on reservoir emissions, they also demand the **cooperation of private operators**. As indicated earlier in this discussion, reservoir operators and managers have themselves limited incentives to engage in such research activities that may cost them significant resources in time, money and reduced operational freedom. As one respondent put it, it will be difficult to gain the support of reservoir managers unless tangible benefits are available to them further down the line. Engaging actors at the local level in environmental protection activities the benefit of which accrues to a public good such as the climate is a universal challenge in the environmental field. One possible pathway to address this problem would be to develop a crediting system in which mitigation measures and efforts required from reservoir operators are recognised and compensated. However, the design and adoption of such instruments requires more detailed knowledge and tools than what existing scientific knowledge covers.

Additional barriers include **time required to change regulatory frameworks** and **fragmentation of the policy field** – these constitute structural barriers to policy development. Especially the latter contributes a significant barrier to policy development. During the study it was found that informants representing the policy community had limited knowledge of the range of areas that should be considered in the interests of comprehensive consideration of reservoir emissions. The relative isolation of different policy aspects may lead to inaction if the cumulative significance is not recognised among policy-makers. Furthermore, this challenge is likely to persist as once the immediate barriers to policy development are overcome, an additional layer of fragmentation needs to be dealt with in implementing future policies. This results from the multitude of sectors that benefit from reservoirs and the multitude of levels at which actors need to be engaged.

It was observed that many decisions to hold back policy initiatives in the area had referred to a generic lack of scientific knowledge. When asked to specify areas and types of knowledge that would be of interest from the policy-making perspective, many informants hesitated or expressed uncertainty of the exact nature of the missing knowledge. While this may simply indicate a lack of knowledge among the interviewed individuals, it may also be a sign of a wider **lack of understanding of the issue among policy-makers** that limits their ability to request or demand targeted knowledge from the science community. Scientists are in a default position to know details of the science best and understand knowledge gaps from the perspective of the science itself. However, their preferred focus areas for research activities risk not corresponding with the most pressing areas that need to be resolved from a policy-making perspective if sufficient dialogue is not established across the science-policy interface.

5.3.3 Key events that may influence policy development

Many of the scientific and political uncertainties form significant barriers to policy development. Progress can, however, be foreseen on both fronts in the form of advances in science and developments in climate policy frameworks. On the science front, the main expectations focus on research outcomes from the ongoing UNESCO-IHA research project, which aims to deliver substantial results in 2010-2011. More results from currently ongoing or soon-to-commence research activities are expected to follow shortly afterwards. These research outcomes are hoped to fill many of the scientific knowledge gaps surrounding the issue of reservoir emissions. Publication of the IPCC's SRREN is another anticipated development as is it may increase high-level recognition of the issue and consequently boost research activities further. Somewhat further down the line is the next IPCC review of methodologies for estimating national GHG inventories. According to one informant, this may take place between 2013 and 2015. International climate change negotiations have gathered momentum in recent months in lead-up to the COP-15 meeting in Copenhagen in December 2009 where the aim is to arrive at a new climate agreement to follow the Kyoto Protocol which covers emission reduction targets up to 2012. It remains to be seen whether the meeting will be able to reach agreement on the second commitment period. Key events in climate policy frameworks and expected scientific developments are illustrated in Figure 5-3 above and below the timeline, respectively.

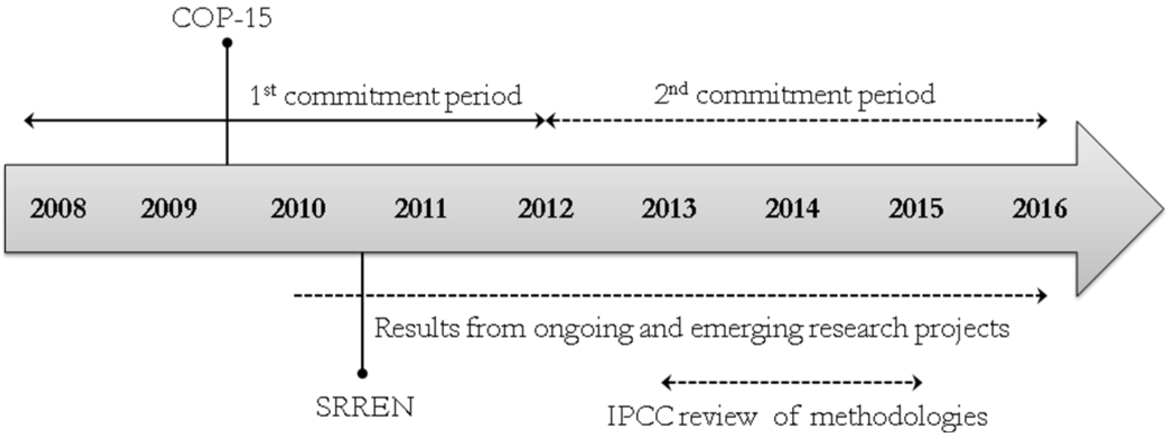

Figure 5-3 Timeline of key scientific and political developments

5.4 Summary of findings

This section summarises the analysis presented in this chapter. The section concludes with a schematic illustration of the policy development continuum in Figure 5-4. The figure combines the current status of the analysed policy areas and future pathways for improved policy development by outlining measures required to move policy development forward.

