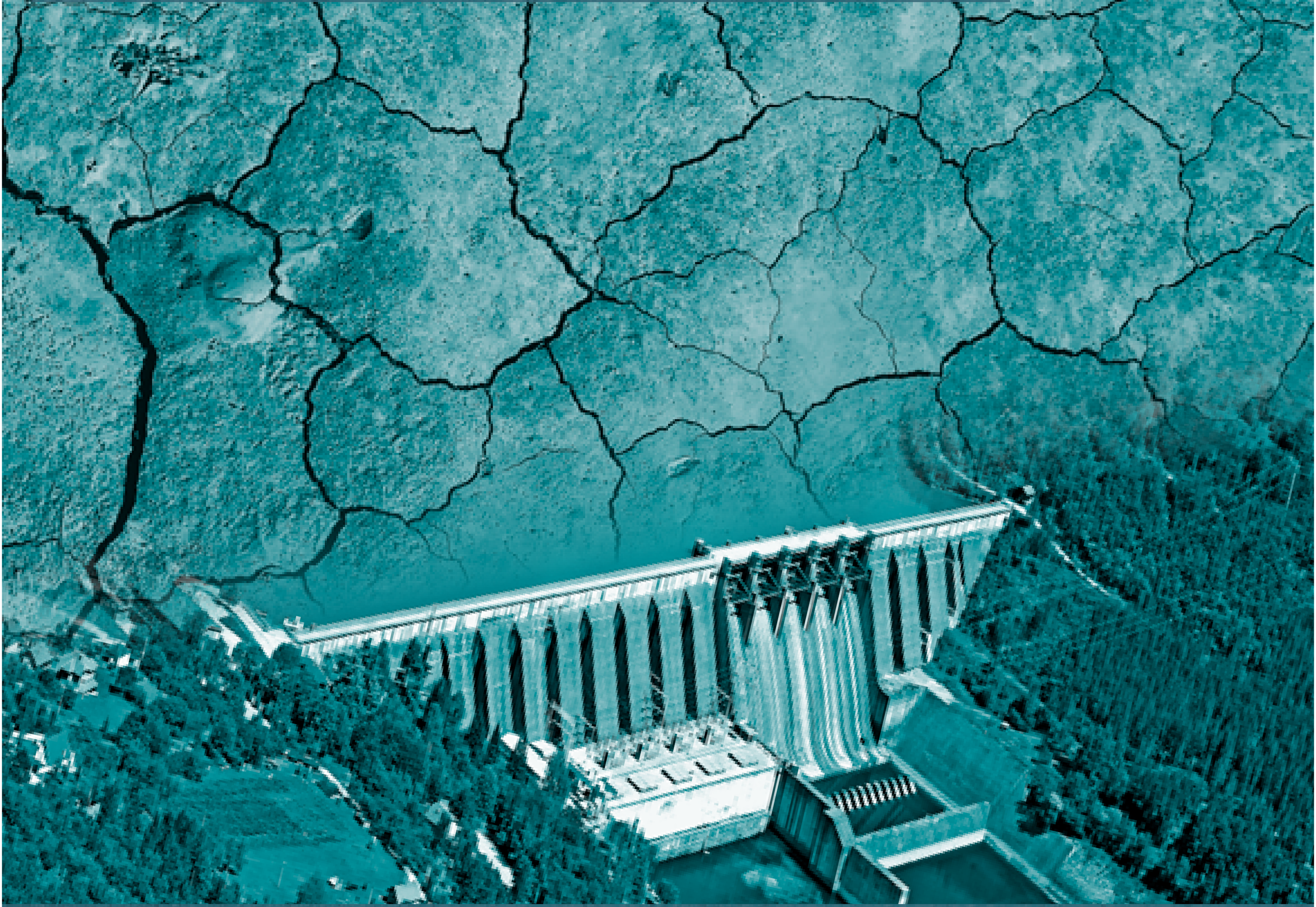
# Riverscope:
# Climate Assessment

*Assessing the impacts and risks of climate change for hydropower*

TMP Systems | October 2021



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> *This report assesses the impacts and risks of climate change for the hydropower sector. It demonstrates that hydropower is vulnerable to climate impacts and is also driving climate change. Climate risks should be more prominent in assessments for hydropower and steps should be taken to develop alternatives that are less exposed to climate change impacts.*

Construction of Nam Theun 1, Laos.
Photo by Polbkt (Shutterstock).

## 1. OVERVIEW & BACKGROUND

The electricity produced by large-scale hydropower is expensive in commercial, social, and environmental terms. Large dams are also particularly exposed to the impacts of climate change. Yet the way in which these projects are assessed systematically underestimates the impacts and risks, meaning that investors, developers, and regulators often make the wrong decisions based on incomplete information.

