CARBON BALANCE OF HYDROPOWER RESERVOIRS

Hydropower is expanding in the tropics, and while reservoirs emit greenhouse gases, they also store carbon in bottom sediments

Hydropower is the world's largest source of renewable energy, currently producing about 16% of global electricity. Most northern countries have already exploited the majority of their hydropower potential and constructed hydropower dams where economically and politically feasible. In the tropics, however, many rivers are still not dammed. Africa and Latin America, for example, use only 8% and 25% of their hydropower potential. In these regions, the freely flowing water constitutes a great and unused source of sustainable energy for economic development. Accordingly, Brazil alone plans 22 new large hydropower dams by 2024 and the International Energy Agency calls for a doubling of global hydropower capacity from around 1,000 to 2,000GW by 2050.

Renewable yet emitting

Hydropower is generally regarded as a 'green' energy source since it is renewable and does not release fossil carbon into the atmosphere. However, hydropower also comes at a cost. Severe damage to regional ecosystems and negative impacts on the socioeconomic conditions of local communities as a result of hydropower dams are well documented. In addition, the emission of the greenhouse gases carbon dioxide and methane from hydropower reservoirs has become a rising matter of concern. It appears that, especially in the tropics, hydropower reservoirs can release substantial amounts of greenhouse gases into the atmosphere. In particular, the emission of methane (aka biogas), a greenhouse gas 28 times stronger than carbon dioxide, has been reported to be high from some tropical reservoirs. The greenhouse gases are produced as water-living microbes degrade organic matter, i.e. remains of land plants that are flushed into the reservoir by rivers, or plants and microscopic algae that grow in the reservoir. The degradation of organic matter in flooded vegetation and soils also contributes to greenhouse gas production.

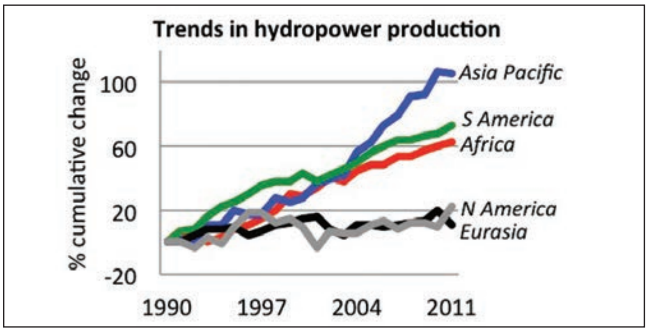

Fig. 1 Hydropower has grown strongly in tropical and sub-tropical regions, and this growth is projected to continue over the coming decades

Reservoir greenhouse gas emissions have triggered an intense debate about the potential effect of hydropower on climate. In a joint effort of the International Hydropower Association and UNESCO, measurement guidelines for reservoir greenhouse gas emission were developed, as well as a reservoir greenhouse gas risk assessment tool. However, current knowledge on reservoir emission is still limited. Many reservoirs are huge (hundreds or even thousands of km^2), and the differences in water quality, organic matter cycling and greenhouse gas emission can be large in different parts of the reservoir. Similarly, greenhouse gas emission can be very different between the numerous smaller reservoirs. While the exact magnitude and significance of greenhouse gas emission from hydropower reservoirs remain unresolved and debated, the emerging picture is clear: hydropower is a renewable but certainly not carbon-free way of energy production.

Sink-to-source balance

The research project HYDROCARB aims to produce new, fundamental knowledge about the carbon and greenhouse gas balances of tropical reservoirs. Funded through the European Research Council, it is different from previous studies in that it investigates not only emissions but also carbon storage in the bottom sediments. It also explicitly covers the spatial variability of both emission and carbon storage in order to be able to capture the variability of these large reservoirs.

HYDROCARB's basic idea is an almost trivial effect of river damming that nevertheless has so far been largely overlooked in the greenhouse gas debate: dams trap sediment. As a dam slows down the water flow of the river, the sediment particles carried by the river settle to the bottom of the reservoir. Current assessments of reservoir greenhouse gas emissions typically ignore that, by this basic process, carbon-containing particles are buried at the bottom. The bottom sediments of reservoirs therefore constitute a carbon sink, which has a cooling effect on climate. Thereby, reservoir greenhouse gas emissions may to a certain, as yet unknown, extent be mitigated. However, the balance between sediment carbon burial and greenhouse gas emission of reservoirs is currently unknown. Its quantification in various different tropical reservoirs is at the core of HYDROCARB.