Drivers and barriers

Principal barriers to policy development in the area of reservoir emissions are four-fold. Lack of scientific knowledge inhibits initiatives to introduce policy measures to address emissions from reservoirs. Lack of high-level recognition and limited incentives among many actors to push the issue forward prevent the issue from entering the policy agenda in a meaningful way. This in turn reinforces the lack of scientific knowledge by restricting public research funding which could increase transparency and thus acceptance of research outcomes. Finally, an apparent lack of understanding among policy-makers of aspects of the scientific problem and vice versa among scientists of knowledge requirements in different policy areas constitute barriers to policy development through increasing confusion at the science-policy interface. In contrast to these multiple barriers, a limited number of driving forces were identified among scientific and NGO communities but these forces have so far been relatively weak. Dynamics of the wider debate on climate change and ongoing negotiations in the area of climate policy emerged as a related driver, as the position of reservoir emissions as part of a larger framework in these negotiations makes them subject to any developments that may emerge from ongoing negotiations.

Scientific, methodological and political issues

Uncertainties and gaps in existing scientific knowledge need to be addressed by significant research efforts. Research is required to improve existing data sets to cover all ecological zones, with special focus to temporal and spatial variations in emission levels. More research is required to better understand processes at reservoir and catchment level that contribute to reservoir emissions. Further efforts are required to establish standard measurement techniques, improve understanding of uncertainty levels associated with different methodologies and develop modelling tools to enable accurate estimation of GHG emissions both for individual reservoirs and at aggregate scales. All research should combine resources from both public and private sectors and be carried out in a transparent manner in order to ensure objectivity of research outcomes and consequently their wide acceptance.

Methodological issues have a bridging role in policy development in the area of reservoir emissions. Firstly, there is a need for improved methodologies for measuring and estimating reservoir emissions that need to be delivered by the research community. Secondly, these methodologies need to be brought into the policy arena to improve existing policy frameworks and be integrated into previously inactive policy areas, which is dependent on structural configurations of such frameworks.

Various external factors influence the science-policy interface. These include vested interests both in terms of industry domination in research activities and national interests in international climate policy negotiations. The general dynamics of climate change negotiations are a major determinant of 'if and how' the issue of reservoir emissions will enter the negotiation agenda, which is a prerequisite for policy development. A significant part of this dynamic is the emerging emphasis on the role of water resources and reservoirs in climate change adaptation. Combined with a lack of awareness among policy-makers and practitioners alike of the issue of reservoir emissions, this driver may be strong enough to constitute the principal barrier to policy development.

