Below is a list of the files that were uploaded as well as a summary / cover page. Click on a file name to view the proof of that file. Files are listed in the order specified by the author.

**Files Uploaded**

Doc47869814-967444921

PDF47869814-967445022

**Other**

Cover & Metadata

Close Window

Integrated Environmental Assessment and Management

# “Pandora's Box” regarding hydropow reflection

| | |
|---|---|
| Journal: | *Integrated Environmental Assessment and Management* |
| Manuscript ID | IEAM-2022-328-3D |
| Wiley - Manuscript type: | Debates, Dilemmas, and Discoveries |
| Abstract: | |
| | |

# “Pandora's Box” regarding hydropower: Carbon-intensive reflection

Rui Zhao[1]*, Kai Shi[2], Gareth Neighbour[3], and Chunqiong Liu[2]

[1] *Faculty of Geosciences and Environmental Engineering, Southwest Jiaotong University, Chengdu 611756, China* *Email: ruizhaoswjtu@hotmail.com
[2] *College of Environmental Sciences and Engineering, China West Normal University, Nanchong 637009, China.*
[3] *School of Engineering & Innovation, The Open University, Milton Keynes MK7 6AA, UK.*

As the world's largest source of clean and renewable energy, hydropower offers an attractive contribution to the battle against carbon emissions with 24 $gCO_2$-eq/kWh (a combined equivalent value from all energy sources) generated, which is approximately 5% of those emissions from gas (Wasti et al., 2022). The very low carbon generation is deemed to be a driving force for energy transition that will support the mitigation of climate change. Hydropower requires that certain geographical constraints are met, such as the ability to capture and contain vast amounts of natural precipitation in mountainous regions (Muller, 2019). However, hydropower is vulnerable to climate change, especially in the event of wide-scale droughts, which inevitably result in low flows, having a profound impact on the robustness of electricity supply (Van Vliet et al., 2016).

This is a simplistic picture and an understanding of how the meteorological drought may further develop into a hydrological drought through complex mechanisms is important (e.g., lack of precipitation combined with higher evaporation). Further, in such cases, reservoirs will face the risk of becoming a carbon source due to the continued decline in water levels; specifically, this will result in carbon dioxide release from sediments through aerobic and anaerobic decomposition of organic matter (Keller et al., 2021). The latter may facilitate an increase in carbon emissions for reservoirs that have experienced increasing drawdown areas over the past three decades, despite the median life-cycle carbon emissions from hydropower is still being far below that contributed by fossil fuel-based energy (Wasti et al., 2022). The cyclic nature of droughts may also accelerate the ‘ageing’ of dams and their potential failure, further exasperating the increase in carbon emissions (Fearnside and Pueyo, 2012).

With the frequent occurrence of extreme weather events and climate in the near future, we argue there is a “Pandora's Box” hidden in the sustainability of hydropower, shifting it from being carbon-free to it being carbon-intensive. While looking at this issue, we further hypothesize that the box switch is triggered by a cliff-edge effect, in which the trade-off between energy consumption and demand plays a key role as a ‘rate variable’, since it is not only very sensitive to climate change, but is also susceptible to industrial production and residential life (See Figure 1).

First, extreme climate events aggravate electricity load through active measures, (e.g., air conditioning), which may further cause the industrial chain to become increasingly reliant on fossil fuels in response to insufficient electricity supply by hydropower. Taking the Chinese province of Sichuan as an example, owing to its unique geographic and topographic conditions, as well as massive water resources, its installed hydropower capacity and annual power generation ranks highest in China. However, this past summer, Sichuan's hydropower supply decreased significantly in the face of prolonged high-temperature weather. As a consequence, industries in Eastern China, such as manufacturing and construction, which heavily depend upon the ‘West-to-East Power Transmission’, have suffered varying degrees of loss. The electricity gap is fulfilled by accelerating coal production and increasing coal purchases, whilst the "high carbon lock-in effect" (i.e. even with possible low carbon alternatives, those production facilities will be locked by high carbon emissions due to their inherent capital-intensive and consumption-intensive characteristics embedded in socio-economic development) is difficult to eliminate as the associateemissions intensity increases.

