Pumped Hydro Atlas progress

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Pumped hydro energy storage (PHES) is the most mature and lowest emitting form of storage currently available (Gilfillan & Pittock, 2022), and lowest cost for longer duration storage needs. PHES involves connecting two reservoirs at different altitudes with either tunnels or penstocks and circulating water between them, in concert with the generation of other electricity plants and demand from the grid. The great majority of installed electricity storage globally is PHES. When installed on-river, pumped hydro can have poor environmental and social consequences, and reservoirs may have huge surface areas and high evaporation. However, by locating the PHES facilities off-river, reservoirs can be made much smaller, and lower the overall impact (Blakers et al., 2021; Stocks et al., 2021).

In order to demonstrate the great abundance of possible off-river pumped hydro sites, the PHES Atlases have been published, showing more than 600,000 sites globally (Stocks et al., 2021). In the past year, the ANU team has completed several upgrades of these Atlases, and undertaken projects in other jurisdictions to upskill stakeholders to use the Atlases for electricity system planning. This paper will detail our progress.

The original Atlas was constructed using the NASA Space Shuttle Radar Topography Mission 1 arcsecond digital elevation data, which has 30m spatial resolution at the equator and 1m height resolution. These data are available for the region between 60°N and 56°S (Stocks et al., 2021). Recently, a new 30m global map of elevation with forests and buildings removed (FABDEM, or Forests and Buildings Removed Digital Elevation Model) was released and has been demonstrated to be more accurate than the other existing global datasets (Hawker et al., 2022). The PHES Atlases have been re-constructed using these data, with many consequent improvements. The removal of trees and forests from the underlying data has improved the hydrological modelling, generally resulting in the algorithm finding larger reservoirs. For example, in Australia, using FABDEM resulted in an increase of 53% in total GWh storage potential, although the total number of non-overlapping sites was 16% lower than found with the NASA data.

The maximum head in the original Atlas was set to 800m. This has been increased to 1600m, along with changes to the cost model to reflect the additional infrastructure needed to create a pumped hydro pair with such a large difference in altitude. Doubling the head effectively halves the cost of storage, and so has led to many more attractive pairs being found.

The original Atlas covered Greenfield PHES, where both reservoirs are artificial dry gully sites. Complementing this, our research group is also in the process of releasing a global Bluefield Atlas, where one or both reservoirs is an existing water body, an Ocean Atlas, where the ocean is used as the lower reservoir, and a Brownfield Atlas, where one or both reservoirs are repurposed mining sites (see Figure 1). Making these Atlases available highlights the vast resource of PHES in every region of the world.

Each of these types of developments has advantages and disadvantages. For example, mining sites typically have electricity infrastructure on site – of the Brownfield sites found within Australia, 84% of possible sites were within 10km of existing transmission lines. Constructing a PHES facility as an end-of-life plan can be a useful way to remediate land that would otherwise be too contaminated for other purposes and would also create a new asset at the end-of-life.

Figure 1: Potential 150 GWh PHES using Bingham Canyon mine. Upper reservoirs (light blue), lower reservoir (dark blue), tunnels (white), dam walls (grey), cost classes (red pins), and an infographic box are depicted.

Ocean pumped hydro might be useful in an arid area, such as the United Arab Emirates, or Egypt. Disadvantages of ocean sites include the need to protect equipment from the saline environment, and the possible impact of rising sea levels, while advantages include no water scarcity issues, and the requirement to only create a single on-land reservoir. Ocean pumped hydro may also be useful for islands, where limited land area may not be able to support a pumped hydro installation with two freshwater bodies of water.

Many existing water bodies already host conventional hydroelectric plants, such as Kulekhani Dam in Nepal. This site currently has less than 100 MW of run of river hydro, whereas our Bluefield Atlas found many opportunities for 2 GWh, 5 GWh or possibly even 15 GWh pairs (pictured in Figure 2). Although there is a large surplus of water in the monsoon period, and water must be released downstream, the water level is very low in the annual dry period, during winter. The construction of a new reservoir and a connecting penstock or tunnel could triple the electricity capacity, whilst creating a useful storage. The local economy is dependent upon tourists from Kathmandu, with water sports, fishing, and other attractions. By replacing the water-dependent run-of-river infrastructure with cyclical PHES, the quality and level of the water could both be improved. Our growing Bluefield Atlas highlights this and thousands of other sites around the world.

The great abundance of PHES options within the Atlases means that site selection can be very specific. In order to support a one hundred percent renewable energy, affluent economy, less than 20 GWh of storage per million people would be required. Existing energy generation, energy efficiency and productivity measures can further lower these figures, while improving cost of living, standard of living, and equity within society. The global Greenfield Atlas alone located more than 50 times the required electricity storage for a 100% renewable electricity world.