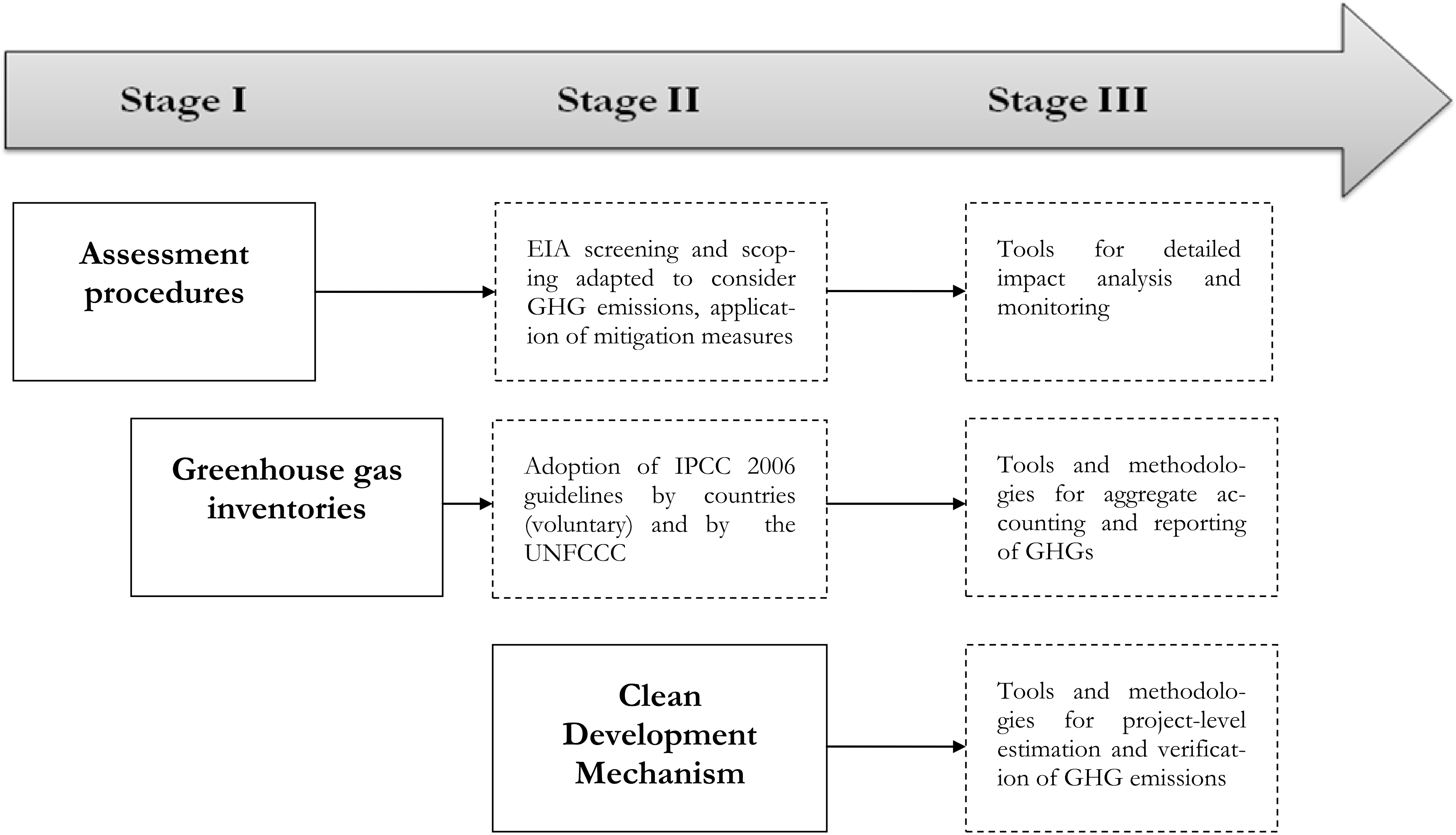

Figure 5-4 Current positioning of assessment procedures, greenhouse gas inventories and the CDM framework on the policy development continuum. Dashed boxes represent some ideas for possible pathways to future development.

6 Discussion

> *"It opens a can of worms to all sorts of things"*
>
> *(industry representative)*

Various aspects of the science-policy interface were explored with the aim of identifying issues that affect policy development in the case of reservoir emissions. The main findings indicate that policy development is dependent on scientific research efforts to clarify uncertainties in the existing knowledge base, dynamics of policy processes primarily at the international level, and interactions between the research and policy communities. This chapter aims to discuss wider implications of these findings for different stakeholders and processes. Due to the instrumental position of scientific research in the middle of the policy dilemma, the discussion begins with research implications.

6.1 Implications for the scientific research on reservoir emissions

This analysis found that whilst existing scientific knowledge offers strong indications of the types of emissions related to water reservoirs and areas where they are likely to present a significant problem. However, it also found that policy uptake of the issue at large hinges upon clear recognition and urgency in a number of areas where current research is considered insufficient, and where levels of uncertainty are perceived as too high for action to be taken. It is thus imperative that these knowledge gaps be addressed through scientific research efforts. Parallel to the research activities, dialogue between research and policy communities is needed to make sure that research efforts are targeted to the most pressing areas and that the information needs of the policy community are sufficiently communicated to the researchers.

Credibility and acceptance of research outcomes by policy-makers and the public alike demand that high quality research is carried out in a transparent way. This implies not only objectivity among the scientists working on the issue but also a wider inclusion of stakeholders and a balance between different sources of funding in research activities. As research activities to date have been steered primarily by industry actors, it is vital that the existing gap in public research funding is addressed. The findings of this research point to two factors that may complicate this process. Firstly, public research funding is often dependent on recognition and importance placed on an issue by high-level actors. In the case of reservoir emissions, the IPCC holds such a central role and its recognition of the issue has in some cases proved instrumental in granting government funding for research in the area. So far, such projects have been limited to a few isolated cases and a critical mass is yet to be reached. Secondly, reservoirs are often private property, which might create additional challenges in jurisdictions where publicly funded research to investigate the extent of an environmental problem linked to private operations might not be standard practice. Even if public funding is granted, cooperation from private operators is required for field research activities to be carried out. As reservoir emissions are potentially important to all types of storage reservoirs, information needs to be disseminated beyond hydropower operators to include a wider range of stakeholders connected to reservoirs from farmers to urban and rural water suppliers.