This document summarizes the impacts and risks of climate change for the hydropower sector, drawing from pilot applications of "Riverscope." Riverscope is a tool that offers a new way to assess large dams by combining geospatial analysis, expert investigation, and financial modelling to produce a multidimensional assessment of hydropower projects (see below for further detail on the methodology). This short report looks at what Riverscope can tell us about the exposure of dams to climate change impacts.

The IPCC's recent Sixth Assessment Report (AR6)[1] emphasized the severity of climate change for people and planet, yet there is a growing consensus that AR6 may still underappreciate the true extent and severity of climate change impacts, and that many climate models are too conservative. These models are, however, getting better at projecting where and how climate impacts are likely to be felt. This information will become increasingly important for energy planning and development, especially for sectors like hydropower.

Large hydropower projects create climate impacts through reservoir emissions as well as through land use change. Perhaps more importantly, these dams are highly dependent on water regimes that will be altered by climate change, resulting in reduced and variable output. As is now becoming more apparent, projects and whole national energy systems can be left high and dry.

This analysis suggests that climate risks are commercially significant for hydropower projects and for the sector as a whole. They can be managed, at substantial cost, but not completely avoided. Similarly, they can be ignored or underplayed but only at risk of even more serious problems for the project. Current assessment processes fail to adequately recognize the scale or complexity of these climate risks, which can contribute to delays, cost overruns and unpredictable power output, while also undermining dam safety.

## 1.1 RIVERSCOPE METHODOLOGY

Riverscope delivers a comprehensive, data-driven and repeatable assessment of social, environmental and commercial risks by an expert third party that could be applied at any stage in a dam's development. The basis of the methodology is quantitative and built on the same foundations as a tool that TMP developed called Landscope.[2] Any shortcomings in quantitative assessment are then addressed in a second, qualitative investigation. See the Resources page at www.riverscope.org for further details on the Riverscope methodology.

The quantitative assessment scores each hydropower project against a set of social and environmental indicators that are statistically correlated with common ESG issues in the hydropower sector. This set of 17 indicators was established by thoroughly analysing 91 cases with reported problems and comparing them to 190 cases which were not found to have reported problems. This allowed us to understand the characteristics that associate with problematic projects, and thus to score any project.

Riverscope then uses previous analysis of delays in hydropower to estimate, at any given level of risk, how long the delay might be if there were problems. The final quantitative step involves converting these projected delays into financial terms. Riverscope uses a bespoke, discounted cashflow model to show how slippage reduces the Net Present Value (NPV) and so increases the likely Levelized Cost of Electricity (LCOE). Based on these metrics, hydropower can be reasonably compared with alternatives like solar and wind.

This quantitative approach delivers an assessment that balances social, environmental, and commercial considerations. But it can be further improved with the application of qualitative investigation and analysis. This can help us to understand the trade-offs that hydropower offers for challenges like climate change, involuntary resettlement and biodiversity. It can also help us to confirm all-important delay projections and provide further evidence for why some projects may experience very significant delays.

Riverscope could be used together with existing tools to better understand climate risk. There is also scope to integrate climate models into the Riverscope assessment process. This analysis relies primarily on past and current experiences of climate impacts in the hydropower sector to demonstrate what has happened and is happening right now. It draws on elements of previous Riverscope assessments to complement the analysis and to demonstrate its current use and potential in the climate context.

# 2. HYDROPOWER IS EXPOSED TO CLIMATE CHANGE IMPACTS

Dams can only provide consistent baseload power (with a high capacity factor[3]) if they use a reservoir to control water and output, which increases the emissions profile of the energy produced and generally leads to a larger social footprint (e.g. on displacement). But climate change is making reservoir storage difficult and the problem will only get worse over time.

Many dams that are developed today are "run-of-river" schemes, in part because they typically have a smaller direct social footprint.[4] One downside is that run-of-river dams are particularly affected by fluctuating water regimes and climate variability, reducing and making more unpredictable their power generation. Many dams must be offline for months at a time during dry seasons, which can be challenging from an energy planning perspective. This section takes a deeper look at these key climate impacts on dam output and risk. It shows that climate factors add to risk and uncertainty for hydropower projects and create considerable problems for countries and regions that are dependent on the technology.

## 2.1 PROJECT-LEVEL CLIMATE IMPACTS

Large hydropower projects have an unusual set of characteristics which make them especially vulnerable to climate uncertainty. First, these projects are long-lived energy assets that can be operational for more than 50 years. Second, each project needs to be designed according to a specific set of environmental conditions, which includes a tolerance for hydrological extremes like flooding and drought. However, these conditions are increasingly uncertain because of climate change and, as a result, dams are increasingly difficult to plan and manage.

