Seasonal Pumped-Storage: An Integrated Approach for Water, Energy and Land

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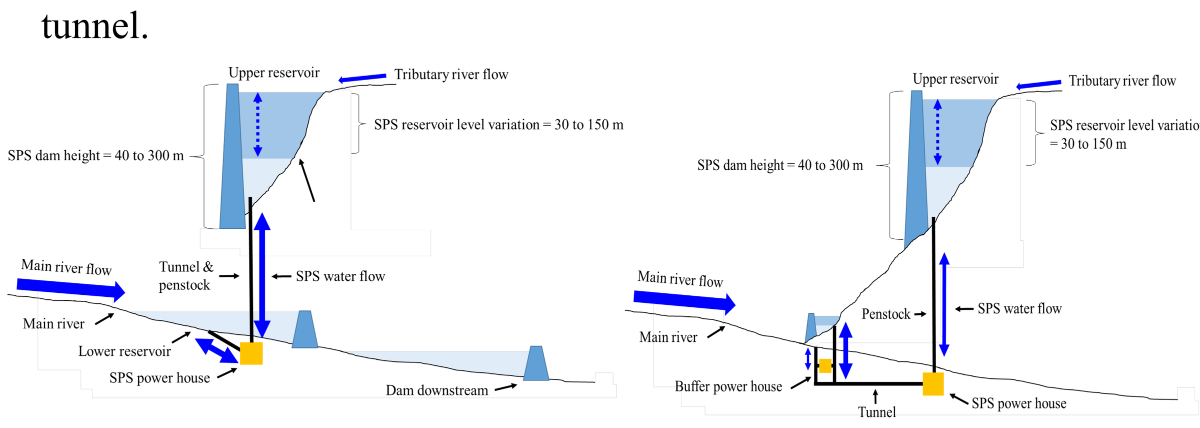
Introduction

Renewable sources of energy are providing an increasing share of the electricity generation mix, but their intermittency drives a need for energy storage. At the same time, water resources are increasingly scarce due to changes in demand, such as from population growth, supply side pressures such as climate change and governance challenges relating to poor management. Large storage reservoirs are used for water management and for energy storage. However, some existing and proposed hydropower reservoirs require vast areas of land and have considerable social and environmental impacts. Due to the growing concern with water-energy-land nexus issues and challenges, we investigate how energy and water storage services could be integrated with seasonal pumped-storage plants, optimizing hydropower generation, electricity grid management and water management, with low land requirements. The cost, land requirement and social impacts of conventional reservoir dams and potential seasonal pumped-storage plants in Brazil are compared. Whilst seasonal pumped-storage have higher capital costs than conventional reservoir dams, given the much lower land requirements and evaporative losses, they are a valuable water and energy storage alternative especially in locations with plain topography and high evaporation.

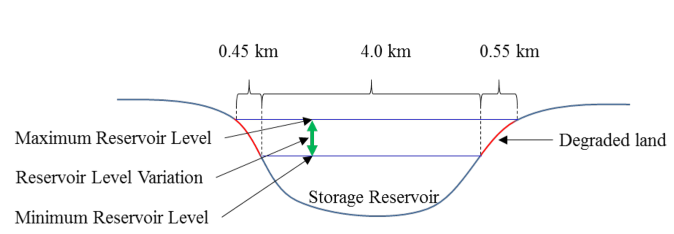
Methodology

This methodology section describes the Seasonal Pumped Storage (SPS) technology used to get the results.

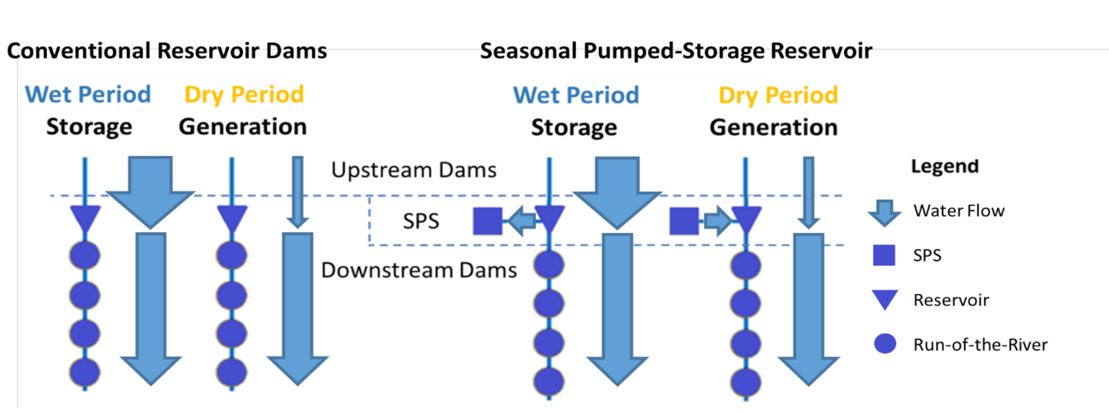
SPS consists of a two reservoir system, one large or small reservoir is the river bed and a large reservoir parallel to the river connected by a tunnel.