An overall challenge for the research community is to reduce levels of uncertainty associated with different measurement techniques and increase levels of accuracy with which the emission levels can be measured and upscaled. Planning of policy interventions as well as new management and operational strategies to address the emissions would ideally be based on accurate information, reliable predictions and low degrees of uncertainty. In the case of reservoir emissions, although emerging, the science may never provide high levels of precision. Due to the multitude of dynamic processes that affect GHG generation in and release from reservoirs, some levels of uncertainty will remain as measurements can never be perfectly replicable. It is, however, crucial that these uncertainty levels are better understood so that they may be taken into account and built into management strategies and policy responses alike.

6.2 Implications for policy-making

6.2.1 Reflections on policy principles

While the multitude of involved actors creates a first challenge at the practical level of carrying out research to improve current understanding of reservoir emissions, it creates additional challenges to correctly identify actors responsible for reservoir emissions which is necessary for the application of **the polluter pays principle**. The hydropower industry has been keen to point out that not all reservoir emissions can be attributed to hydroelectric generation. Although their argumentation has largely focused on upstream activities that increase the carbon loading of a reservoir and thus contribute to observed emissions from reservoirs, another argument that has not been advanced explicitly to date is that an equitable manner in which reservoir emissions are allocated among the different beneficiaries is required. Solutions to this question are likely to be found in the realm of devising appropriate market based instruments (environmental economics) rather than the hydrological or climate sciences. One possibility offered by an informant is to allocate emissions to different activities based on the percentage of water they use from a reservoir. An immediate complication of this arithmetic is that water use is easily double-counted – for instance the amount of water "used" by fisheries is likely to be also used by farmers for irrigation or released by the operation of hydropower turbines in a dam. Furthermore, some beneficiaries of a reservoir may not use the water as such at all. For example, reservoirs that are built for flood control operate to store the water rather than use it. Such purposes are also non-private by nature as they provide an explicitly public utility. Another approach is thus required to address these complications of how to define water use or how to accommodate the multiple beneficiaries of water reservoirs that can be of both public and private nature. A solution that might help is to account for the economic benefits gained by different users of a reservoir and use their shares of the total economic benefits created by a reservoir to allocate proportional responsibility for emissions. Some benefits such as income from selling fish, crops or electricity are easily calculated, but others are much less tangible. Even these can, however, be addressed using a number of tools developed by economists to facilitate the valuation of non-tangible benefits such as avoided damages to infrastructure due to prevented floods. There are further considerations, such as the fact that some emissions are caused by a specific activity (such as degassing emissions from the operation of hydroelectric turbines). Overall, all these aspects imply that the issue of assigning responsibility for reservoir emissions is a highly complex task. Solving it will require information among all actors connected to reservoir operations, bringing these stakeholders together and having expertise available from multiple areas such as natural sciences and economics.

The principle of **common but differentiated responsibilities** is another central principle in international climate policy frameworks. The principle assigns that while all countries have a common responsibility to work towards the overall objectives of the UNFCCC, the burden is distributed among countries based on their historical contribution to the problem as well as their available technical and financial capacities. This is one of the fundamental principles upon which the Kyoto Protocol was drafted. Largest cuts are required from those countries that have historically contributed most GHG emissions, and consequently binding emission reduction targets were only set for industrialised countries. Large developing countries such as India and China have since been shown to emit comparable or even higher levels of emissions than many industrialised countries today and their emissions are growing more rapidly than in many developed countries. Future climate agreements might thus witness new interpretations of this principle. It has been shown that current scientific research indicates that the problem of reservoir emissions is most pressing for tropical areas where most developing countries are situated. The issue of reservoir emissions thus offers an interesting contrast to the conventional application of the principle of common but differentiated responsibilities, as for this particular aspect of GHG emissions the burden is likely to fall on developing countries where future dam construction will be focused.

