

A new framework for designing resilient renewable energy systems in hot desert climates¹



Source: KAUST Photolibrary 2021.

Note: Aerial view of the KAUST campus.

Renewable energy systems face special challenges in deserts

As global energy consumption soars, many communities are turning to local renewable energy sources. For hot desert areas, such as those in Saudi Arabia, designing resilient renewable energy systems presents difficulties, notably accounting for the effects of long-term climate change and extreme weather events. Yet most research on renewable systems in Saudi Arabia has examined only a single typical year of weather. This narrow focus ignores how long-term weather trends and variability affect energy supply and cooling needs.

To address this knowledge gap, the study incorporates 25 years of detailed weather data into a framework for designing a resilient, cost-effective, and sustainable energy system, applied to a specific Saudi Arabian community: the KAUST campus, located in Thuwal. Resilience in this context means the system can absorb, adapt to, and withstand the uncertainties and disruptions of long-term climate shifts and severe weather events.

The bottom line

- A team of KAUST² researchers, working with KAUST's campus and community utility services, proposes a framework for developing a resilient renewable energy system tailored to Saudi Arabia's hot desert climate.
- The resulting system would balance reliability in the face of long-term extreme weather events with concerns for cost and carbon dioxide (CO₂) emissions.
- The analysis suggests a design that leverages the operational flexibility of water desalination, a major energy consumer, to reduce cost and add resilience.
- The analysis uses the KAUST campus, located in Thuwal, as a case study, drawing on 25 years of hourly weather data to shed light on the potential impact of climate change and extreme weather on system



The proposed framework balances resilience, cost, and sustainability under extreme weather conditions

This study proposes a framework for developing a resilient renewable energy generation and storage system tailored to Saudi Arabia's hot desert climate. The framework would enable users to balance the system's reliability in the face of long-term climate change and extreme weather events with total life-cycle costs and CO₂ emissions.

The framework can also account for potential gains in resilience and cost savings from greater flexibility in the demand for energy, specifically through operational flexibility in energy use of water desalination plants.

The framework allows different combinations of renewable energy sources, including concentrated solar power, photovoltaic solar power, and wind turbines, coupled with battery and thermal technology to store energy. Working with detailed historical weather data that capture extremes, an iterative model calculates the implications for resilience, life-cycle costs, and CO₂ emissions, with and without demand flexibility. Incorporating extreme weather reduces the odds of system failure under adverse conditions, such as low solar radiation or high-temperature days, when the demand for electricity might otherwise exceed the supply. The approach "aims to enhance system resilience, reduce costs, and provide actionable guidance for sustainable energy planning under the region's extreme climatic conditions."³

A case study demonstrates the value of the framework

A case study using the KAUST campus illustrates both the trade-offs in design, performance, and cost, and the value of considering them. For example, in that case study, the least-cost, off-grid, highly resilient configuration would draw nearly all the energy, 96%, from concentrated solar power with associated life-cycle costs of about \$1.5 billion, before accounting for any additional energy generation and storage needs. The system would boost the community's energy resilience, but the gain would require more power generation and storage, increasing the life-cycle cost by 19% over the \$1.5 billion baseline.

However, pairing the system with operational flexibility in water desalination would offset the cost by 2.7%, and improve the system's resilience. In general, the desalination plant produces more water than needed during some periods and stores the excess. This allows the energy system to respond more flexibly to surges in demand caused by extreme weather events.

All told, this off-grid system would avoid about 330,900 tons of CO₂ emissions annually.

By contrast, an energy system in which 99% of the demand is met renewably and 1% is sourced from the grid is substantially less expensive — an estimated 31% cheaper over its life cycle — and still greatly reduces CO₂ emissions. The differences in cost and performance between the fully renewable and "99%" systems demonstrate the value of considering trade-offs among system features.



Source: ©Shutterstock/StockStudio Aerials 2019.

Note: Tower and mirrors for concentrated solar power.

The analysis further suggests that, under current electricity pricing arrangements in Saudi Arabia, fully renewable energy systems are not financially viable compared with grid-only power. However, adding a carbon tax to the current grid's emissions would increase the grid's long-term cost, making renewable systems more competitive.

The KAUST community presents a useful case study

KAUST is a good test location because the community:

- Wants to lower its carbon emissions.
- Is isolated and well-defined.
- Is substantial, with roughly 8,700 people, including faculty, staff, and students, and needs a high peak power of about 80 megawatts to serve university buildings, homes in several neighborhoods, schools, health facilities, recreation centers, shops, and restaurants.
- Relies heavily on electricity, especially for water desalination and cooling.
- Tracks hourly electricity demand.

These conditions enable a rigorous comparison of a grid-based energy system and alternative renewable systems in a real-world setting with the potential for adoption to meet environmental goals.



The study makes three noteworthy methodological contributions

The study's main innovations consist of

- A new approach to system design that uses 25 years of hourly weather data, including data on extreme weather events, and maps incremental changes in generation and storage capacity against both resilience and cost. The long-term data on local weather conditions provide a detailed understanding of extreme weather's occurrence, duration, magnitude, and seasonal timing.
- A system design that connects water desalination plants' energy use and water storage to the energy system. Using water storage flexibly helps balance energy demand, making the whole system more resilient and cost-effective.

- Comprehensive results on how technology, specifically concentrated solar power, influences renewable energy system design and cost, and how extreme weather affects the system's capacity and reliability.

Summing up

This study proposes a framework for designing a resilient renewable energy system, applied to the KAUST campus, located in Thuwal, Saudi Arabia. The framework considers options for concentrated solar power, photovoltaic power, and wind technologies coupled with battery and thermal storage, with opportunities for demand flexibility in desalination, to handle long-term extreme weather events. The aim is to improve system resilience, reduce costs, and provide actionable strategies for sustainable energy planning in harsh environments.



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1. This policy brief summarizes findings from Souayfane, Farah, Ricardo M. Lima, Asaad Katoua, and Omar Knio. 2026. "Integrating Weather Extremes and Desalination Flexibility to Design a Resilient Concentrated Solar Power-Photovoltaic-Wind System with Battery and Thermal Storage Using TRNSYS." *Energy Conversion and Management* 351. <https://doi.org/10.1016/j.enconman.2026.121064>. All rights and any third-party permissions remain with the respective rightsholders.
2. King Abdullah University of Science and Technology (KAUST).
3. Souayfane et al. 2026, n.p.