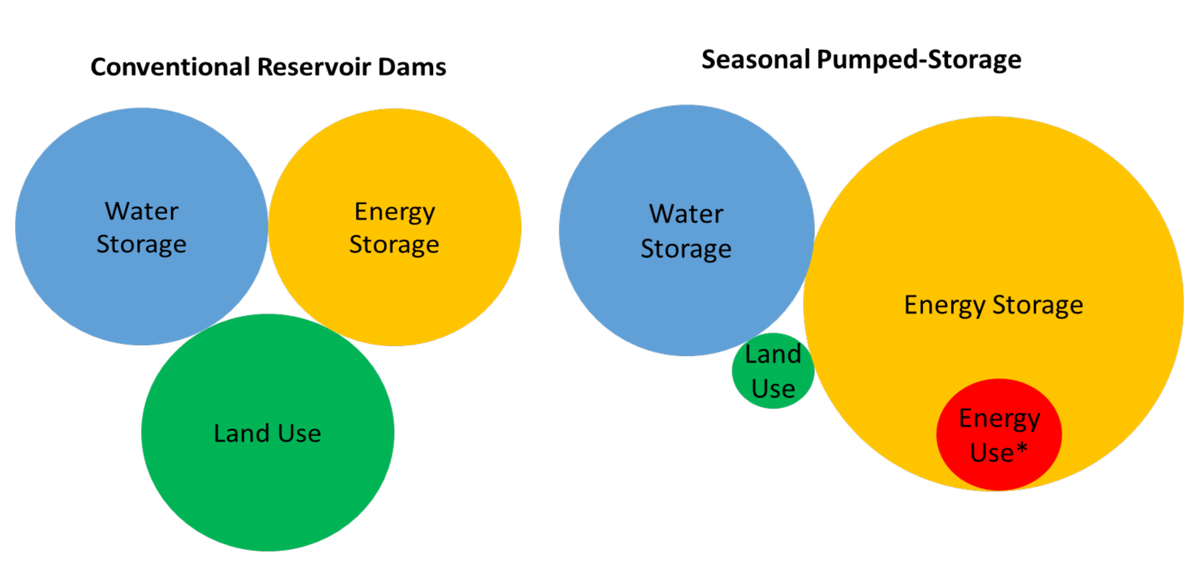
The possibility of building SPS reservoirs parallel to the main river allows the construction of more appropriate reservoirs.



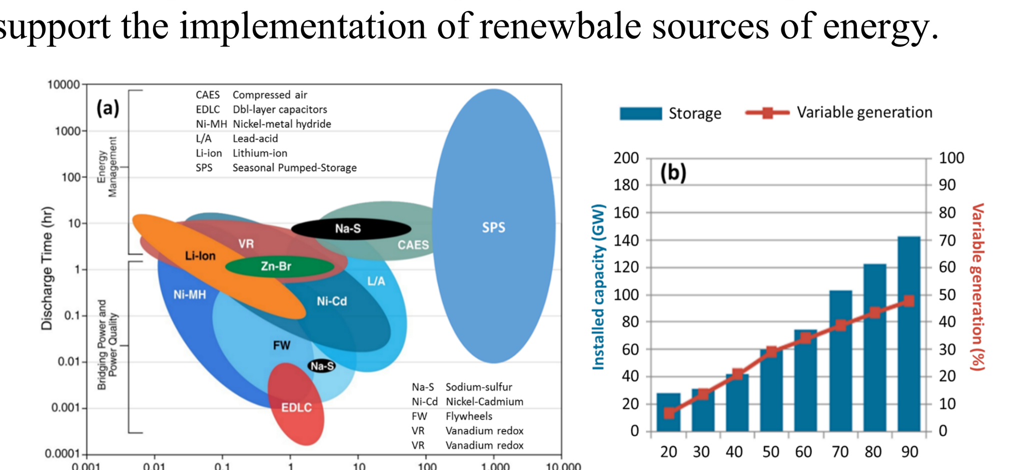
These SPS reservoirs can be combined with a series of dams in cascade with the objective of regulating the flow of the river, similarly to convencional reservoir dams (CRD).