The third principle touched upon in this paper is the **precautionary principle**. In Article 3(3) of the UNFCCC, the principle ascribes the adoption of precautionary measures to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects. A former Executive Director of the European Environment Agency (EEA) has described two challenges related to the principle from a policy-making perspective: how to acknowledge and respond to scientific uncertainty, but also how to address ignorance (EEA, 2002). Consequently, the precautionary principle can be applied in policy-making when enough is known of the problem at hand, and when policy-makers act wisely enough on early warning signs and in good time. The principle was included in climate policy agreements almost two decades ago, but its translation into action has stumbled on many occasions in face of economic and political forces that surpass environmental concerns. In the specific case of reservoir emissions, it is questionable to what extent current knowledge offers opportunities for action. The research has clearly indicated that in some areas measures have already been taken, and further opportunities exist and are likely to increase in some years as scientific knowledge of the issue increases. Much thus depends on political will and the policy community's ability to act on the issue.

6.2.2 Bridging scales and breaking silos

Policy-making and implementation occur at multiple levels from the international to the local. At these different levels, policies have different goals, use different instruments and affect different actors. A primary challenge for the issue of reservoir emissions is that climate policy is orchestrated at the international level, while the majority of practical action and implementation of mitigation efforts occur at reservoir and catchment levels. Engaging such local actors to global objectives is thus a challenging task. It is, however, a necessary task as managers of water resources at reservoir and catchment levels are likely to have the largest impact in any efforts to mitigate reservoir emissions. As confirmed in the study, local actors have limited incentives to engage in such activities unless they are compensated in some way for their efforts. Finding ways to bridge these different scales and set up crediting systems or other instruments to create incentives for different actors to engage in action on the issue will be instrumental in the course of future policy development and planning for action.

In addition to the vertical complexity of the policy arena, further challenges emerge from the multitude of activities and sectors benefiting from reservoirs that are regulated by separate policy areas. For a multi-purpose reservoir, multiple actors can be identified as being partially responsible for GHG emissions from a reservoir. The emissions as such are primarily a concern for climate policy, which usually trickles down to sectoral policies. Climate policy is currently connected to policies in areas of energy, agriculture and land use planning. The link between climate policy and the water sector is, however, currently missing. Furthermore, policies tend to be targeted at specific activities such as energy projects. In the case of policy interventions to target emissions from water reservoirs, wider implications on multiple sectors would follow due to high level of penetration that water has in different economic activities. Consequently, future considerations of the climate impact of water supply for various activities are likely to have implications for policy frameworks in the different sectors benefiting from reservoirs.

6.3 Implications for future dams

Dams and reservoirs are widely recognised as performing a range of tasks and bringing multiple benefits. Large dams can also be highly controversial as their development can have severe negative impacts on the environment and affected communities. The need for water, energy and food is pressing and growing in most corners of the world, which highlights the importance of water reservoirs from a developmental perspective and the continued need to build more dams in the future. This trend is further strengthened by the emerging focus on climate change adaptation and the related needs to secure water supply through increased storage capacity and increase the resilience of communities against extreme weather events such as floods and droughts. However, large dams will continue to be developed in the future, which leaves the questions regarding where and how this development will take place. Various initiatives aim to make sure that dam construction proceeds in the most sustainable way possible and this study indicates that the issue of reservoir emissions warrants to be incorporated into these safeguards. The increasing momentum on dam building in response to the pressures described above warrants that steps are taken to integrate the issue into relevant processes as soon as possible as interventions at an early stage have demonstrated advantages over end-of-pipe solutions to environmental problems.

Rather than constituting the placement of a moratorium on future dams, the issue of GHG emissions is likely to have primary implications on the building and management of reservoirs. Assessment procedures discussed in section 5.2.2 above provide multiple opportunities for acting on the existing knowledge on reservoir emissions by integrating sustainable design features and mitigation measures into future dam projects. SEA and EIA processes can be modified to integrate considerations of reservoir emissions, and assessment tools such as CBA and LCA can be adapted to include the issue. Due to the multitude of involved actors and administrative fragmentation in the policy field linked to reservoirs, the need for holistic assessments is vital in ensuring that reservoir emissions are considered in a comprehensive manner. Given the demonstrated challenges in integrating the issue into climate policy frameworks, assessment procedures can provide accessible opportunities to move the issue forward. For example, many of the mitigation measures already available could be introduced through different assessment processes, particularly EIA. Practical measures could also prove helpful in the process of increasing awareness of the issue among reservoir operators and other stakeholders groups. In the least, tangible measures that can be taken to manage the issue of reservoirs need to be included in the debate on reservoir emissions to facilitate a balanced and reasonable treatment of this issue.

6.4 Applications of this research

An exploratory approach was selected for this study in order to collect preliminary information and help define a previously unknown area of research. Sometimes the research went up alleys that turned out to be "dead ends", at other times numerous avenues for further inquiry presented themselves. The research needed to adapt to the emerging data and efforts to refocus were required in early stages of the research as the story begun to unfold.