Dried Avalanche Lake, India.
Photo by Shravan K. Acharya (Unsplash).

Hydropower output is vulnerable to periods of drought, especially run-of-river schemes that are unable to store water for when levels get low. In 2017, drought conditions forced Kenya's Masinga run-of-river project offline, while the following year the 80MW Sondu Miriu project operated at just 12% capacity.[5]

Conventional dams can also suffer major generation losses during prolonged dry spells. During Brazil's drought between 2013-2015, the average loss of generation across 9 of its main reservoir dams was ~33%, with the 390MW Três Marias dam experiencing losses as high as 46.4%.[6] Between just 2013-2014, hydropower production dropped to 15% below average.[7] At the time of writing, Brazil is facing yet another drought, which continues to undermine its energy security.[8] The 645MW Hyatt dam in California has also been forced offline over low water levels.[9]

These increasingly frequent disruptions undermine the commercial viability of hydropower projects, making them loss-makers. The table overlay provides a sense of how drought conditions might impact the value of a dam—each of the five Riverscope pilots, in this case—by reducing its annual capacity factor.

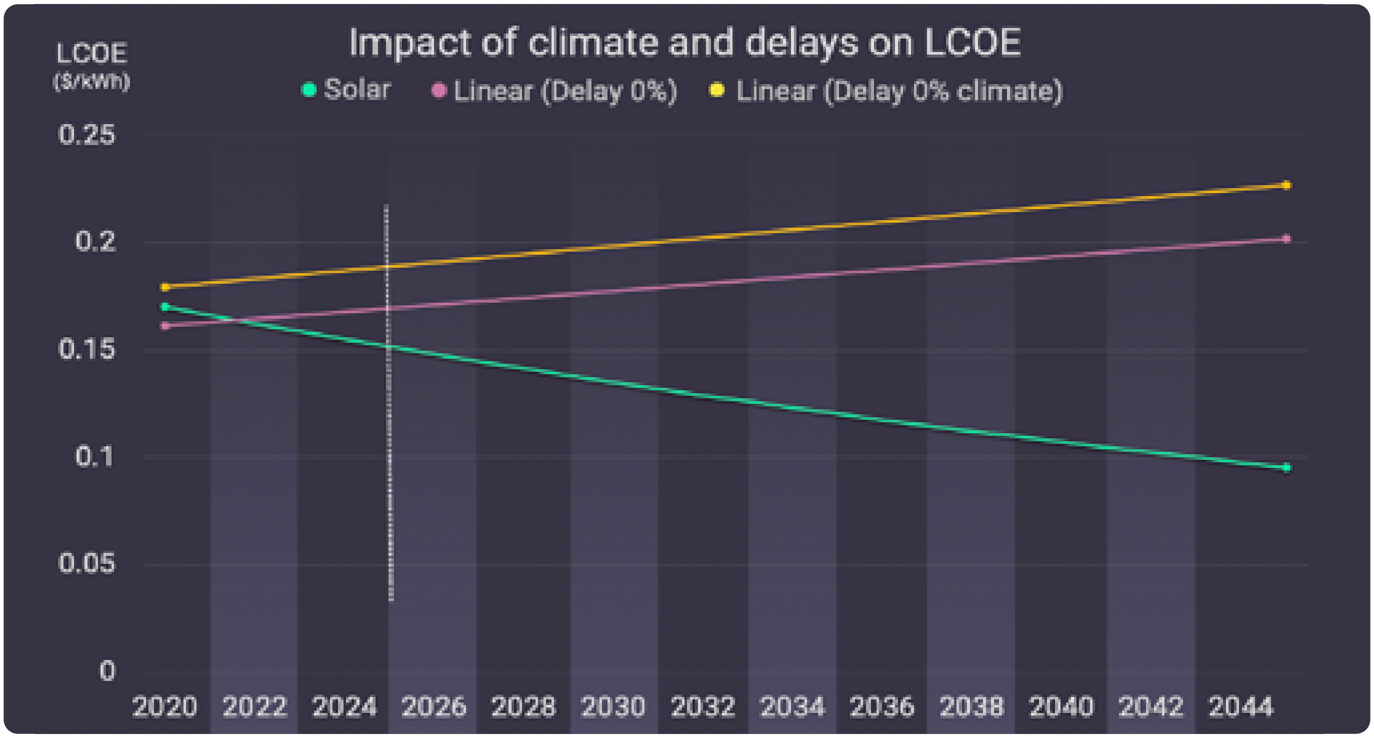
Riverscope shows that the five pilots' NPVs are impaired by delay and increasing costs ("NPV loss (%/$)" columns in the table).[10] The table compares this with NPVs with a capacity factor reduction of 5% ("NPV with drought (%/$)" columns), based on Brazil's drought experience during 2013-2014.[11] While Brazil's experience may appear extreme, the IPCC's AR6 suggests that such events are likely to become both more frequent and more severe with climate change. These figures are plausible, even conservative, for large hydropower projects in a context of future climate extremes, especially given their 50+ year life expectancy.

