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Seasonal Energy Storage To Support South Africa’s Energy Transition

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This study investigates the technical feasibility and financial viability of Seasonal Energy Storage in South Africa's future decarbonized power system.

South Africa's Energy Transition

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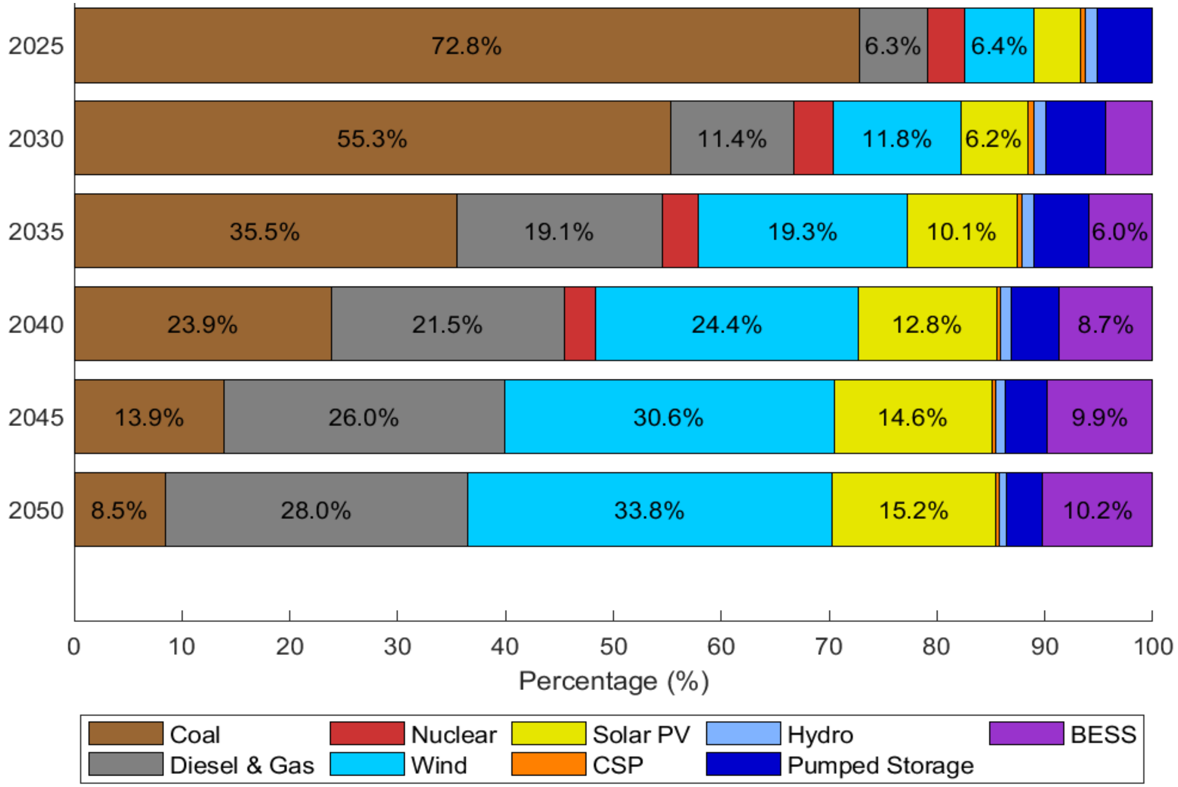
- As of 2024, SA's **coal fleet** contributes approximately **80%** of the total energy mix, (72.8% nominal capacity)
- The Integrated Resource Plan (IRP) aims to add significant **wind** and **solar** by 2050
- Variable renewable energy (VRE) is **seasonal** in nature, a VRE-dominated mix poses potential challenges such as **energy imbalances** across seasons.