While this type of approach has proved useful in achieving the aims of this research, it does place some restrictions on the use of the research outcomes. Limited time and available resources influenced heavily what aspects of the problem could be studied and the results reflect these restrictions. As such, the study has provided some ideas into why policy development for the issue of reservoir emissions is stalling, but this is only one snapshot view of possible interpretations of the reality. The main outcome of this exploratory study has been to identify a range of issues that influence the science-policy interface for reservoir emissions. It is considered that this can contribute to a better understanding of the complexities of policy-making in this area. It is hoped that these results can help the research and policy communities to better understand the dynamics of the ongoing debate and increase dialogue between the two communities. Such dialogue is vital if the issue is to be resolved in a rational way. Beyond simple suggestions of policy implications and opportunities for action to move the issue forward, the results cannot be taken to provide definite solutions to the policy problem in this particular area nor offer any generalisations of environmental policy-making at large.

7 Conclusions and recommendations

This final chapter presents main conclusions drawn from the analysis of the debate on reservoir GHG emissions, and the factors that influence policy development in this area. The chapter begins by revisiting the research questions that guided the study. Additionally, based on the analysis some general observations regarding the dynamics of the science-policy interface are presented. Finally, areas for further research are suggested.

7.1 Revisiting the research questions

Question 1: Why are policy-makers not yet acting upon the available scientific knowledge on reservoir GHG emissions?

Findings of this study indicate that the primary barrier to policy development is insufficient scientific knowledge regarding the measurement and upscaling of GHG emissions. An overview of the existing scientific knowledge and an analysis of the ongoing debate on reservoir emissions revealed that there are three significant knowledge gaps in the scientific understanding of reservoir emissions. The gaps relate to the quantification of reservoir emissions, the processes that contribute to their generation in and release from reservoirs, and the availability of tools and methodologies to estimate reservoir emissions as well as levels of uncertainty associated with such methods.

Another major barrier to policy uptake of the issue is limited incentives on part of many stakeholders to raise the issue on the national and international agenda. For instance, the issue stands opposed to the mainstream agendas promoted by industrial actors as well as many environmental groups engaged with freshwater issues. At the international level, national interests are a major political driver influencing if, how and when the issue enters the climate negotiation agenda. Many of the negotiating parties who have access to national data and research expertise on the topic also those for whom the stakes are the highest and thus they have strong interests to control the negotiations and how the issue of reservoir emissions features in them.

Limited awareness of the reservoir emission problem outside the small community of scientists working on the issue is a further contributing factor slowing policy uptake. Water practitioners indicated they had a low levels of awareness as did some of the interviewed experts. This limited awareness level implies that the public demand for policy intervention is minor if not non-existent, which then diminishes the pressure on policy-makers to act on the issue.

Furthermore, limited understanding of the issue within the policy community emerged as a reason for low policy uptake. Many initiatives to integrate reservoir emissions into existing climate policy frameworks had been either blocked or watered down on account of generic uncertainties and lack of scientific information on reservoir emissions. This lack of information prevents the policy community from requesting targeted information from researchers, which may lead to discord in the objectives of research activities and the information needs of policy-makers.

Finally, policy development is stalled by the structures of existing policy frameworks and the dynamics of the broader climate debate of which reservoir emissions form a small part. Uncertainties regarding international climate agreements in the post-2012 period extend to include the uncertain role of reservoir emissions as part of GHG emission accounting and reporting within the LULUCF sector. High levels of uncertainty regarding the future of the CDM framework also create disincentives for different actors to introduce methodological improvements within the regulatory framework. The rules and procedures of the existing frameworks require a number of years to introduce any changes – thus becoming a significant structural barrier to policy development.

Question 2: How might policy uptake of this issue be facilitated?

Just as insufficient scientific knowledge emerged as the main barrier to policy development, improving the existing knowledge base through research activities is suggested as the main pathway to facilitate future policy development. Research is required to improve the existing data sets so that they will be able to describe all ecological zones, with special attention on the temporal and spatial variations of emission levels. More research is required to better understand the processes, at reservoir and catchment levels, contributing to reservoir emissions. Further efforts are required to establish standard measurement techniques, improve understanding of uncertainty levels associated with different methodologies, and develop modelling tools to enable accurate estimates of GHG emissions both at the individual reservoir and at national levels. Currently many active research projects are aimed at clarify a number of these issues.

All research should combine resources from both public and private sectors and be carried out in a transparent way in order to ensure objectivity of the research outcomes and consequently their wide acceptance. This study found only a few of the ongoing research projects are publicly funded. The current dominance of industry-led research efforts needs to be balanced by more public research into reservoir emissions. An increase in public funding would both raise the cumulative knowledge on the issue through increased quantity of research and improve the balance of funding and thus the acceptability of overall research efforts. High-level recognition of the issue by actors such as the IPCC may improve the availability of public funding for reservoir emissions.