With the added exposure of climate impacts, the pilots show losses of between $288–$1,660 million, or average losses of $778 million. Losses from drought alone ("Drought difference (%/$)" columns) range between $110–$376 million, or $189 million on average. While these figures are indicative, they provide a sense of the commercial risks that large hydropower projects will increasingly be exposed to as climate impacts get worse.

| DAM | NPV LOSS (%) | NPV WITH DROUGHT (%) | NPV LOSS ($) | NPV WITH DROUGHT ($) | DROUGHT DIFFERENCE (%) | DROUGHT DIFFERENCE ($) |
|---|---|---|---|---|---|---|
| KOUKOUTAMBA | -32 | -65 | -178m | -288m | -33 | -110m |
| BATANG TORU | -29 | -49 | -286m | -417m | -20 | -131m |
| PAK LAY | -44 | -62 | -476m | -593m | -18 | -117m |
| LUANG PRABANG | -54 | -83 | -719m | -932m | -29 | -213m |
| SAMBOR | -39 | -58 | -1,284m | -1,660m | -19 | -376m |

The graph below demonstrates how the same drought conditions might also increase the end cost of electricity (or the levelized cost of electricity (LCOE)) of a dam—Koukoutamba, in this case. By the earliest possible operation date, 2025,[12] drought could push this cost above 18 cents per kilowatt hour compared to just 15 cents per kilowatt hour for solar, the cost of which is rapidly falling. This would make Koukoutamba at least 11% more expensive than initial projections.

On the opposite extreme, hydropower is directly exposed to the risks of flooding or severe weather events which are getting worse with climate change. In recent years there have been numerous cases where extreme rainfall events have contributed to dam failure or collapse. In 2018, Malaysia's Swar Chaung dam's spillway collapsed following heavy monsoonal rains, flooding around 100 villages.[13] Similarly, two of China's dams collapsed after a torrential downpour earlier this year.[14] Although dams are designed to tolerate extreme weather events, in a context of future climate change there is increasing uncertainty around the severity and frequency of such events, creating clear safety risks for downstream areas.



Graph 1. Created by TMP Public

Flooded town, Malaysia
Photo by Pok Rie (Pexels).

Flood events can also create considerable operational risks for hydropower projects. Floods are often associated with increased sedimentation and debris, which can reduce storage capacity and cause structural damage.[15] China is regularly forced to shut down hydropower generators during the rainy seasons to safeguard plants and prevent downstream flooding.[16] Similarly, flooding damaged two dams in Malawi in 2019, reducing the country's hydropower capacity from 320MW to 50MW.[17]

During construction, flooding can cause delays which add to the costs of hydropower. The 520MW Tapovan Vishnugad hydropower project in India has been damaged several times by flash floods throughout construction and is running significantly over schedule and over budget. The most recent flash flood occurred in early 2021, and has now brought the economic viability of the project into question, 15 years down the track.[18]

This kind of delay is financially significant and can leave large holes in energy plans. Large hydropower projects will increasingly face a tradeoff between increased climate exposure and lower capacity factor or increased costs and construction times. As demonstrated above, both options will considerably reduce project values and increase the cost of electricity from hydropower.

## 2.2 MACRO-LEVEL CLIMATE IMPACTS

Climate impacts typically affect hydropower production at a national or regional level. There are numerous examples of countries that have seen large drops in power output during droughts due to an overreliance on hydropower.[19] Zambia lost 50% of its hydropower generation during a drought in 2014-2015, which meant buying expensive and fossil-fuel based emergency power from Mozambique. In addition to the debt accrued from this purchase, Zambia's mining industry also suffered and plunged the Zambian economy into crisis.[20]

In this context, countries like Zambia that remain over reliant on hydropower will continue to be adversely affected during drought conditions. These dry periods of low output often overlap with periods of high demand, for example where energy is needed for cooling and pumping. At the same time, by withholding water to ensure there is still power available in the near term, dams can heighten the impact of drought in downstream areas. This dynamic recently played out in the Mekong region, where China was criticized for exacerbating the impact of a regional drought for downstream countries through its cascade of state-owned dams upstream.[21]