Comparison between conventional reservoir dams and seasonal pumped storage.

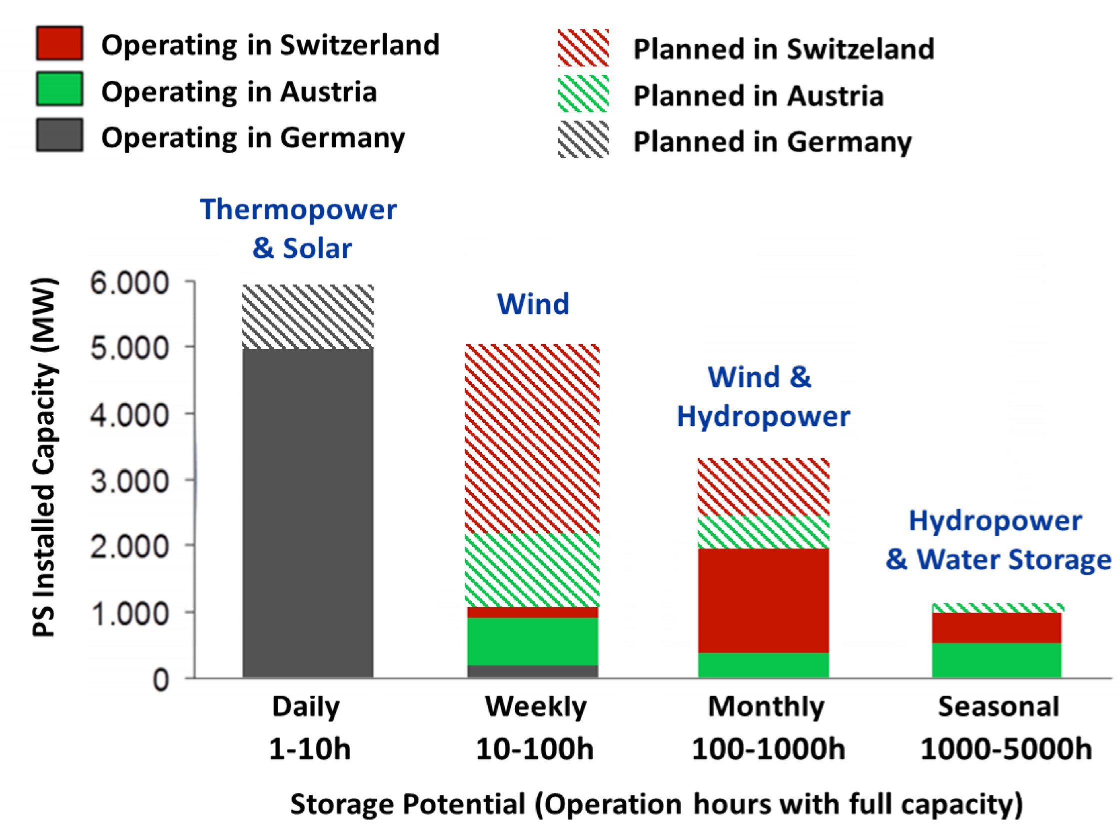


SPS can be operated integrating for hourly, daily, weekly, month, seasonal and pluri-annual storage cycles. It is an important alternative to support the implementation of renewbale sources of energy.



Results

This research looked at the potential for seasonal Pimped Storage around the world. The figure below presents the constructed and planned SPS plants in Germany, Switzerland and Austria. The description above, for example "Wind", present the need for weekly energy storage.



