

A Comprehensive Comparison Study Between Energy Storage Systems along the Oldman River Basin

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Summary

Variable renewable energy (VRE) is a crucial source to mitigate climate change and to help decarbonize the power sector. Because of their intermittency and unpredictability, the growing share of variable renewables may lead to numerous problems in power systems (Sinsel et al., 2020). Energy storage systems (ESSs) can stabilize and balance the power output (Tee et al., 2024). This paper will offer a comprehensive comparative MCDM-based analysis of three energy storage systems: pumped hydro energy storage (PHES), compressed air energy storage (CAES), and battery energy storage (BESS) in Oldman River Basin, Alberta, Canada. The evaluation will be conducted using a multi-criterion approach that encompasses both technical and socio-economic perspectives. Moreover, the paper examines the policy frameworks of Canada, specifically Alberta, to determine whether any of these storage systems are preferred. This study also aims to evaluate the risks and benefits that each energy storage system may pose to nearby Indigenous communities, particularly the Piikani Nation. The outcomes of this study are crucial to guiding energy storage policy and decision-making procedures, especially in Canada.

Introduction

The global energy industry is undergoing a phase of transition from the production of power through fossil fuels to renewable sources. This inclination towards more integration of VRE is substantially motivated by the negative impacts of emissions and the global vision of “decarbonization”. Alberta has seen a rapid growth of VRE in the province, currently Wind and Solar account for 22% of Alberta’s capacity (CLEAN ENERGY CANADA, 2023). This growth of variable renewable energy in Alberta led to the provincial government introducing a 7-month moratorium on wind and solar projects (Weber, 2023) and concerns about grid instability. These concerns are highlighted by the recent weather phenomenon in the province that occurred between January 11th and 14th 2024 where the wind was operating at near zero capacity as turbines were shut down due to the risk of brittle fracture (Zinchuk, 2024). Solar was also operating around a 6.0% capacity factor due to reduced daylight hours. Hydro dams in Alberta such as the Oldman River Dam were not producing any power due to seasonal trends. The variance in power production by wind and solar over January 2024 is shown in Figure 1.