The Mekong's 2019-2020 drought was one of the worst in recent history, which resulted in reduced hydropower capacity and rolling blackouts for major cities like Cambodia's Phnom Penh.[22] Such climate shocks raise questions about the Mekong's current reliance on hydropower (see table below[23]). They are also concerning for large projects like Luang Prabang, Pak Lay and Sambor, which may only come online in the next decade or later,[24] and which are all planned run-of-river schemes that are particularly vulnerable to climate variability. This vulnerability undermines the viability of these and similar projects, but could also be detrimental for future energy planning and regional development.

| DAM | % HYDRO IN POWER GENERATION |
|---|---|
| LAOS | 62.6 |
| MYANMAR | 55.7 |
| CAMBODIA | 48.6 |
| VIETNAM | 45.5 |
| CHINA | 17.5 |
| THAILAND | 2.8 |

Both cumulative hydropower impacts and climate impacts are very difficult to predict. The interaction between these two processes is therefore highly uncertain and will become increasingly difficult to manage. As climate impacts become more severe, and hydropower development continues unchecked, the sector could face major problems (e.g. extreme drought and flooding), or projects will need to be designed to tolerate these extremes, which is likely to be costly.[25] Both scenarios undermine the commercial case for hydropower, which could become more expensive while simultaneously less productive.

Climate change is likely to create energy supply gaps for countries and economies, like those in the Mekong region, that remain reliant on hydropower. At the same time, however, these gaps in energy supply create investment opportunities for alternative forms of renewable energy. Through effective energy planning and management, hydropower could also support such investment with energy storage, especially for variable technologies like solar and wind. Off-river pumped storage may also be an attractive option from an environmental and social perspective and could support the expansion of low-cost, low-emission solar and wind technologies.[26]

## 3. HYDROPOWER CONTRIBUTES TO CLIMATE CHANGE IMPACTS

Hydropower has been widely held as a low-carbon option for energy production and as an important climate mitigation technology, but there is increasing evidence that this is often not the case. The average greenhouse gas (GHG) emissions of hydropower are much higher than solar and wind alternatives, while the emissions of some projects have been found to exceed fossil fuel equivalents.[27]

Mekong drought, Thailand.
Photo by Khong Jiam (Shutterstock).

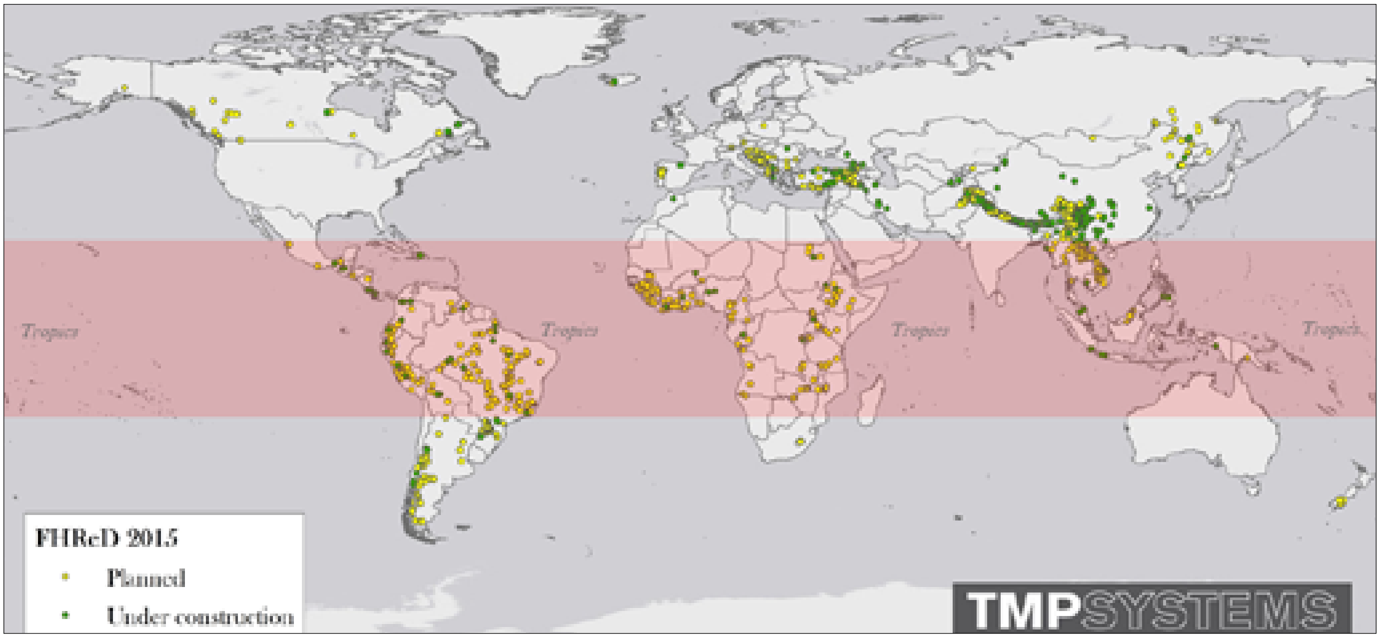
Hydropower contributes to climate change directly through reservoir GHG emissions, especially in tropical regions, and indirectly through deforestation. These impacts on climate change can be considerable at the individual project level, but are rapidly scaled by the cumulative impacts of multiple projects along a single river system. Mitigating these contributions to climate change impacts can be challenging, time-consuming and expensive.

