HYBRID ENERGY GENERATION AND ALLOCATION SYSTEM WITH PUMPED HYDRO STORAGE

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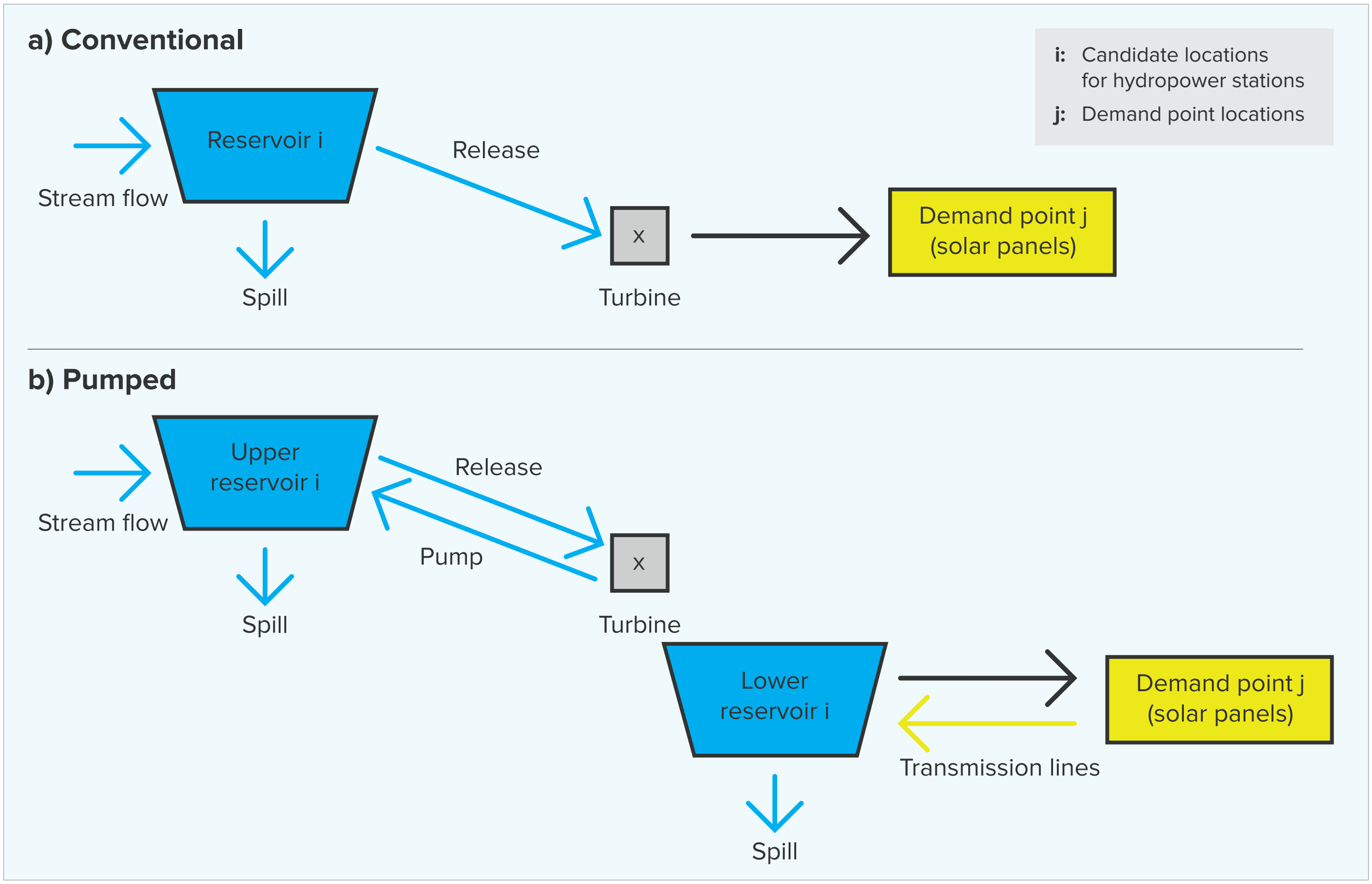


Figure 1: Hybrid Energy System with a) Conventional Hydropower Station, b) Pumped Hydropower Station

Current supply for electricity generation mostly relies on fossil fuels. International Energy Agency (IEA) estimated that primary sources of electricity in 2011 consisted of 41.3% coal, 21.9% natural gas and 4.8% petroleum summing up to a 68% share for fossil fuels in primary electricity consumption in the world . However, fossil fuels are finite and their combustion results in greenhouse gas emissions, which contribute to global warming and health hazards. Therefore, energy models that involve clean and renewable energy sources are necessitated to ease the concerns on the electricity generation that meets the projected demand.

Transition to alternative renewable energy sources is inevitable. However, renewable sources are generally variable and heavily dependent on the spatial location (e.g. sunshine while more predictable, is limited to daytime hours). Thus if a future energy system wants to predominantly rely on these sources, it must utilize one of the following:

1. A mix of variable and dispatch-able resources that are interconnected, thus requiring investments in transmission
2. Back-up dispatch-able resources, fossil fuels or hydro in the near term
3. Storage, for example, pumped hydro or compressed air energy storage
4. Some of the energy generated to be curtailed or use intelligent demand side management.

For cost-effectiveness of the overall system, the approach is likely to be all of the above.

Model

For the sake of demonstration we imagine a long-term scenario that primarily relies on solar and hydro as the renewable resources and assume that fossil fuels will be expensive and hence judiciously used.