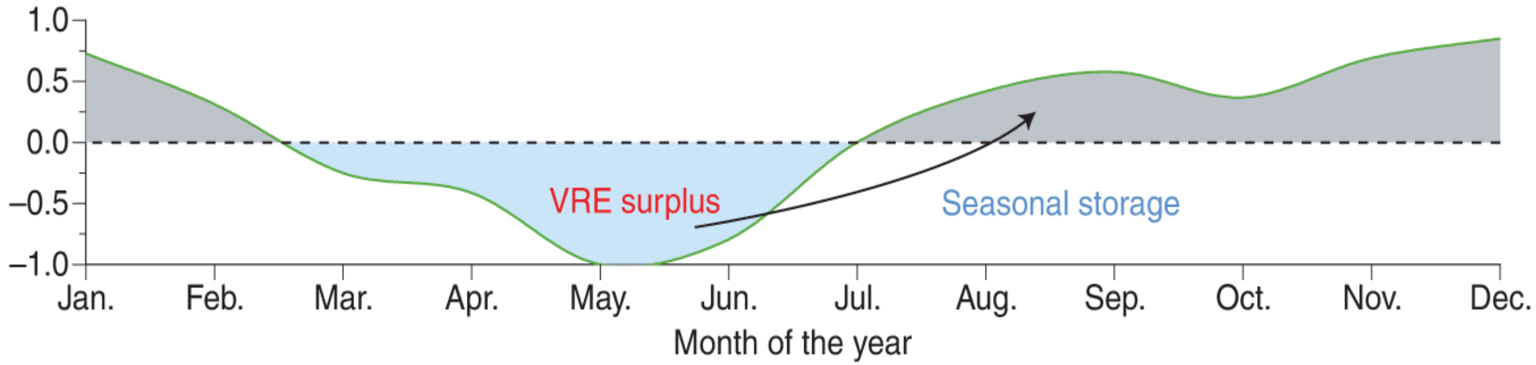


South Africa's nominal capacity mix for the period 2025 to 2050 based on the Reference IRP 2023 Scenario

Department of Mineral Resources and Energy, "Integrated Resource Plan," Government Gazette, 2023

Seasonal Energy Storage

- SES offers a potential solution by storing excess energy generated during seasons of high renewable output and releasing it in lower generation seasons
- IRP - only batteries with 4-hour energy capacity.
- SES typically involves energy capacities of one to four weeks



Study objectives

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Determine the **operational** and **financial** benefits SES can provide

Determine if SES is **financially viable** and **when** in SA's energy transition it occurs