## 3.1 TROPICAL RESERVOIR EMISSIONS

Tropical reservoirs are known emitters of methane, which has a global warming potential 84-86 times greater than carbon dioxide in the near-term.[28] Large dams are increasingly being developed in tropical and subtropical regions (see map below[29]), including in Brazil's Amazon, where reservoir emissions are particularly high given that many dams inundate portions of rainforest. All pilot cases assessed through Riverscope were also located in tropical regions.[30] Rapid hydropower development in these warmer climates could lead to considerable GHG contributions, as biomass is decomposed in the resulting large areas of inundation.

Reservoir emissions are minimized by run-of-river schemes which reduce the extent of inundation but, as noted, are also particularly exposed to the impact of climate change and cumulative hydropower development on water regimes. Another way to

Construction of Xayaburi Dam, Laos. Photo by Onutto (Shutterstock).



minimize reservoir emissions is by clearing the inundation area of biomass, but these areas are often extremely large, so thorough clearing can be both time-consuming and expensive and is seldom carried out.

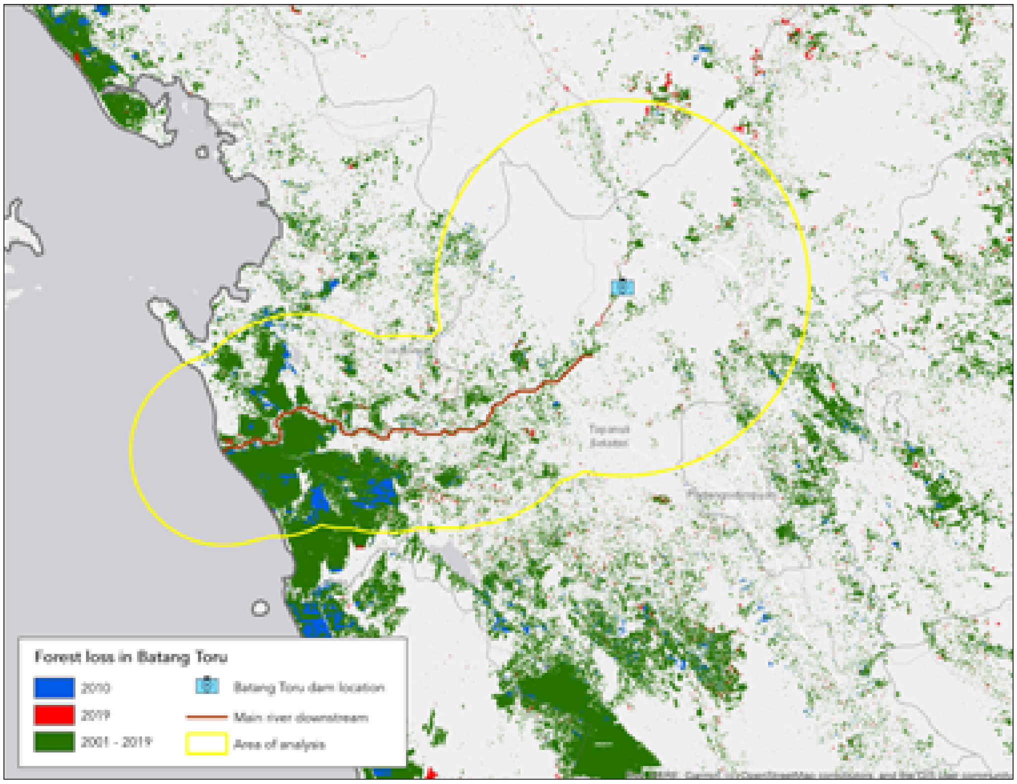
Clearing at scale is also increasingly challenging because it is at odds with concerns for biodiversity, which are a source of opposition for hydropower development that can add to delays and costs.[31] Again, hydropower is caught in a tradeoff between its impacts and its commercial success.

