Submitted Abstract

ID IMC22-FSAbstr- 284

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Country	Nepal
Region	Asia

Title	The Gap Between Theoretical And Sustainable Hydropower Potential For Science-Based Hydropower Development In The Upper Indus Basin.
Keywords	Hydropower Development, Water-Energy-Food-Environment Nexus, Science-Society
Type	List Of Focus Session
Focus Session ID	31

Abstract

Hydropower is a cost effective option for energy generation in the remote mountains of the upper Indus. Hence, sustainable hydropower development is essential to sustainable mountain development in this region. Hydropower is intricately linked to the sustainable development goals (SDGs) related to the water-energy-food-environment nexus. Hydropower is also connected to other SDGs on conservation of biodiversity, disaster risk reduction and investments in resilient infrastructures. Considering these interlinkages, we develop a modelling framework to demonstrate how hydropower potential is linked to socio-political choices regarding scale of hydropower development, perception of risks of natural hazards and priorities within the water-energy-food-environment nexus. Our framework takes a systems approach to quantify the gap between theoretical and sustainable hydropower potential by successively considering natural, technical, financial, anthropogenic, environmental, and natural hazard risk constraints on hydropower potential at individual sites as well as at the basin scale. We model three energy development scenarios representing different scales of hydropower development of interest to the government, the private sector or the local communities. Focusing on large scale development reveals technical potential at 16% and sustainable potential at only 3% of the basin theoretical potential of about 1200 Terawatt-hours per year. A more inclusive scenario, combining small community-led and large privately or publicly funded hydropower development, reveals technical potential at 25% and sustainable potential at 8% of the theoretical potential. Further relaxing natural hazard risk criteria can increase the sustainable potential to 13% of the theoretical. As such, our optimization framework shows that under the current hydro-climatology, sustainable potential is only a small portion of the theoretical potential. Other anthropogenic and environmental water usage represent the strongest constraints with nearly a third of the technical potential being reduced when adding these to evaluate sustainable potential in the upper Indus. The Indus main, Swat and Kabul sub-basins have a larger proportion of cheaper and sustainable hydropower plants compared to other sub-basins where development plans visualized by riparian governments already tap into high potential river segments. Our framework expands traditional technical-economical considerations in hydropower planning to include socio-ecological constraints and impact of policy choices in the first order identification of sustainable hydropower plants. This approach can provide a solid basis to develop science-based hydropower development pathways that maximize the synergies between water, food, energy and the environment.