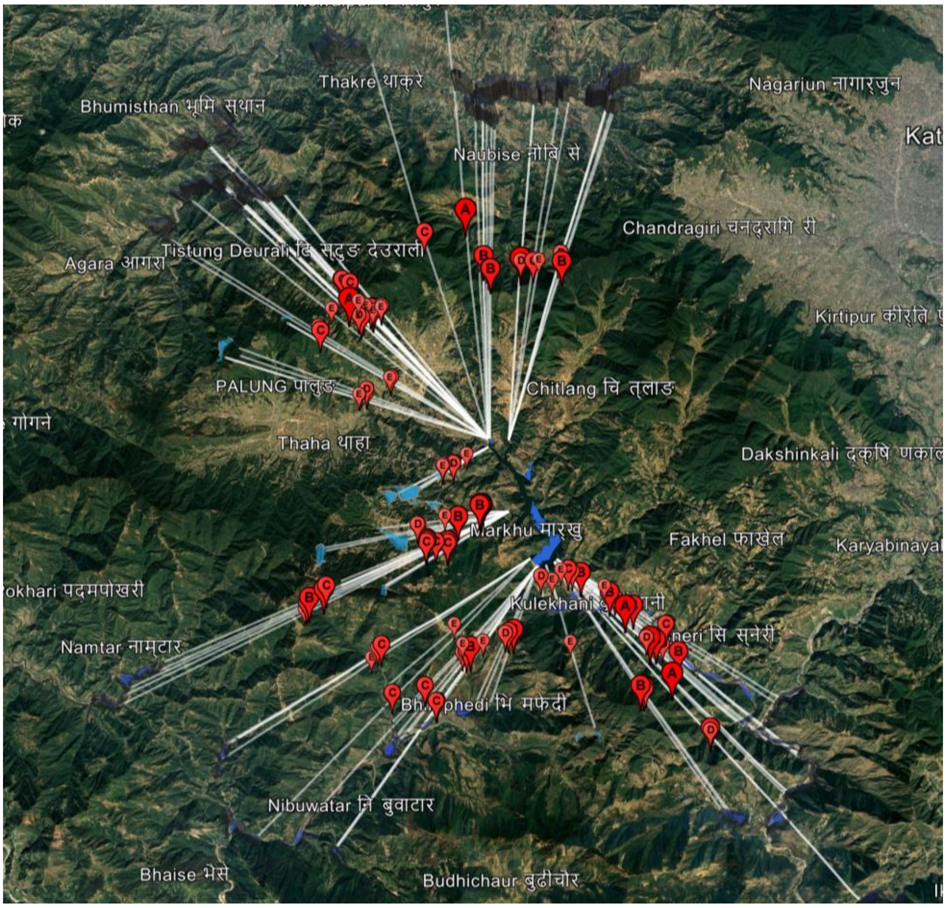

Figure 2: Kulekhani reservoir with 2, 5, 15GWh options, Google Earth

The Atlases depend upon publicly available data, such as FABDEM, and the United Nations Protected Planet data, which is updated monthly and at the time of publishing included 16% of terrestrial area around the globe. Applying local knowledge and filtering out inappropriate locations leads to a more manageable shortlist for possible pumped hydro sites.

Our research group has led two projects to do just this. The first was based in Malaysia, where we worked with the national electricity utility, Tenaga Nasional Berhad, to explore the potential of PHES in this locality. This was supported by the Australian Government through Partnerships for Infrastructure. The project included several workshops aimed at increasing knowledge sharing and skills between stakeholders, and a collaborative site selection process.

A project supported by the Australian Water Partnership applied the Greenfield and an improved version of the Bluefield Atlas to three jurisdictions within the Himalayas in May 2023. These were Bhutan, Nepal, and Sikkim, a state within India. Although each of these countries is very different from governance, social, and environmental perspectives, their electricity systems have striking similarities and future needs. These include a huge off-river pumped hydro resource that is largely undeveloped, current dependence upon seasonal conventional on-river hydroelectricity (see Figure 3), water availability that is determined by the monsoon and the lean season, growing electricity consumption and need for stable electricity supply, grid interconnection with India, and good solar resource. There is limited wind resource within this region. This project included pre-departure and in-country workshops, field visits, community consultations, and updated maps for each locality.

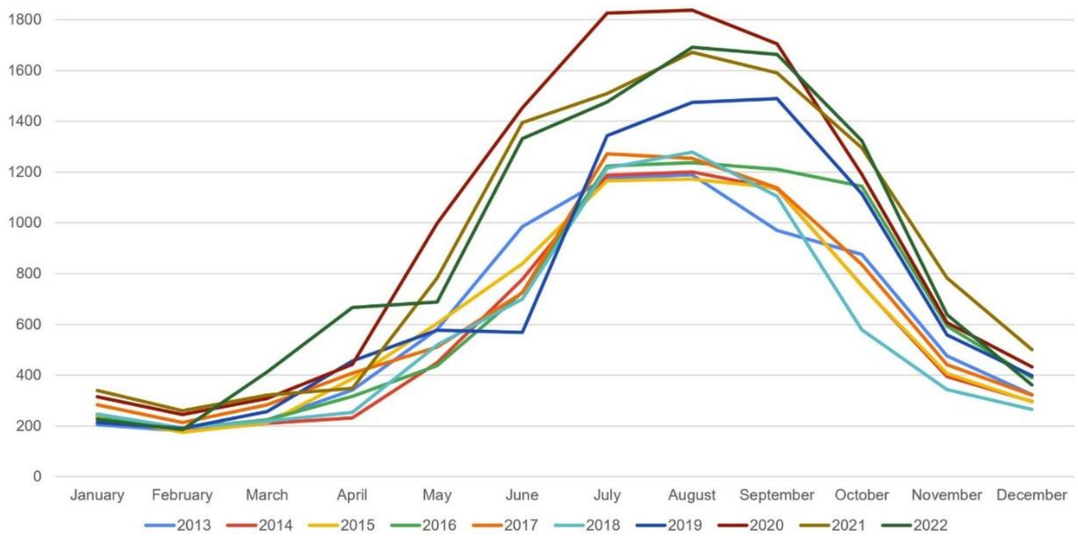

Figure 3: Monthly GWh output from Bhutanese hydroelectric plants, showing significantly lower output during the lean winter period, data from Druk Green Power.

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