Increased dialogue between research and policy communities is required to improve information dissemination among policy-makers and understanding of the policy framework information requirements among researchers. Findings of this research highlight a generally limited awareness level within the policy community and, in particular, a lack of integrated knowledge and expertise of the different areas in which reservoir emissions are relevant for policy considerations. Such fragmentation of knowledge between different actors, and between and within stakeholder groups must be addressed if policy development is to be pushed forward so that the current piecemeal approach can be replaced with a more holistic approach.

National and regional initiatives may provide an avenue of increasing the policy uptake of reservoir emissions. Efforts at the international level take time to achieve due to the need for globally representative data sets as well as international consensus. Leading countries in research may have nationally representative data accessible before globally comprehensive results are available, which gives them the opportunity to act on the issue at national level. National efforts could also support subsequent international efforts through the availability of reference cases or examples of initiatives that could be either scaled-up, or offer lessons for international initiatives. National actors are also in prime position to act on currently available knowledge and integrate it into policy and assessment frameworks to the extent that the information currently allows.

7.2 General observations about the science-policy interface

Findings of this research suggest that scientific research has a seemingly dominant role in the science-policy interface for the issue of reservoirs. It is both an important (potential) driver for policy development and currently a significant barrier due uncertainties and gaps in scientific knowledge of the issue. Scientific research efforts are thus likely to shape the policy field significantly in the coming years, especially after results from currently ongoing efforts begin to unfold. Some of the important research efforts relate to standardising methodologies for measuring and estimating reservoir emissions. Once the methodological issues are resolved at the scientific level, they need to be integrated into policy frameworks, both existing frameworks as well as additional areas and processes where reservoir emissions are currently overlooked. Policy development is not, however, solely driven by science. The international nature of climate policy makes negotiations highly political. In some cases, national interest and other political drivers may overtake the role of science. Any future treatment of reservoir emissions by international climate policy frameworks will be influenced by political motives as well as scientific facts.

Beyond the immediate dynamics of the science-policy interface, the wider implications need to be considered in the face of strong drivers that push dam construction activities at an increasing pace. Demand for water, food and energy especially in developing countries along with the need for climate change adaptation compel dam development. It is necessary that the risk of exacerbating GHG emission levels through emissions from reservoirs is recognised and steps taken to avoid and minimise these emissions where possible. In order to achieve environmentally sustainable development of water resources in the future, a holistic view that includes all adverse impacts on the environment must be taken.

7.3 Suggestions for further research

Exploratory research approaches often deliver more questions for further research than is answered by the research itself. This study is no exception. Among the variety of questions that emerged during the study, the following areas are considered important for further research into the policy aspects of reservoir emissions:

- More detailed scientific investigations are required to better understand ways and opportunities to integrate reservoir emissions into policy frameworks. Given the significant uncertainties concerning future climate agreements, this type of research would be most beneficial once the future of climate agreements in the post-2012 period is known.

- A multilevel stakeholder engagement approach to scientific research could greatly improve the understanding of the actors (i) involved in the science-policy interface and (ii) who are likely to be affected by the issue and whose efforts will be required at the local level to mitigate and manage the issue. The latter suggests an analysis from an operational perspective, which could be combined with a study on the application of mitigation measures.

- More in-depth and comprehensive studies of the interactions across different policy areas and between different policy levels as they are linked by the issue of reservoir emissions.

- Study of tools and instruments provided by environmental economics such as appropriate market based instruments that could help address the complexities related to multi-purpose reservoirs and in particular ways to calculate the costs of reservoir emissions and allocate these costs in a fair way between different beneficiaries of reservoirs.

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Abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
CBA	Cost-Benefit Analysis
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CH_4	methane
CO_2	carbon dioxide
COP	Conference of the Parties
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DNA	Designated National Authority
EB	Executive Board
EEA	European Environment Agency
EIA	environmental impact assessment
EIS	environmental impact statement
EPS	Electric Power Sector
EU	European Union
EU-ETS	European Union Emissions Trading Scheme
GHG	greenhouse gas
GPG	Good Practice Guidance
ICOLD	International Commissions On Large Dams
IEA Hydro	International Energy Agency's Hydropower Implementing Agreement
IHA	International Hydropower Association
IHP	International Hydrological Programme
IPCC	International Panel for Climate Change
IRN	International Rivers Network
IWRM	Integrated Water Resources Management
KP	Kyoto Protocol
LCA	Life Cycle Assessment
LCD	Least Developed Country
LULUCF	Land Use, Land-Use Change and Forestry
MW	megawatt
NAMA	Nationally Appropriate Mitigation Actions
NGO	non-governmental organisation
OECD	Organization for Economic Cooperation and Development
REDD	Reducing Emissions from Deforestation and Degradation
SEA	strategic environmental assessment
SRREN	Special Report on Renewable Energy Sources and Climate Change Mitigation
UN	United Nations