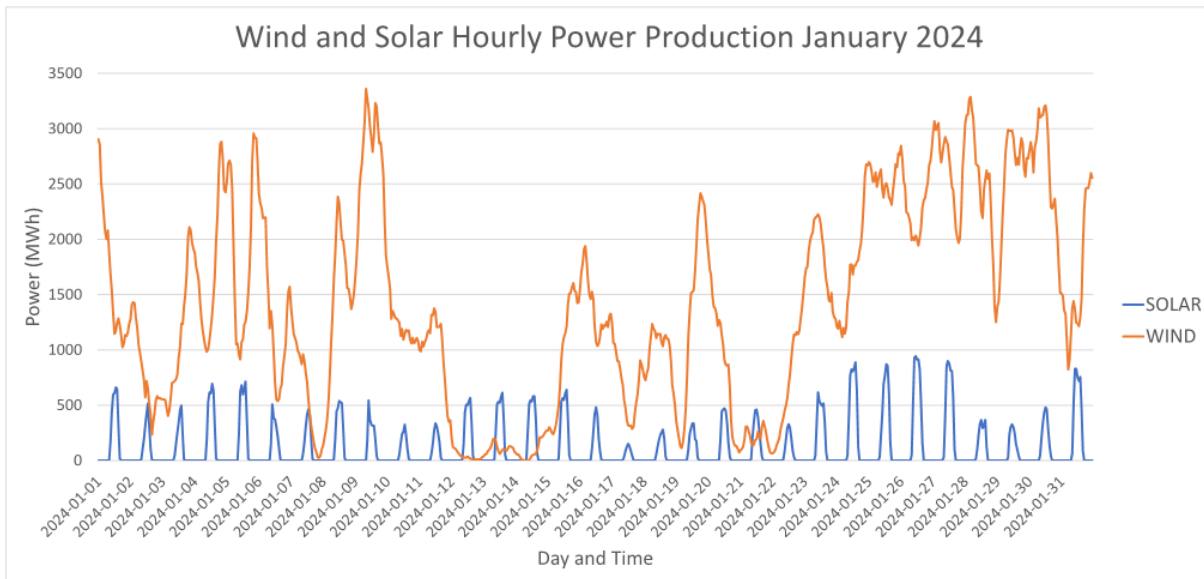


Figure 1 Total Wind and Solar Hourly Power Generation in Alberta from January 1st to 31st 2024.

At the same time, Alberta set a new record for peak demand at 12384 MW on the evening of January 11th. Prices surged to a peak of \$667 per MW (Zinchuk, 2024). To help stabilize Alberta's grid both British Columbia and Saskatchewan provide power to Alberta. Saskatchewan provided 153 MW of power (Quon, 2024) and British Columbia provided 200 MW of power (Vaski, 2024). With Alberta's grid frequently facing challenges like this, further deployment of energy storage facilities is necessary to mitigate the consequences of seasonal weather events that cause VRE power production to decline to near zero for extended periods. A number of energy storage facilities have been already developed, of which pumped hydro energy storage (PHES), compressed air energy storage (CAES), and battery energy storage (BESS) systems are going to be evaluated here.

In battery energy storage systems (BESS), the lithium-ion batteries will be charged by electricity from the power grid and then will be returned to the power grid when power demand is high. Lithium-ion batteries were first commercially produced by Sony in the early 1990s and were originally used primarily for small-scale consumer items such as cell phones. Recently, they have been used for larger-scale battery energy storage and electric vehicles.

Pumped hydro energy storage (PHES) is considered as one of the most widely used large-scale storage technologies to address the intermittency and variability challenges of renewable energy sources. PHES systems pump water to an elevated reservoir to store any available excess energy. This stored energy can be retrieved by releasing water

from the upper reservoir to a lower one. However, PHES is limited by natural conditions, such as topography and water resources. (Yurter et al., 2024).

CAES is also one of the most promising large-scale energy storage technologies due to its large scale, fast response, and low operating cost. Large-scale CAES generally require the use of underground spaces, including abandoned mine caverns, depleted oil and gas repositories, and salt caverns. The CAES salt cavern is used to store compressed air during off-peak periods and to release it to generate electricity during peaks. The use of CAES salt caverns is an important method for resolving the challenge of peak shaving and off-peak filling in renewable energy electricity systems (Li et al., 2023).

This study focuses on the Oldman River Basin in Alberta, Canada, a region intrinsically linked to the Piikani Nation, part of the Blackfoot Confederacy. The Oldman River, named after Napi, the creator figure in Piikani mythology, holds significant cultural importance for the Piikani people. This region, particularly the Old Man's Playing Ground, has been a central part of Piikani life, serving as a gathering place for cultural activities. Historically, the Piikani were a nomadic tribe, relying on natural resources like buffalo, a practice that was disrupted by European contact in the 18th and 19th centuries. The first European to explore the region was Peter Fidler, a surveyor for the Hudson's Bay Company, in the winter of 1792-93. European settlement, initially driven by the fur and whiskey trades, began in earnest in the 1870s, drastically altering the landscape and way of life for the Piikani (Newton, 2021).

The Piikani Nation, have a deep-rooted connection and understanding of their local environment, cultivated over generations. Their knowledge and insights are invaluable in assessing the environmental impact of energy systems and ensuring they align with sustainable practices. Involving indigenous communities in decision-making respects and upholds their rights, acknowledging their historical and ongoing relationship with the land. This approach aligns with broader principles of equity and justice, recognizing the adverse effects past projects have had on indigenous populations. Collaboration with the Piikani Nation facilitates a more holistic and culturally sensitive approach to energy development, ensuring that projects do not only meet technical, political and economic criteria but also align with the cultural, spiritual, and social values of the community. Such inclusive practices foster goodwill, trust, and long-term partnerships, essential for the success and sustainability of energy projects. Therefore, the integration of indigenous perspectives is not only a matter of ethical responsibility but also a strategic approach that enriches the project with a diverse range of insights and fosters a more sustainable and harmonious relationship with the environment and its original stewards.