Hotspots of emission

The assessment of spatial variability is another core property of HYDROCARB. Most of the river particles are deposited where the river enters the reservoir, and the water slows down. Previous research has shown that vast amounts of methane can be produced by sediment-living microbes in areas where a lot of sediment is deposited. This is because the sediment contains organic matter particles, such that with high sediment deposition, a lot of food is provided to the methane-producing microbes. River inflow areas are therefore prone to be hotspots of methane emission, with the potential of emitting several times more methane than near-dam areas. As past studies have generally focused on near-dam areas, current estimates of reservoir methane emission may be much too low. HYDROCARB systematically investigates for the first time the occurrence of methane emission hotspots in the inflow areas of reservoirs, as well as the sediment carbon sink in the inflow areas, again aiming at quantifying the balance between greenhouse gas emission and the sediment carbon sink.

Transforming water plants to methane

Another important, and thus far overlooked, effect of river damming is related to the water becoming standing and more transparent when the particles settle. This allows water plants and phytoplankton, microscopic algae, to grow. Water plants and phytoplankton take up and bind carbon dioxide as they grow, so initially their growth is lowering greenhouse gas emission. But when they die, they sink to the bottom where they are digested by methane-producing microbes in the sediment. Thereby, the carbon dioxide that water plants and phytoplankton took up as they grew is partly transformed to the even more potent greenhouse gas methane. While this transformation may be responsible for a fair share of reservoir methane emissions, it also opens up a potential management of reservoir methane emission. Curbing the supply of nutrients to water plants and phytoplankton, e.g. by sewage treatment, could lead to a corresponding reduction in methane emission. HYDROCARB investigates this transformation pathway by a series of laboratory experiments.

Accomplishments so far

HYDROCARB is based on measurement campaigns and samplings in the field, and all field work is conducted in Brazil. This is possible thanks to strong collaboration between the Limnology programme at Uppsala University in Sweden and the Aquatic Ecology Lab at the Federal University of Juiz de Fora in Brazil. Both units have a very strong record of research and education in aquatic ecology and biogeochemistry, as well as a history of successful collaborations. In total, the HYDROCARB crew consists of about ten scientists at different levels, based in both Sweden and Brazil, with backgrounds in different disciplines, a prerequisite for the success of a multidisciplinary project that stretches in methodology from physics to ecology, and in concepts from ecosystems to geomorphology.

The project crew has up to now conducted fully-fledged field campaigns in four reservoirs, situated in the Atlantic Forest, Savannah and Amazonian ecoregions of Brazil. Each field campaign consists of several weeks of measurements using boats that carry equipment to map the thickness of bottom sediments, the volume of methane bubbles rising from the sediment, the concentrations of greenhouse gases in the surface water, and many ancillary parameters. Hundreds of sediment cores have been taken and analysed for carbon content and methane concentrations. Chambers and inverted funnels have been deployed hundreds of times on the water surface to capture gas emissions. Field samples have been taken to the lab to conduct experiments on the effectiveness of carbon burial in reservoir sediments, and on the transformation of phytoplankton debris to methane. Geochemical analyses of sample material will help to discern the origin of the carbon buried in the sediments, as well as the origin of the methane produced in the sediments. And more field work is underway: in October the crew will re-visit the Amazonian reservoir.

Fundamental research for real-world issues

What is the goal of all this work? We want to understand the balance between greenhouse gas emission and the sediment carbon sink, and we want to identify the fundamental mechanisms behind these processes. Under which circumstances is emission higher than the sediment carbon sink, and which factors turn the balance around? With such knowledge gained, we will be able to make estimations of emission and burial of other reservoirs, and even in other parts of the world. And we want to make our results useable by eventually including the new insights into the International Hydropower Association's Greenhouse Gas Risk Assessment Tool.

Challenges and chances for intersectoral research

Even with HYDROCARB filling major gaps in our understanding of the environmental effects of hydropower reservoirs today, significant challenges remain. For example, in order to quantify the overall net effect of a hydropower dam, the carbon balance of the landscape before flooding needs to be subtracted from the carbon balance of the reservoir (i.e. the flooded landscape). This is a complex and long-lasting task which requires the measurement of various landscape elements pre-flooding, as well as several years of measurements post-flooding – in other words, it is a major scientific endeavour that is only possible with long-term support and commitment from several partners, both academic and industrial.

A Canadian hydropower company has financed an independent research chair at a public university to quantify, for the first and so far only time, the net effect of a hydropower dam on the landscape's greenhouse gas and carbon balance. For tropical and sub-tropical regions, where reservoir emissions can be much larger and hydropower is growing, similar financing models may be feasible. In addition, policy makers and funding agencies in Europe should also be aware that hydropower, while being an important means for economic development in many countries, has unresolved environmental impacts that require more research.

UPPSALA UNIVERSITET

European Research Council
Established by the European Commission

Dr Sebastian Sobek
Department of Ecology and Genetics, Limnology
Uppsala University

+46 18 471 2718

sebastian.sobek@ebc.uu.se
http://www.ieg.uu.se/limnology/