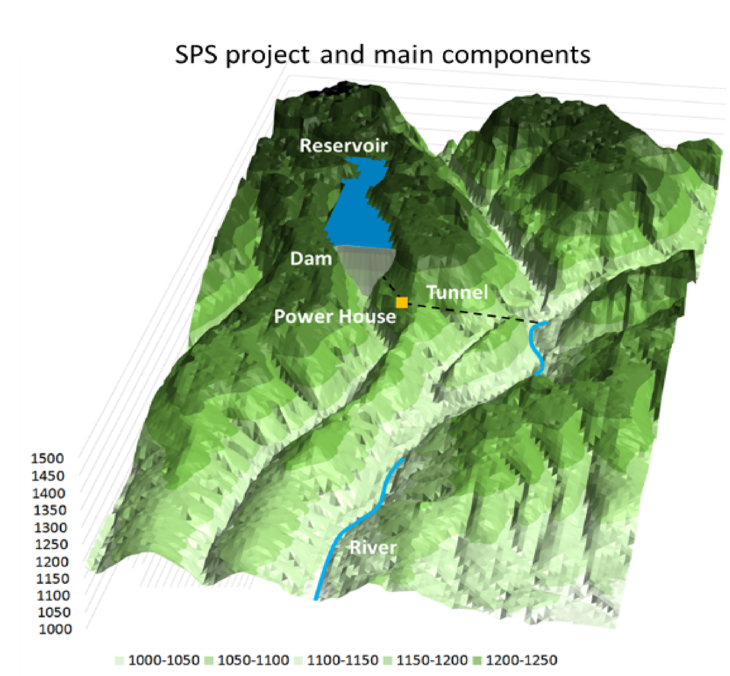
The Table below presents the main services provided by SPS.

Pumping/ Generation Head & Storage Years	Multi-Purpose SPS Applications												Country
	Energy						Water					LD	
	PG	IS	TO	HP	ES	HO	WS	ER	TW	BT	FC	LD	
High (500-800m) One year storage	• • •	• • •	• • •	• • •	• •	•	•	• • •	•	•	•	•	Austria, Switzerland
High (500-800m) Multiple years storage	• • •	• • •	• • •	• • •	• • •	•	• •	• • •	• •	• •	•	•	Norway, Sweden
Medium (100-500m) One year storage	• •	• •	• •	• •	• •	• •	• •	• •	• •	• •	• •	• •	Canary Island
Medium (100-500m) Multiple years storage	• •	• •	• •	• •	• • •	• •	• • •	• •	• • •	• • •	• •	• •	New Zealand Iceland, Canada, Brazil, Australia, USA
Low (50-100) Multiple years storage	•	•	•	•	•	• • •	• • •	•	• • •	• • •	• • •	• • •	USA

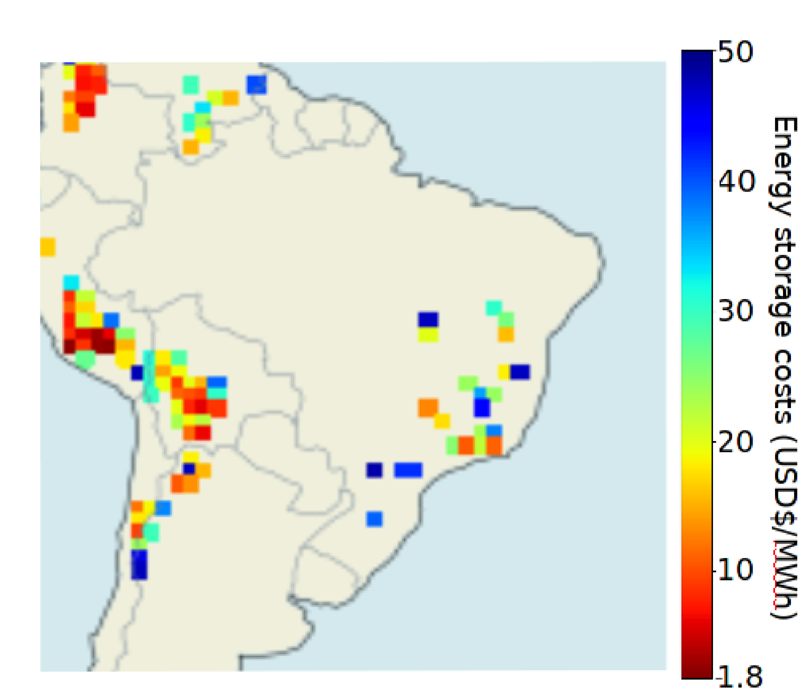
Peak Generation, Intermittent Generation Storage, Transmission Optimization, Hydropower Generation, Energy Security, Cascade Hydropower Optimization, Water Supply, Evaporation Reduction, Transport with Waterways, Inter-Basin Transfer, Flood Control, Land Requirement