We imagine the demand profiles of a specific country and model the long-term investments and storage while capturing the volatility of hourly supply and demand. We identify candidate basins for hydro power stations and aggregated demand point locations (the cities or the states of the country). Then, we determine the possible transmission network between supply and demand points. We mathematically model two hybrid energy generation and allocation systems where time variability of energy sources and demand is balanced using the water stored in the reservoirs. In the first model, Figure 1a, we use conventional hydro power stations where incoming stream flows are stored in large dams and water release is deferred until it is needed, and in the second model, Figure 1b, we use pumped hydro stations where water is pumped from the lower reservoir to the upper reservoir during periods of low demand to be released for generation when demand is high.

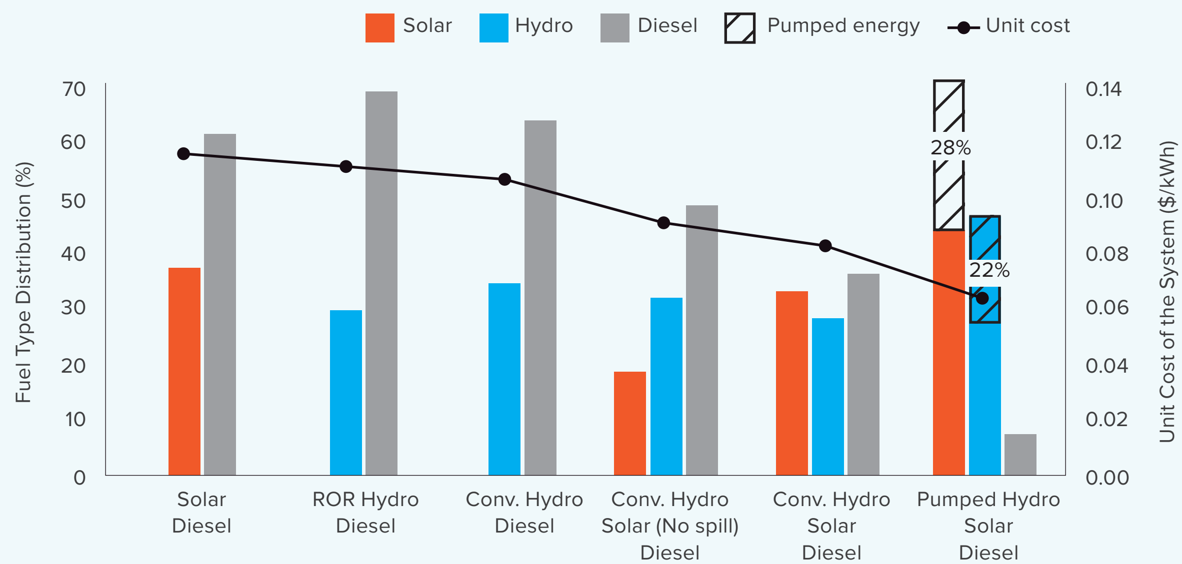
Goal

The aim of the models is to determine optimal sizing of infrastructure needed to match demand and supply in a most reliable and cost effective way. An innovative contribution of this work is the establishment of a new perspective to energy modeling by including fine-grained sources of uncertainty such as stream flow and solar radiations in hourly level as well as spatial location of supply and demand in national level. In addition, we compare the conventional and the pumped hydro power systems in terms of reliability and cost efficiency.

In practice

Using India as a casestudy for our model, we look to answer whether solar energy in addition to high hydro power potential in Himalaya Mountains would be enough to meet growing electricity demand if fossil fuels could be almost completely phased out from electricity generation.

Starting with no renewable source (100% diesel), we gradually modify the system to include more advanced use of renewable sources and finally obtain the pumped hydro model. We compare the systems in which we combine diesel with solar, run-of-the-river (ROR) system and a hydropower station with conventional and pumped hydro reservoirs.



	Solar Diesel	ROR Hydro Diesel	Conv. Hydro Diesel	Conv. Hydro Solar (No spill) Diesel	Conv. Hydro Solar Diesel	Pumped Hydro Solar Diesel
Upper Reservoir (km3)	-	-	0.24	0.24	0.29	0.15
Lower Reservoir (km3)	-	-	-	-	-	0.04
Generator (GW)	-	1.09	1.13	1.05	1.06	1.50
Solar Panel (km2)	16.61	-	-	6.42	12.50	28.18

Figure 2: Alternative Technologies

In conclusion

Figure 2 shows that combining different renewable sources in a hybrid system and using storage reduces the intermittency of renewables, reduces the use of fossil fuels as well as the unit cost of the system. An even greater reduction is created by the use of pumped hydro storage—where the losses of the pumping process makes the pumped hydro stations a net consumer of energy overall (6% is due to losses). Additionaly, energy can be stored in the pumped systems, reducing variability of clean energy sources and also decreases the unit cost of the system (25% in this casestudy). It is also possible to observe that the addition of a small lower reservoir to the system (0.04 km3) allows a smaller upper reservoir compared to conventional hydro system (0.15 km3 compared to 0.29 km3), which is environmentally favorable.

This shows us that with today's technology and cost structure, it is possible to reduce fossil fuel's role in electricity generation to less than 10% for the area of interest in India. Furthermore, it is expected that solar power will become more attractive to consumers over the next two decades as prices decline and technologies expand. For these reasons, our study combined solar and hydro power, however, wind and nuclear could also be promising sources, making it an even more viable solution. Therefore, it is possible to conclude that it seems very promising to eliminate fossil fuels from India's electricity generation.