This paper will present a comprehensive MCDM-based comparison of three energy storage systems: pumped hydro energy storage (PHES), compressed air energy storage

(CAES), and battery energy storage (BESS). The three energy storage systems will be evaluated for their suitability to be deployed along the Old Man River Basin on their technical capabilities, economic benefit, policy support, and their impact on Indigenous communities.

Methodology

This study will use Multi-Criteria Decision Analysis (MCDA) to compare the ESS technologies across their technical capabilities, economic value, policy support, and impacts on Indigenous people. MCDA is one of the most accurate methods of decision-making, as it allows for qualitative and quantitative criteria to mathematically find the best solution (Taherdoost and Madanchian, 2023). While ESS projects can be selected for their technical capabilities or their economic benefit, they have far-reaching impacts on Indigenous communities and are greatly affected by public policy therefore it is required to use MCDA to evaluate the deployment of ESS technologies along the Oldman River Basin. Four different categories will be used to compare the three selected ESS technologies: Technical Capabilities, Economic Value, Policy Support, and Impacts on Indigenous People each of these categories will be equally weighted. Within each category, several different criteria will be used to assess each technology. Table 1 shows a breakdown of category and criteria weighting.

Category	Weighting	Criteria	Criteria weighting
Technical Capabilities	0.25	Site Availability	0.042
		Response time	0.042
		Discharge time	0.042
		Lifespan	0.042
		Efficiency	0.042
		Life cycle emissions	0.042
Economic Value	0.25	Net-Present-Value	0.083

		Internal Rate of Return	0.083
		Return on Investment	0.083
Policy Support	0.25	Subsidies/ Tax credits	0.125
		Existing framework	0.125
Impact on Indigenous People	0.25	Risk to Communities	0.083
		Opportunities	0.083
		Land use	0.083

3.1 Technical Criteria

For technical aspects, factors such as response time, discharge time, life cycle time, and efficiency for each system need to be taken into account to compare the various ESS options. In addition, the “site availability” criterion will investigate the the proximity of mountainous areas and underground geological formations is critical for successful efficient PHES and CAES operations, respectively. Besides, the growing incorporation of variable renewable energy (VRE) and corresponding energy storage facilities mitigates climate change and helps decarbonize the power sector. Therefore, the extent to which each ESS would reduce the emissions of CO₂ in their respective life cycles has to be taken into consideration.

3.2 Economic Criteria

VRE and ESS systems require high up-front capital costs for example TransAlta’s Ghost Power Plant WaterCharger Battery Storage Project is Estimated to cost \$120.0M to provide a 180 MW of storage (Major Projects Alberta, 2024) and the Marguerite Lake Compressed Air Energy Storage Projects is Estimated to cost \$500.0M for 320 MW of storage (Major Projects Alberta, 2024). With such high capital costs and the volatility of electricity prices, economic evaluation is key in determining VRE project viability (Dranka et al. 2020). As this paper seeks to compare three different ESS technologies it must

address the financial advantages and disadvantages of each technology in the Albertan market.

To evaluate each technologies economic viability for project development along the Oldman River Basin three indicators have been selected. Net-Present-Value (NPV) calculated at 20 years will be used to compare the project's long-term viability. Alongside NPV, the Internal Rate of Return (IRR) will also be used as an economic indicator to compare the technologies. Both NPV and IRR are commonly used tools in evaluating VRE projects (Dranka et. al 2020). To further compare the three ESS technologies, return on investment (ROI) will also be used.