## 3.2 DEFORESTATION

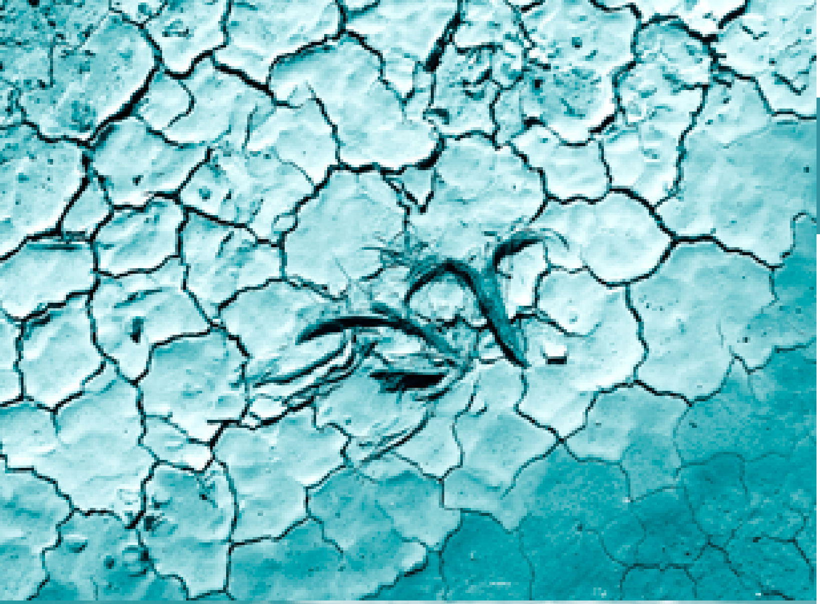
It is well known that forest clearing and climate change are strongly interconnected.[32] Forest loss is particularly severe in tropical regions associated with high forest cover, like the Amazon rainforests and, as is shown in the figure above, many of these same areas are undergoing rapid hydropower development. While there are multiple factors that can influence an increase in deforestation, such as population growth and agricultural expansion, recent studies have now drawn links between hydropower development and tropical deforestation.[33]

The figure below shows how forest loss is an issue on either side of the river downstream from the planned Batang Toru dam, with deforestation concentrated at the river mouth. Yet, the development of large dams can lead to the fragmentation of forest areas through reservoir inundation, the expansion of road infrastructure, new settlements, and increased logging.[34] In this case, Batang Toru could therefore add to this trend of deforestation in the relatively untouched areas upstream, which has the potential long-term consequence of connecting the two areas through forest loss.

The loss of forest cover has been connected to changes in precipitation and water availability.[35] This has direct implications for hydropower, which relies on this availability for energy production, yet a project like the planned Pak Lay dam is alone expected to inundate a 1,427ha area of forest, excluding forest clearing for transmission lines and other ancillary infrastructure.[36] Recent studies have also confirmed that hydropower dams are a driver of deforestation in parts of the Mekong[37] and Amazon[38] basins. In this way, deforestation through continued hydropower development could undermine regional water availability and ultimately the long-term productivity of the sector.



Map created by TMP Public



Top: Dry, cracked earth.
Photo by Jeremy Bezanger (Unsplash).

Middle: Submerged trees in Balbina reservoir, Brazil.
Photo by Arnika Ganten (Shutterstock).

Bottom: Deforestation on the banks of the Xingu River, Brazil.
Photo by Marcio Isensee (Shutterstock).

# 4. KEY TAKEAWAYS

- Large hydropower is commonly misunderstood. It is not a weapon in the climate fight but is rather a growing chink in the armor. As the climate crisis continues to take hold, and given that hydropower is directly reliant on water regimes, **large dams are likely to become increasingly vulnerable to climate extremes** and their effect on water.
- **Hydropower is both vulnerable to, but also a contributor toward, climate change.** Tropical reservoirs are known for their considerable GHG emissions which directly contribute to global warming, while hydropower contributes indirectly to climate change through deforestation.
- **Increasingly unpredictable climate impacts could directly affect the output of hydropower plants** during periods of drought, while climate-induced flooding can add to construction delays and cost overruns, as well as threaten dam safety.
- **Energy planning needs to be more systematic in its approach to account for the climate and cumulative impact of dams**, amongst other environmental, social and commercial factors. Failure to recognize the inherent complexity of large hydropower projects or the inextricable linkage of social, environmental and commercial risks has led to consistently poor decision-making.
- **Much more extensive efforts are needed to exhaust alternative options before dams are developed** and much better monitoring and regulatory systems are needed to avoid the worst climate impacts of hydropower.
- **Existing dams can play a supporting role in climate mitigation by providing alternative, variable renewable energy technologies** with pumped storage. Smaller, existing dams can also support climate adaptation strategies by providing water management, where appropriate.