UNCED	United Nations Conference on Environment and Development
UNCHE	United Nations Conference on the Human Environment
UNECE	United Nations Economic Commission for Europe
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WCD	World Commission on Dams

Appendix 1

Conducted interviews

Number	Date	Interviewee	Position	Method
1	11/7/2009	Danny Cullenward	energy policy expert, Stanford University, USA	telephone
2	14/7/2009	Miguel Doria	Assistant Programme Specialist, International Hydrological Programme, UNESCO	face-to-face
3	21/7/2009	name withheld	former programme director, WWF International	telephone
4	22/7/2009	Stuart Hoverman	Strategic Director of Water Resources, Brisbane City Council, Australia	face-to-face
5	24/7/2009	Mukand S. Babel	Professor, Water Engineering and Management, Asian Institute of Technology, Thailand	face-to-face
6	31/7/2009	name withheld	Policy Advisor, GTZ, Germany	telephone
7	1/8/2009	name withheld	senior expert on LULUCF and consultant to the UNFCCC, inter-governmental organisation	telephone
8	3/8/2009	Payal Parekh	Climate Campaigner, International Rivers	telephone
9	6/8/2009	Lau Saili	Policy Analyst: Water - Energy - Climate Change, International Hydropower Association	telephone
10	6/8/2009	name withheld	IPCC WG3 co-chair	email
11	12/8/2009	Tonya del Sontro	research scientist, EAWAG & Swiss Federal Institute of Science and Technology	telephone
12	13/8/2009	Sam Hitz	Senior Policy Advisor, The Climate Registry, USA	telephone
13	20/8/2009	Bradford Sherman	Senior Research Scientist, CSIRO Land and Water, Australia	telephone

Meetings and conferences

9/7/2009	UNESCO-IHA meeting, UNESCO headquarters, Paris, France
20-22/7/2009	AMSI/MASCOS/UNESCO international workshop on Future Models for Water and Energy Management, Brisbane, Australia
24/7/2009	UNESCO-HELP workshop on Integrated Water Resources Management, Brisbane, Australia
16-19/8/2009	World Water Week, Stockholm, Sweden

Appendix 2

QUESTIONNAIRE

GREENHOUSE GAS EMISSIONS FROM FRESHWATER RESERVOIRS

Are you aware of the possibility that freshwater reservoirs may emit greenhouse gases (GHG)? If yes, please complete section 1. If not, please complete section 2.

SECTION 1

Question	Yes	No	Comment / Please elaborate your answer
Are you aware of recent debates surrounding the topic?			
If yes, what is your position?			
Are you aware of any existing policies that address the issue of reservoir emissions?			
If yes, which ones?			
Do you think these policies are sound?			
Are you aware of any ongoing policy developments in the area?			
If yes, which ones?			
Do you think the issue should be addressed by climate change and/or water policies?			
If yes, where and at what level?			

Would you like to take part in an open discussion on the topic? Yes No

BACKGROUND INFORMATION

Name ____________________

Position and organisation ____________________

Area of expertise ____________________

Can you be contacted for further details? If yes, please give your contact details below.

SECTION 2

Since the mid-1990s, increasing attention has been given to the topic of greenhouse gases from freshwater reservoirs in response to scientific findings of GHG emissions from dams. Carbon dioxide and methane are produced through the decomposition of organic material in the watershed. They are released at the water-air interface and water released through hydroelectric turbines and spillways (Soumis et al., 2005). Research indicates that emission levels can be significant, especially from tropical reservoirs which have favourable conditions for generating methane (St. Louis et al., 2000; Fearnside, 2004), which has 25 times the global warming potential of carbon dioxide (IPCC, 2007). According to a recent study, reservoirs have been estimated to contribute an additional 30% to known anthropogenic sources of methane at a global scale (Lima et al., 2008).

Question	Yes	No	Comment
Do you think this issue is of importance for policy-making?			
Do you think these emissions should be addressed by climate change and/or water policies?			
If yes, where and at what level?			

Would you like to take part in an open discussion on the topic? Yes No

BACKGROUND INFORMATION

Name ____________________

Position and organisation ____________________

Area of expertise ____________________

Can you be contacted for further details? If yes, please give your contact details below.