RESEARCH ARTICLE | DECEMBER 11 2020

Techno-economic evaluation of long-term energy storage option for CSP and other variable renewable energies in South Africa FREE

Johan D. Burger ✉; Thomas M. Harms; A. Ben Sebitosi

AIP Conf. Proc. 2303, 170003 (2020)
https://doi.org/10.1063/5.0028938

Techno-Economic Evaluation of Long-Term Energy Storage Option for CSP and Other Variable Renewable Energies in South Africa

Johan D Burger[1, a)], Thomas M Harms[1, b)] and A Ben Sebitosi[1, c)]

[1] *Department of Mechanical and Mechatronic Engineering, Stellenbosch University, Stellenbosch, South Africa*

[a)] Corresponding author: handre.burger@gmail.com
[b)] tmh@sun.ac.za
[c)] sebitosi@sun.ac.za

Abstract. This study sets out to identify suitable technologies for long term storage of energy generated via CSP and other variable renewable energies (VRE). A method of evaluation of candidate technologies was developed which considers technical and economic performance based on niche energy storage applications. Based on current and projected market data, several storage options are recommended.

INTRODUCTION

South Africa's installed energy mix consists of approximately 88 % of non-renewables like coal (Rankine cycles with some substantial dry cooling), gas (Brayton open cycle) and nuclear (pressurized water reactors, sea water cooled Rankine cycles) [1]. These power plants use synchronous generators which can connect directly to the grid, according to the national grid code, because they have an operational inertia that stabilizes the system during periods of sudden load change [2]. With increased grid penetration of variable renewable energies (VRE), installation curtailment is often enforced due to capacity limitations of traditional power networks [2-3]. Integration of VRE into the grid pose several technical challenges according to South Africa's grid connection code [4]. Therefore, the intermittent nature of VRE inhibits larger penetration into the energy mix as they cannot operate as a baseload plant.

To overcome this limitation and facilitate a greater penetration of VRE into the market, a combination of long-term storage with direct grid generation is proposed. Long-term storage of excess energy generated during peak production periods would allow VRE systems to reliably produce power indefinitely, filling the role of traditional baseload like coal and nuclear fuel-based plants and without making use of gas peaking plants to supplement production. In this case, long-term, refers to storage capacity of generated energy for several weeks or months, with a target scenario of at least seasonal storage although even longer-term storage may be a national requirement. This type of storage capacity would allow VRE to store excess energy generated in peak-producing months for later use, removing it's susceptibly to weather patterns and safe-guarding against unexpected generation outages, giving them true base load capability.

Concentrated solar power (CSP) plants are ideal candidates since they traditionally use low cost thermal storage to store heat to drive steam turbines, with some CSP plants reaching up to 15 hours of storage in e.g. China [5]. CSP is often disregarded for its high apparent cost compared to PV and wind but it is important that the quality of power supplied (i.e. the smoothing out effect of rotational inertia and storage) and so the cost of storage be incorporated. Another advantage of CSP, compared to other VRE, is its quoted installation cost usually includes storage and electricity generated with the steam turbines is supplied directly to the grid. Clearly the grid benefits from a very stable supply, which storage and the rotational inertia ensure.

SolarPACES 2019
AIP Conf. Proc. 2303, 170003-1–170003-5; https://doi.org/10.1063/5.0028938
Published by AIP Publishing. 978-0-7354-4037-1/$30.00

NOMENCLATURE

Abbreviations			
aCAES	adiabatic compressed air energy storage	OPEX	operational expenditure
CSP	concentrated solar energy	VRE	variable renewable energy
CAPEX	capital expenditure		
LCOE	levelised cost of electricity	*Symbols*	
LCOS	levelised cost of storage	A_t	annual cost of system
PSH	pumped-storage hydroelectricity	i	interest rate
PtG	power to gas	n	number of annual load cycles
PtGtP	power to gas to power	t	current year
PV	photovoltaic	W_{out}	average annual power output

OBJECTIVE

The objective of the study is to identify technologies suitable for medium to long-term storage of energy generated by CSP in South Africa and compare the financial and technical performance to that of other VRE. Due to rapid growth in the storage market, future projected values from the literature are also used to compare potential technologies 10-20 years from now.

Existing literature was reviewed to identify current state-of-the-art technologies that are suitable for medium to long-term energy storage and develop a method of evaluating technologies that are suitable for medium to long-term energy storage. The developed model was then used to compare costs of different VRE and storage combinations.