3.3 Policy Criteria

The role of the policy is crucial to addressing concerns around ESS related to social equity, the environment, sustainability, operation, and construction. Apart from that, policies also typically address questions like who should own energy resources, how they should be used, and what kind of energy sources or energy storage systems should be employed. Therefore, a Canadian, and Albertan policy comparison of different ESS is necessary in the multi-criterion decision approach to obtain an idea of which type of energy storage system is favored by the Canadian and Albertan governments.

The evaluation of various energy storage systems concerning the policy domain in the Oldman River Basin will be using two criteria available Tax credits/ Subsidies and approval frameworks will be compared. Based upon the nature of storage and investment required the federal government as well as the provincial government have policies that offer certain subsidies or tax credits to particular types of storage systems. Thereby, the evaluation of the total tax credits as well as incentives offered by both governments by various policies can help in deciding the energy storage system that is favored or promoted by the government. This evaluation upon approval framework will be based upon the environmental regulations and operating standards that each system has passed through to get approval as per the Energy regulatory framework. In addition, the time of approval for each of the proposed energy storage projects will be also included in this to assess the systems on policy criterion.

3.4 Indigenous Criteria

Evaluating the risks and hazards of different energy storage systems (BESS, PHES, and CAES) in the context of their impact on the Piikani Nation of the Oldman River Basin is a complex course of action. It involves understanding the specific technical and environmental characteristics of each system, as well as how these might intersect with the unique cultural, ecological, and social dynamics of the Piikani Nation.

This paper will investigate the potential risks and hazards associated with these systems, such as fire, explosion, toxicity, and environmental pollution, and also examine the potential conflicts arising because of the energy storage systems in the Piikani traditional territory. To mitigate these risks, this paper proposes several approaches including implementing robust safety measures, effective battery management systems, regular maintenance, comprehensive hazard analyses, and environmental impact assessments (Conzen et al., 2022).

The potential hazard evaluation methodology can be a hybrid approach combining different methods to comprehensively assess the potential hazards in energy storage systems (EES). This approach can be broken down into several key steps (Qi et al., 2021):

1. Preliminary Identification of Hazards: The first step involves using the Hazard Identification (HAZID) method to preliminarily identify major hazards associated with each EES system. The types of hazards are then determined.
2. Detailed Analysis of Types of Hazards:
 - Storage Hazards: These refer to potential damage in the event of an unintended release of stored energy. For storage hazards, possible accident scenarios for each EES storage unit are outlined. A consequence-based analysis is then used to evaluate the worst-case consequences based on the instantaneous release of the entire inventory, without considering existing safeguards. This step assesses the inherent level of the storage hazard by estimating the energy damage areas for different storage hazards.
 - Operational Hazards: These are evaluated using a Hazard and Operability study (HAZOP) combined with a risk matrix method. This method systematically analyzes process hazards during operations through team-based brainstorming. A risk matrix is applied to determine the risk level of identified operational hazards based on the likelihood of occurrence and severity of consequences.
 - Connection Hazards: These hazards depend on system connectivity and are analyzed by examining published integrations of the EES systems with other energy sources and systems. The analysis focuses on potential risks and sources of hazards induced by these system combinations.
3. Proposal of Hazard Mitigation Approaches: Based on the results of the hazard identification, the study will propose several hazard mitigation approaches. These

approaches include both engineering and administrative controls and consider a full range of inherent, passive, active, and procedural safeguard options.

This paper seeks to emphasize the importance of engagement and consensus building, effective negotiation, fostering cooperative land use agreements, and accommodating the diverse interests and needs of the Piikani Nation. As such this paper will compare the potential benefits these ESS could offer Piikani Nation. These benefits include cheaper energy, especially during peak times through advance purchase agreements, enhanced power stability to prevent winter blackouts, job opportunities for community members, and land rental agreements for projects located on Indigenous territory.

Finally, this paper will seek to compare the three ESS on their land-use implications.

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