Perform a **techno-economic assessment** of potential SES technologies

Methodology

PLEXOS power systems simulations software

South Africa's power system using a single node "copper plate" model

Unit-commitment and economic dispatch model

2025 to 2050

PLEXOS BY ENERGY EXEMPLAR

Model input data and assumptions

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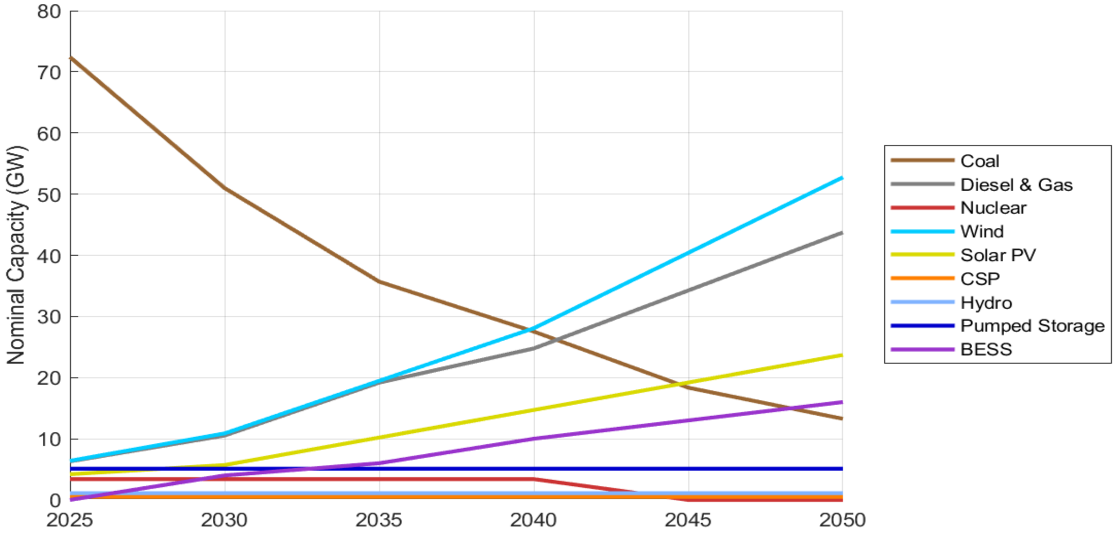
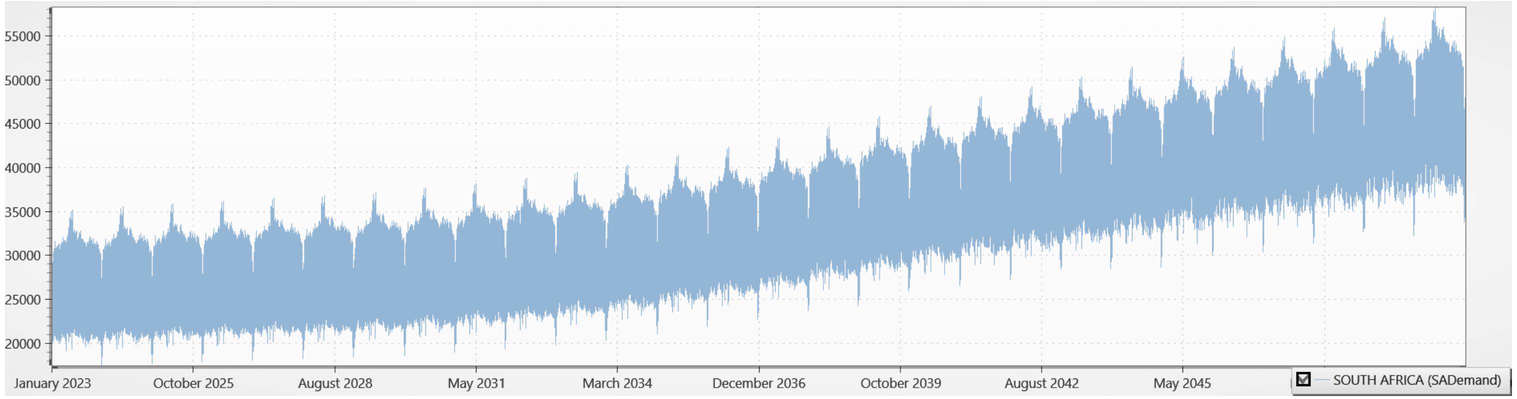
- **Generation capacities**
  - Modeled according to the 2023 IRP reference scenario



South Africa's nominal capacity mix projections based on the Reference IRP 2023 Scenario

- **Forecasted demand profile**
  - Hourly aggregated demand profile projections up to 2050 (sourced from Energy Systems Research Group at University of Cape Town)



Hourly aggregated forecasted demand for South Africa up to 2050

B. Merven and J. Tatham, "DEMAND PROJECTION MODEL IN SUPPORT OF IRP UPDATE 2023," 2023.

Model input data and assumptions

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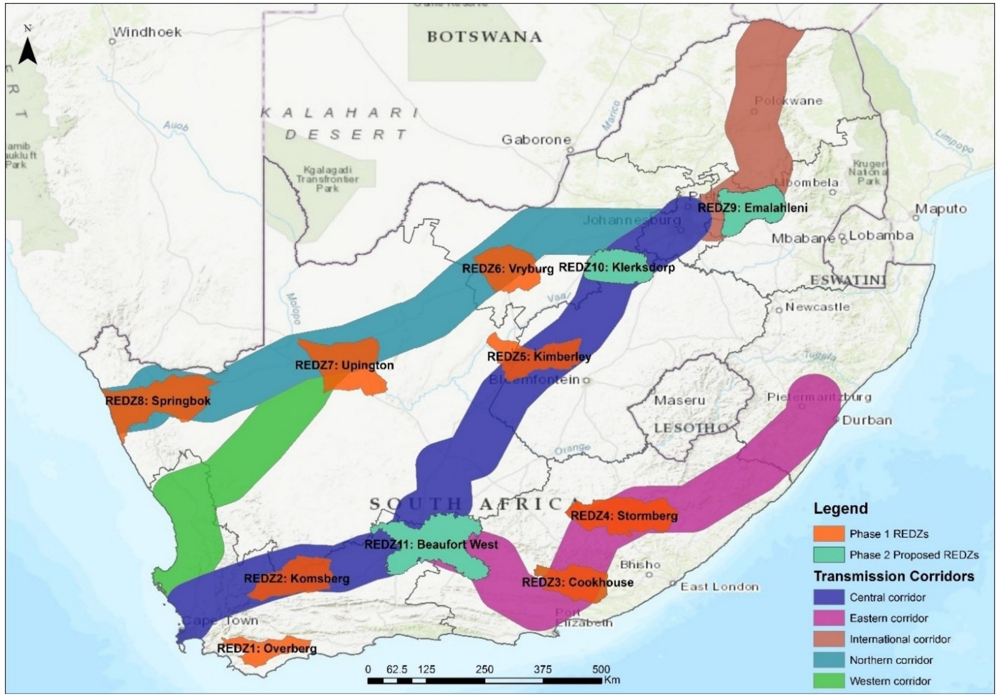
- New VRE locations
  - Wind and photovoltaic (PV) generation are evenly distributed across South Africa's Renewable Energy Development Zones (REDZ)
- VRE profiles
  - Hourly wind and solar profiles are based on the 2019 MERRA-2 dataset.
  - These profiles are normalized and imported into PLEXOS