# ENDNOTES

1. https://www.ipcc.ch/report/ar6/wg1/
2. Landscope was developed by TMP together with development finance institutions (DFIs), NGOs, private investors, international companies and government expertise. It has hundreds of regular users and features on Bloomberg's Terminal product. It has been tested thoroughly by comparing its results with real world experience and with the outputs of fieldwork. This process has benefited significantly from DFI support including testing across thousands of assets and dozens of portfolios.
3. Capacity factor refers to the ratio between real output and theoretical output.
4. While run-of-river schemes are regularly purported to have lower social and environmental impacts than conventional hydropower dams, diversion run-of-river schemes and pondage schemes operated for peaking power, in particular, can both have significant negative impacts on aquatic ecosystems, even for small-scale projects: https://www.sciencedirect.com/science/article/abs/pii/S1364032121001271
5. https://www.hydroreview.com/world-regions/drought-straining-kenya-s-hydroelectric-resources/
6. https://www.projetouhr.com.br/asel/reviewcausescrisesbrazil.pdf
7. https://ascelibrary.org/doi/abs/10.1061/9780784479858.010
8. https://www.ft.com/content/958e313a-c474-4b0a-80c5-2679ee4bb307
9. https://www.hydroreview.com/business-finance/california-dwr-takes-645-mw-hyatt-powerplant-offline-due-to-low-lake-levels/
10. In this case a 2-year delay for Koukoutamba and Batang Toru, a 3-year delay for Pak Lay, Luang Prabang and Sambor (as determined by Riverscope) and a CAPEX overrun of 33%, which is average for large hydropower: https://www.tandfonline.com/doi/full/10.1080/07900627.2019.1568232
11. We used an average capacity factor reduction of 15% every 3 years (or 5% annual reduction) whereas Brazil experienced a 15% reduction over 1-2 years during 2013-2014.
12. This is conservative: Riverscope suggests that Koukoutamba is likely to be delayed by at least 2 years, until 2027.
13. https://www.theguardian.com/world/2018/aug/29/myanmar-dam-breach-people-evacuate-homes-officials-say
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19. https://ascelibrary.org/doi/pdf/10.1061/9780784479858.010 (Brazil); https://recipp.ipp.pt/bitstream/10400.22/17085/1/COM_GECAD_ZitaVale_2019_5.pdf (Portugal); https://www.

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bbc.com/news/world-africa-34491984 (Tanzania); https://www.reuters.com/business/sustainable-business/inconvenient-truth-droughts-shrink-hydropower-pose-risk-global-push-clean-energy-2021-08-13/ (various)

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22. https://www.stimson.org/wp-content/uploads/2021/09/Stimson_Lower-Mekong-Energy-Developments_Final_May-2021.pdf
23. Table data from: https://www.eria.org/uploads/media/Books/2021-Energy-Outlook-and-Saving-Potential-East-Asia-2020/Energy-Outlook-and-Saving-Potential-East-Asia-2020-1504.pdf
24. Riverscope found that Luang Prabang, Pak Lay and Sambor would likely only start operation in 2030, 2032 and 2039, respectively, after ESG-related delays are factored in. Their individual assessments are available at: https://riverscope.org/resources/
25. The MRC Technical reviews of Luang Prabang and Pak Lay found that these two dams had insufficiently factored the impacts of climate change on hydrology into the project designs. This again raises questions around future dam safety and impact in a context of climate uncertainty.
26. https://www.sciencedirect.com/science/article/pii/S0360544221016352
27. https://www.eenews.net/assets/2019/11/15/document_ew_01.pdf
28. http://www.climatechange2013.org/images/report/WG1AR5_Chapter08_FINAL.pdf
29. Map only includes projects ≥50MW. Data from the Future Hydropower Reservoirs and Dams Database (FHReD), 2015, available at: http://globaldamwatch.org/fhred/
30. The Riverscope pilots are all in their planning phase of development, which means it is difficult to understand their climate impacts at this early stage. We would, however, expect Koukoutamba to be particularly high emission given that it is planned to submerge a portion of the Moyen-Bafing National Park.
31. https://news.mongabay.com/2020/07/batang-toru-hydropower-dam-tapanuli-orangutan-delay-nshe/; https://india.mongabay.com/2020/11/over-1800-rainforest-trees-to-be-axed-to-for-hydropower-project-near-athirapilly-dam/
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38. https://www.mdpi.com/2073-4441/11/3/566/htm

Cover Image (main): Cracked earth by Ramin Khatibi (Unsplash);
Cover Image (secondary): Hydropower by Goce Risteski (Adobe Stock)