METHODOLOGY

Due to the high variability of storage plant design parameters and the high sensitivity of capital (CAPEX) and operational (OPEX) costs to these variables, it was deemed necessary to evaluate the various systems using a model like levelized cost of electricity (LCOE). Typical design parameters include the system size (MW), the discharge duration (h) and the amount of annual load cycles (n). These inputs vary greatly depending on the application of storage and end use case.

Developed by [6], the levelized cost of storage (LCOS) enables the direct comparison of several technologies, irrespective of original system parameters. Where possible, technical and economic data was sourced from market values which are more accurate but, in most cases, the appropriate values could only be found in literature. The LCOS was calculated using the equation:

$$\text{LCOS}= \frac{\text{CAPEX}+\sum_{t=1}^{t=n}\frac{A_t}{(1+i)^t}}{\sum_{t=1}^{t=n}\frac{W_{out}}{(1+i)^t}} \tag{1}$$

Where the annual cost (A_t) includes OPEX and annual reinvestments in the storage system as well as the annual cost of electricity purchased. Fig. 1 illustrates the evaluation process that was followed. The combined evaluation takes into consideration various use-cases and technology readiness levels. To establish a framework for evaluation, a base case was assumed for the modelled system, the details of which can be seen in Table 1. The model's design parameters were selected based on average CSP plant sizes in South Africa [5].

TABLE 1. Design parameters of modelled system

	Value	Unit	Cycles/year
Power rating	100	MW	-
Medium-term capacity	4	h	365
Long-term capacity	720	h	12

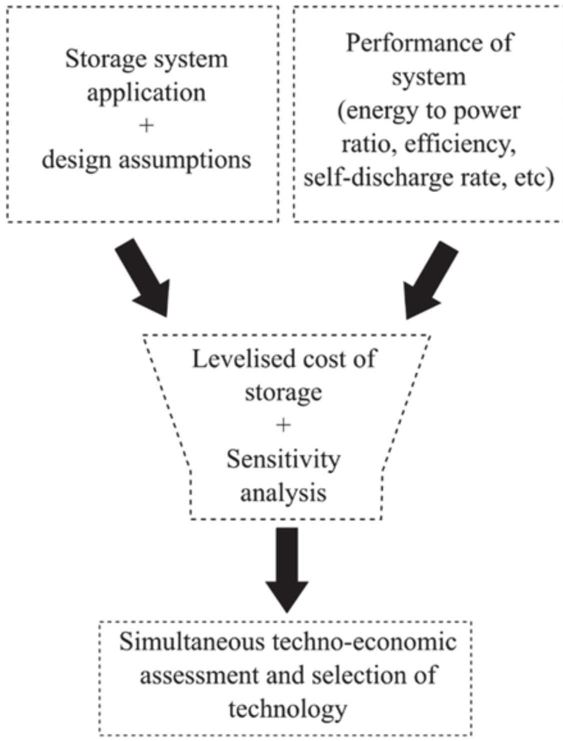

FIGURE 1. Flow diagram of the techno-economic evaluation process used in study. Adapted from [7]

RESULTS

Technologies presented in Table 2 were found to be the most cost efficient long and medium-term storage systems for the present and near future, based on projections from the literature. Like in previous studies [6-7], it was found that pumped-storage hydroelectricity (PSH) could become more cost competitive with power-to-gas-to-power (PtGtP) technologies in the near future if existing infrastructure was employed.

Through the sensitivity analysis, it was again found that LCOS is strongly dependent on operating conditions and the usage case of the system, and that selection of a technology would need to occur on a per-case basis, that considers all the factors.

From the investigation, it was also seen that battery technologies have a high range of LCOS due to the direct relation between installed capacity and CAPEX and the variability of these factors.

Other technologies to keep an eye on are Vanadium redox flow (VRF) and Lithium-ion batteries, which are projected to be as cost competitive as adiabatic compressed air energy storage (aCAES) in the following decades.

TABLE 2. Summary of most cost-effective energy storage technologies

	Long-term (720 h)	**Cost (€ct/kWh)**	**Medium-term (4h)**	**Cost (€ct/kWh)**
Present day	PSH	103 – 144	PSH	5 - 11
Projected: 2030-2040*	PtG (H_2)	24 – 59	aCAES	12 - 15

*It is important to note that the projected costs are speculative and are highly dependent on development of each respective technology and market growth.