Renewable Energy Development Zones for South Africa

F. A. F. DEPARTMENT OF ENVIRONMENT, "Renewable Energy Development Zones (REDz)," 2020. [Online]. Available: http://redzs.csir.co.za;

SES modeling

SES sizing
- Maximum capacity – 500MW (represents 1% of peak demand in 2050)

Three technologies
- Pumped Hydro Energy Storage (PHES)
- Compressed air energy storage (CAES)
- Hydrogen Energy Storage (HES)

Three discharge durations
- One week
- Two weeks
- Four weeks

Modelling the dispatch profile

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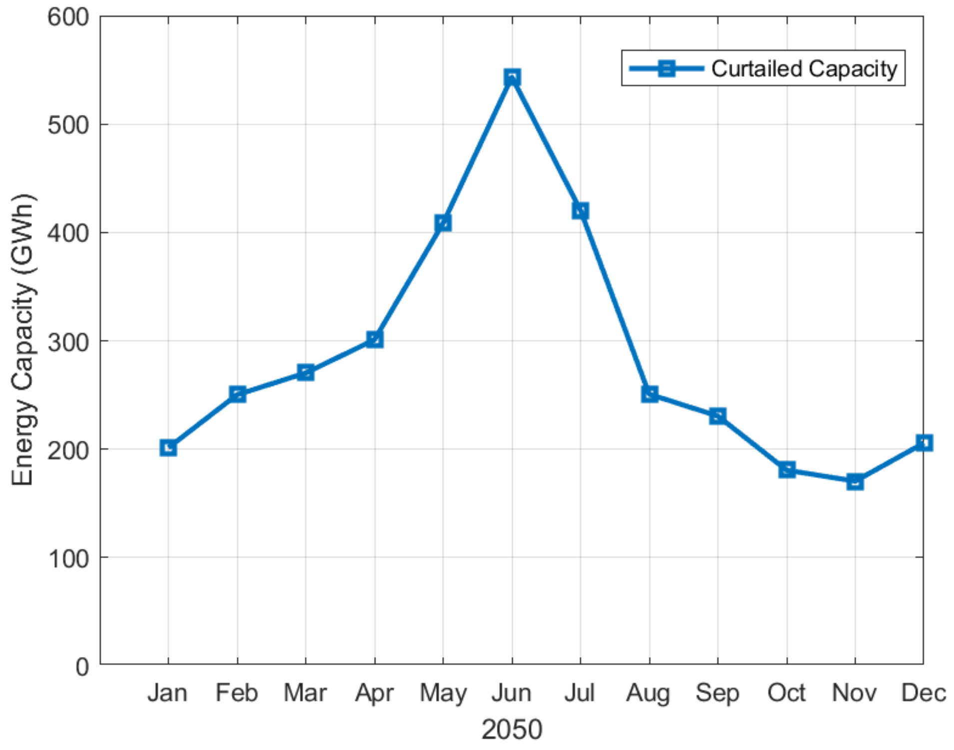
- Monthly end volume targets determined using the curtailed generation capacity profiles for each year
- Monthly targets allows for short-term dispatch in addition to seasonal dispatch
- This significantly increases the value and benefits that the SES system can provide.