Challenges	Benefits of deploying seasonal pumped-storage
Highly seasonal hydropower generation	Increase water and energy storage in water basins to regulate the river flow and increase hydropower generation. Store excess water during periods of high hydropower generation and reduce spillage.
CO_2 emissions reduction	Hydropower, solar and wind generation usually do not have the same seasonal generation profile as the demand for electricity. Natural Gas is an option for flexible electricity generation, however, it is a fossil fuel based source of energy and emits CO_2. A seasonal storage option should be considered by countries that intends to considerably reduce CO_2 emissions.
Solar power generation	Countries in high latitudes have a very seasonal solar power generation profile. Seasonal storage allows using the energy stored in the summer during the winter, when there is lower solar generation.
Seasonal demand variations	Countries in mid and high latitudes tend to have a seasonal electricity demand profile, consuming more electricity summer for cooling and during the winter for heating purposes, respectively. Typically, the peak national grid demand can be two to three times as high as the minimum demand. [22].
Electric Heating	With the electrification of the heating sector in countries at high latitude, the demand of electricity during the winter will increase even further.
Low energy security	Reduction in fluctuation of electricity prices with fossil fuel prices and supply. Reduction in fluctuation of electricity prices with renewable energy availability, especially hydropower. Reduction in fluctuation of electricity prices with the demand for electricity.
Low power plant capacity factor	Large part of the generation capacity of a country is at stand-by for energy security reasons. The number of stand-by plants would reduce it seasonal pumped-storage is implemented.
Island electricity generation	Costs of oil and diesel based electricity generation might be higher than the combination of renewable sources and energy storage.
Inappropriate topography	SPS plants can store water on higher ground away from the river, in cases where along the river is infeasible
High evaporation rates	Water storage in reservoirs with high level variation considerably reduces evaporation rates due to higher volume to area ratio.
High storage reservoir sedimentation	SPS projects have much smaller sedimentation rates than conventional dams due to the small catchment area.
Lower environmental and social impacts	Damming a major river for storage would affect a higher environmental and social impact than damming a small tributary river. SPS allows water storage without fragmenting the ecosystem of a main river.
Better water quality control	Storing the water parallel to the river, allows for a better control of the water quality in the reservoir. As it would not be directly affected by the fluctuations in water quality in the main river.
Flood control	SPS plants can be used in combination with conventional flood control mechanisms to improve their efficacy.
Transport with waterways	SPS plant channels could be also used for transport in waterways, combining the transport of water and goods. Additionally, the improvement in water management resulted from a SPS plant would reduce the changes that a waterway runs out of water.
Interbasin Transfer	SPS projects can be combined with an interbasin transfer project to increase the water security of a region or provide balancing between watersheds.
Water security	Increase the water storage capacity in regions where conventional storage reservoirs are not appropriate.

An example of SPS project developed for the Upper Zambezi basin is presented below:



Preliminary results for current research on the World Potential of Seasonal Pumped Storage are presented below:



Conclusion

Given the growth of wind, solar and other intermittent electricity generation sources to meet the Sustainability Agenda, the need for energy storage solutions also grows. Water supply and management is also increasing in importance due to climate change and population growth. This research compared conventional reservoir dams and seasonal pumped storage reservoirs looking at the water-energy-land nexus and concludes that SPS in general requires 1-2 orders of magnitude less land than CRD to store similar volumes of water and energy.
SPS should be designed as a multi-purpose plants to deliver reduced evaporative losses, increase the energy storage potential of the stored water, water supply storage, flood risk reduction, transport in waterways, optimization of hydropower generation, peak hours electricity generation, storage of intermittent renewable generation, electricity transmission optimization, inter-basin transfer and increase energy security.
Given the increased awareness and understanding of important water-energy-land nexus interactions, our findings suggest that seasonal pumped-storage can be a favorable and sustainable alternative for managing water and energy systems with low land requirements.

Acknowledgments

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Literature Review

This poster has been based on current research developed at IIASA and on the paper below

Hunt, J. Byers, E., Riahi, K., Langan, S. Comparison between seasonal pumped-storage and conventional reservoir dams from the water, energy and land nexus perspective. Energy Conversion and Management 166, 385-401, 2018.