CSP Compared to Other Variable Renewable Energy:

The results of this study have allowed for cost comparison of traditional CSP plants with storage to other VRE coupled with various electricity storage systems. PV and wind energy being of interest due their low LCOE.

CSP with traditional thermal storage (like molten salt or rock bed) was found to be more cost effective than the combination of wind or PV with technologies like Lithium-ion batteries for specific storage applications. A caveat being that this finding highly depends of the application of storage.

In the case of this study, CSP with thermal storage proved cheaper for peak-shifting (medium-term) applications with a single load cycle per day. Applications that require fast response on a small scale, like frequency regulation, are more cost effectively handled with current Lithium-ion batteries.

Technologies like PtG could prove to be more cost competitive with CSP if the production processes of these gasses were improved.

DISCUSSION AND RECOMMENDATIONS

This study set out to investigate the cost of CSP compared to leading VRE combined with storage. Although it was found that CSP with built in thermal storage was only cheaper in a few scenarios, it seems necessary that there should be a way to quantify the other benefits of CSP like direct grid generation with rotational inertia and cheap thermal storage.

Retrospectively, it can be said that there are too many input parameters and applications for which storage can be used and that the results of this study only cater to very small region of the market for energy storage. In order to fully account for all the possible use cases and designs, a more robust method of evaluation should be developed. With ever growing demand for energy storage, such a method or tool could be used to design a storage system on a per-case basis. Future research might investigate the viability of developing such a tool.

CONCLUSIONS

This study reviewed several energy storage technologies through a combination of technical and economic evaluation. Current state-of-the-art technologies were identified that best serve to store energy generated from CSP and other VRE for long and medium-term applications. Levelised cost of energy storage was used to compare systems of various input specifications and use cases. Due to the high variability of input assumptions it was also necessary to conduct a sensitivity analysis.

It was found that for long-term storage, PSH is presently the most cost effective, with PtG technologies projected be viable leading up to 2040. From the study it was clear that CSP has a potential to be cost competitive with wind and PV when the price of equivalent electricity storage capacity is factored into the LCOE calculations.

CSP is at an advantage compared to other VRE because it’s quoted installation cost usually includes storage and electricity generated with the steam turbines is supplied directly to the grid. Clearly the grid benefits from a very stable supply, which storage and the rotational inertia ensure. Added benefits such as these have not been factored into previous LCOE calculations and should weigh in on the decision to commission CSP plants.

ACKNOWLEDGEMENTS

The authors thank the Department of Mechanical and Mechatronic Engineering at Stellenbosch University, the Solar Thermal Energy Research Group (STERG) and the National Research Foundation (NRF) for funding of this research.

REFERENCES

[1] Department of Energy South Africa, "Integrated Resource Plan (IRP) 2018_Draft Update", 2019. Accessed on: April 15, 2019. [Online]. Available: https://www.ee.co.za/wp-content/uploads/2019/04/Updated-Draft-IRP2019-6-March-2019.pdf

[2] M. S. Thopil, R. C. Bansal, L. Zhang, and G. Sharma, "A review of grid connected distributed generation using renewable energy sources in South Africa", Energy Strategy Reviews, vol. 21, no. 5, pp. 88–97, 2018.

[3] X. Yan, X. Zhang, C. Gu, and F. Li, "Power to gas: addressing renewable curtailment by converting to hydrogen", Frontiers in Energy, vol. 12, no. 4, pp. 560–568, 2018.

[4] R. G. C. Secretariat, "Grid connection code for renewable power plants (RPPs) connected to the electricity transmission system (TS) or the distribution system (DS) in South Africa," vol. 8, no. 11 pp. 1–61, 2012.

[5] J. Lilliestam, M. Labordena, L. Ollier, S. Pfenninger, R. Thonig, and T. Tröndle, CSP.guru (Version 2018-05-14) [Data set], 2018, Accessed on: May 1, 2019. [Online]. Available: http://doi.org/10.5281/zenodo.1342716

[6] A. Abdon, X. Zhang, D. Parra, M. K. Patel, C. Bauer, and J. Worlitschek, "Techno-economic and environmental assessment of stationary electricity storage technologies for different time scales," Energy, vol. 139, pp. 1173–1187, 2017.

[7] V. Jülch, "Comparison of electricity storage options using levelized cost of storage (LCOS) method," Applied Energy, vol. 183, pp. 1594–1606, 2016.