Monthly curtailed generation capacity for 2050

Cost-Benefit Analysis

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Levelized cost of energy storage (LCOE)

- CAPEX
  OPEX
  Fuel costs
  Energy Discharged
- **Does not** consider avoided operational and capacity value

Benefit-cost ratio (BCR)

- Based on benefits outweighing the costs
- **Does consider** avoided operational value and capacity value

Determining the Capacity Value

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- **Operational value** – total avoided production costs (fuel costs, startup and shutdown costs, and VO&M costs)
- **Capacity value -** represents capacity of conventional peaking generators that SES can replace

Solving capacity value using a reliability-based approach with Loss of Load Probability

Run model without SES → Calculate LOLP for each year → Run model with SES → Remove OCGT units until LOLP is the same → Capacity value is the value of removed OCGT units

Benefit-cost ratio

Metric	Formula	Variables
Capital recovery factor	$CRF = \frac{r(1+r)^{\tau}}{(1+r)^{\tau}-1}$	τ - lifetime of each technology, r is the discount rate.
Total capital cost	$TCC = C_p P_{cap} + C_e E_{cap}$	Capacity overnight costs (C_p), Power capacity (P_{cap}), energy capacity overnight construction cost (C_e), Energy capacity (E_{cap})
Levelized annual cost	$LAC = CRF * TCC$	Analysed period (T)
Total system value	$TSV = \frac{OV + CV}{(1+r)^{t}}$	Operational value (OV_t), Capacity value (CV_t), each year (t)
Benefit-Cost Ratio	$BCR = \frac{TSV}{LAC}$	Total system value (TSV), Levelized annual cost (LAC)

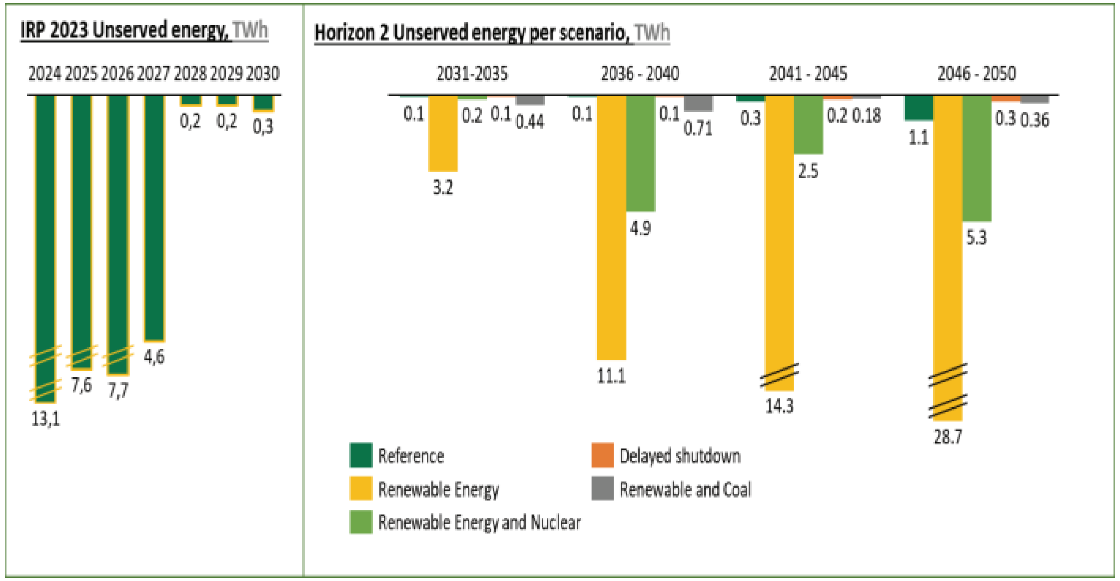
Model validation

- Historical validation
- Comparing capacity factors of all generators of ESKOMS real-world data to PLEXOS model

- The **future** unserved energy of the PLEXOS model is compared with the IRP scenario

Results of PLEXOS model vs real world ESKOM yearly capacity factors for all generators in 2024