Second, power restrictions triggered by extreme climate events may undermine confidence in low-carbon consumption. In the past two decades, the Chinese government has been committed to promoting new energy vehicles (NEVs) (often called Plug-in Electric Vehicles (PEV) elsewhere). However, public charging stations are called for off-peak charging under the influence of power cuts, causing panic among NEVs owners. In particular, electric taxis and on-line car-hailing vehicles have flooded into the stations for fear of power outages, leading to the paralysis of the charging system. This will create uncertainty on the public's purchase intention and willingness to pay for NEVs, which further has an impact on the potential for carbon emissions reductions from consumers. Confidence in the system is critical for its success and although beyond the scope of this analysis, the importance of infrastructure and accessibility to accessing the electricity supply is also critical.

Unpredictable and extreme climate events are increasing and consequently result in perturbations in the normal wet and dry seasons, thus altering the expected patterns of hydropower. From a grid management perspective, this makes production planning much more arbitrary. Given such uncertainty, small-sized power stations are struggling to survive, and are bargaining for a share of supply commensurate with large hydropower providers./span> Another aspect that requires consideration is the offsetting of carbon emissions from decommissioning redundant plants at the end-of-life, such as the small-sized power stations that failed to contribute effectively. Apparently, this is an area that requires further investigation, as small-sized power stations are generally much younger than the large infrastructure. There is a shift to small-sized power stations, (e.g., small-scale module nuclear reactors in western Europe), and this may indicate sub-optimization in this scenario.

The way to offset these carbon emissions will also come with a dilemma of sustainability. It is underappreciated that sustainability is part of a complex system of positive and negative feedback cycles, and how these systems can flip or tip behavior in unexpected and underappreciated. In planning future energy supply, it is important that providers understand this, and plan intervention strategies to ensure that the mode remains carbon free.

**Figure 1. Pandora's box shifting hydropower from carbon-free to carbon-intensive**

## Acknowledgement

This study is sponsored by the National Key Plan for Research and Development of China (No. 2019YFC1905600), and Sichuan Youth Science and Technology Innovation Team Funding (No. 2022JDTD0005).

## References

Fearnside, P. M., and Pueyo, S. (2012). Greenhouse-gas emissions from tropical dams. Nat. *Clim. Change* ***2***, 382-384.

Keller, P. S., Marcé, R., Obrador, B., et al. (2021). Global carbon budget of reservoirs is overturned by the quantification of drawdown areas. *Nat. Geosci*. 14, 402-408.

Muller, M. (2019). Hydropower dams can help mitigate the global warming impact of wetlands. *Nature* 566, 315-317.

Van Vliet, M. T., Wiberg, D., Leduc, S., et al. (2016). Power-generation system vulnerability and adaptation to changes in climate and water resources. *Nat. Clim. Change* 6, 375-380.

Wasti, A., Ray, P., Wi, S., et al. (2022). Climate change and the hydropower sector: A global review. *Wires. Clim. Change* 13, e757.

## Conflict of interest

All authors declare that they have no real or perceived conflict of interest.

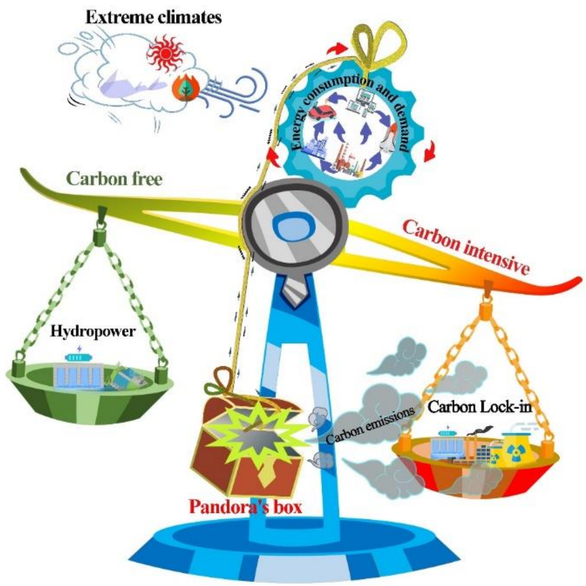


**Figure 1. Pandora's box shifting hydropower from carbon-free to carbon-intensive**