Generator	ESKOM capacity factor (%)	Model capacity factor (%)
Coal	50	49.88
Nuclear	47.7	47.2
Hydro	20.4	19.7
OCGT	6.2	6.7
PHES	19.4	18.8
CSP	30.5	29.7
Wind	36.8	35.8
Solar PV	26.3	25.4

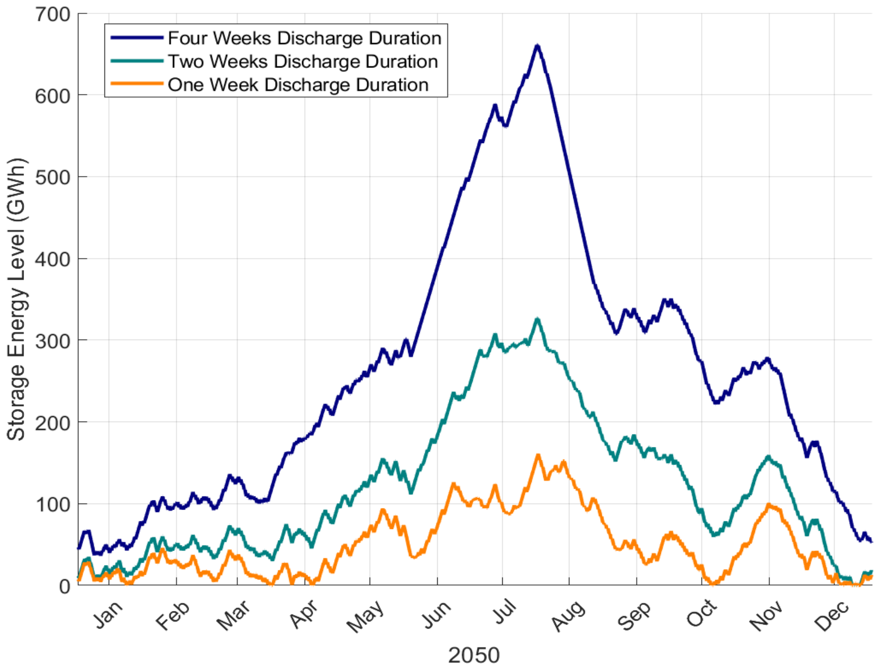


Expected Unserved Energy per scenario according to the IRP 2023

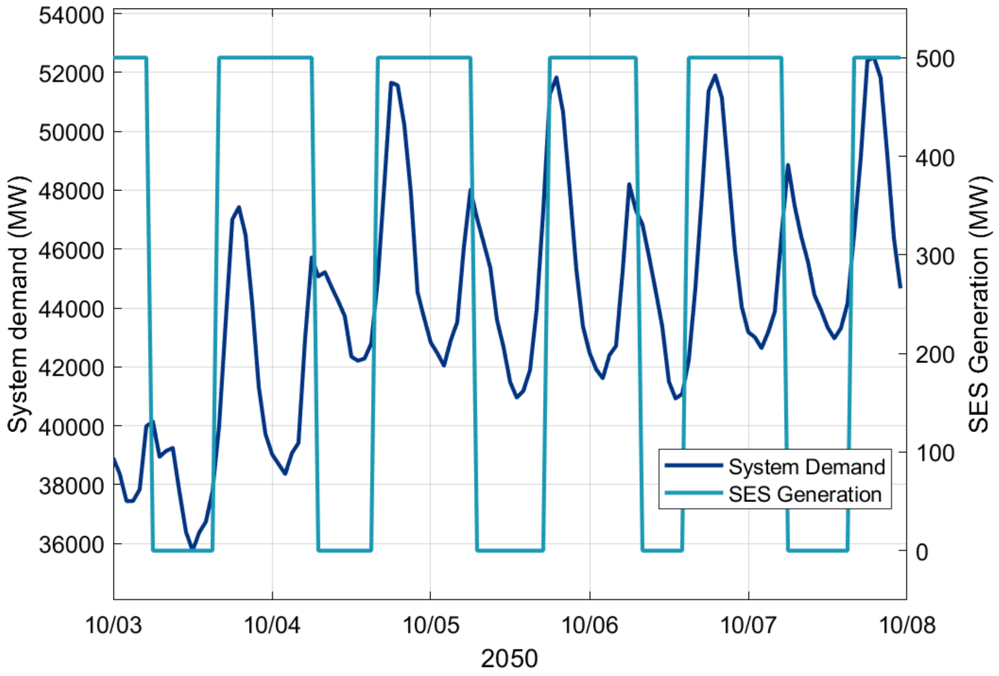
Eskom Holdings SOC Ltd., "Eskom data portal."
Department of Mineral Resources and Energy, "Integrated Resource Plan," Government Gazette, 2023

Results

Dispatch profile of the SES



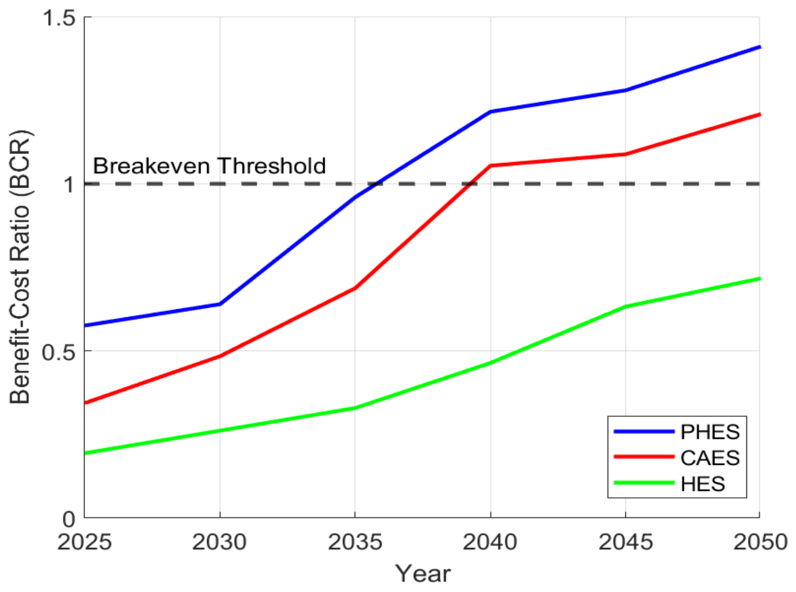
Dispatch profile of SES for different discharge durations



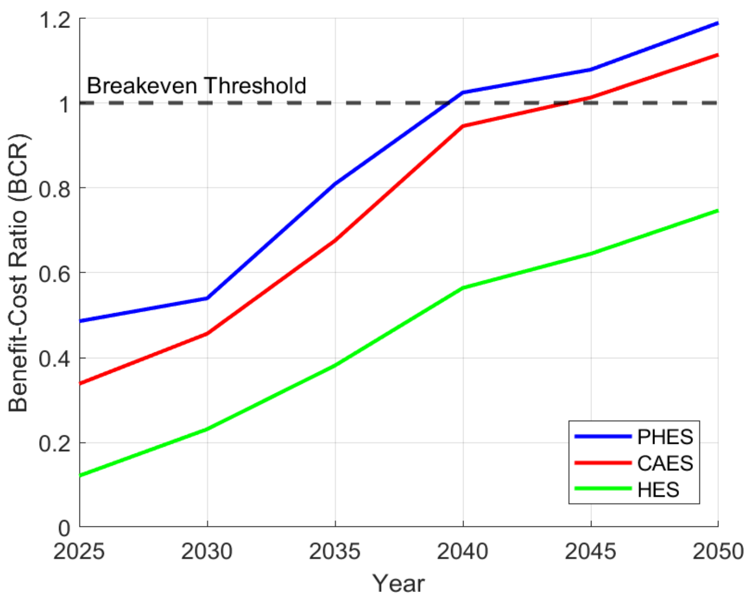
Short-term dispatch profile for 2050, comparing the system demand vs storage system's charge and discharge

Results

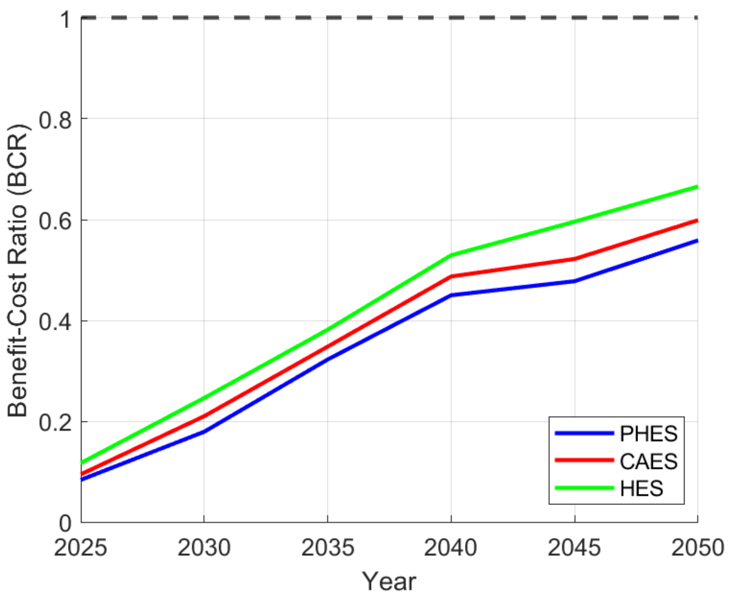
Benefit-cost analysis



Benefit-cost ratio for **one-week** discharge duration



Benefit-cost ratio for **two-weeks** discharge duration

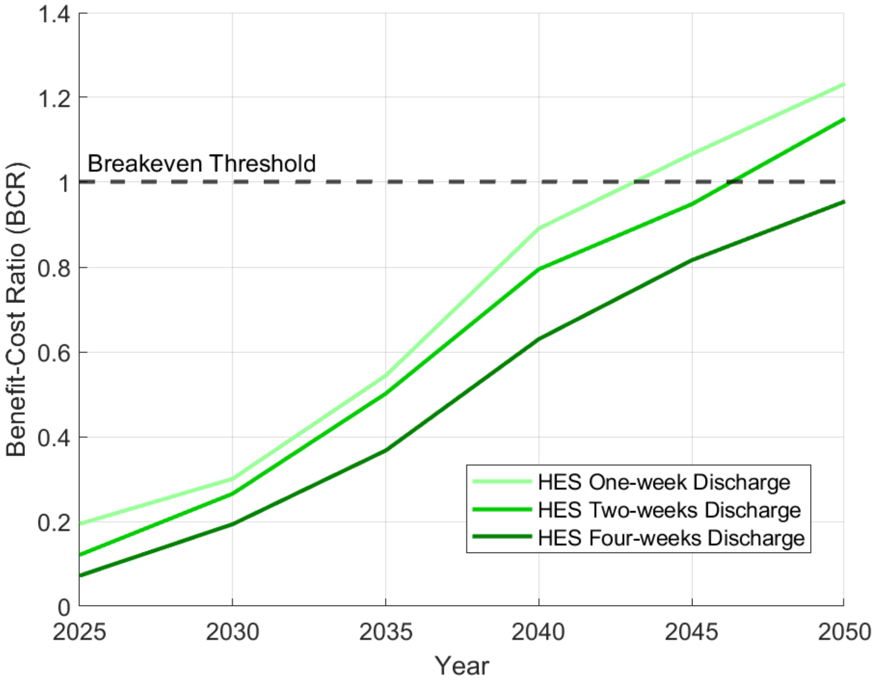


Benefit-cost ratio for **four-weeks** discharge duration

Results

Sensitivity analysis: Potential reduced cost projections for HES

Date	2025	2030	2035	2040	2045	2050
Investment cost of HES	100%	87%	78%	73%	70%	67%



Benefit-cost ratio for HES with reduced cost projections

O. Schmidt, S. Melchior, A. Hawkes, and I. Staffell, "Projecting the Future Levelized Cost of Electricity Storage Technologies,"

Conclusion

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- The potential for SES to:
  - Improve the seasonal imbalance in higher VRE scenarios and reduce curtailment.
  - Replace expensive peaking generators

- This study has demonstrated that SES can be financially viable but only beyond 2035
- PHES appears to be the most financially viable option
  - And potential learning rates in Hydrogen costs indicate HES financial viability in mid-2040s

Future research

- Include multi-node transmission network – determine effects of SES on congestion relief, and potential locations
- Study different storage sizing methods
- Consider the other possible IRP scenarios

Supported by: science & innovation, Eskom, german cooperation, giz

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Thank you
Enkosi
Dankie

Photo by Stefan Els