A Sustainable Microgrid for a Community of 200 Homes in North Texas

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Introduction

- The significant rise in greenhouse gas concentrations has been strongly linked to climate change, necessitating immediate efforts to mitigate global CO_2 emissions
- Two primary strategies for reducing CO_2 emissions are (1) transitioning from fossil fuel based electricity to renewable energy sources, and (2) lowering global energy demand through resource conservation and improved efficiency

Objective

This project investigates the design of a grid-independent residential community in Fort Worth, consisting of 200 homes powered exclusively by solar and wind energy. Project data, provided by Dr. Michaelides, includes Excel-based datasets and supporting research used to evaluate building efficiency and optimize system performance. The proposed design integrates energy generation, consumption, and storage into a cohesive system. Specifically, the community utilizes a single wind turbine supplemented by solar power, with hydrogen energy storage to ensure reliability. Analytical calculations were conducted to determine the required storage capacity and to appropriately size the solar array needed to sustainably meet the community's energy demands.

Methods

The Goal: Determine the required photovoltaic (PV) cell area, *A*, such that the initial stored energy (E_0) equals the stored energy at the end of one year (E_{1yr}).

Key Assumptions

- A coefficient of performance (COP) of 9 is assumed, achievable through the implementation of ground-source heat pumps (GSHPs)
- Energy storage is designed to maintain a minimum reserve of 10 days (240 hours) to ensure system reliability

$$E_{PVi} = A\Delta t \eta_{Ti} S_i \quad \text{[Eqn 1.]}$$

E_{PVi} energy generated by PV cells
A area of PV cell
t time period
η_{Ti} generating efficiency of PV cells
S_i total irradiance in region

$$E_{Pi} - E_{Di} = \delta E_{Si} \quad \text{[Eqn 2.]}$$

E_{Pi} renewable energy produced
E_{Di} energy demanded
E_{Si} stored energy

Procedure

1. Sum energy hourly demand for entire year
2. Select initial storage, E_0
3. Assume PV area, A
4. Compute annual energy supply (wind + solar)
5. Determine end-of-year storage (E_{1yr})
6. If $E_0 < E_{1yr}$, decrease A (surplus)
7. If $E_0 > E_{1yr}$, increase A (deficit)
8. Repeat process until $E_0 = E_{1yr}$

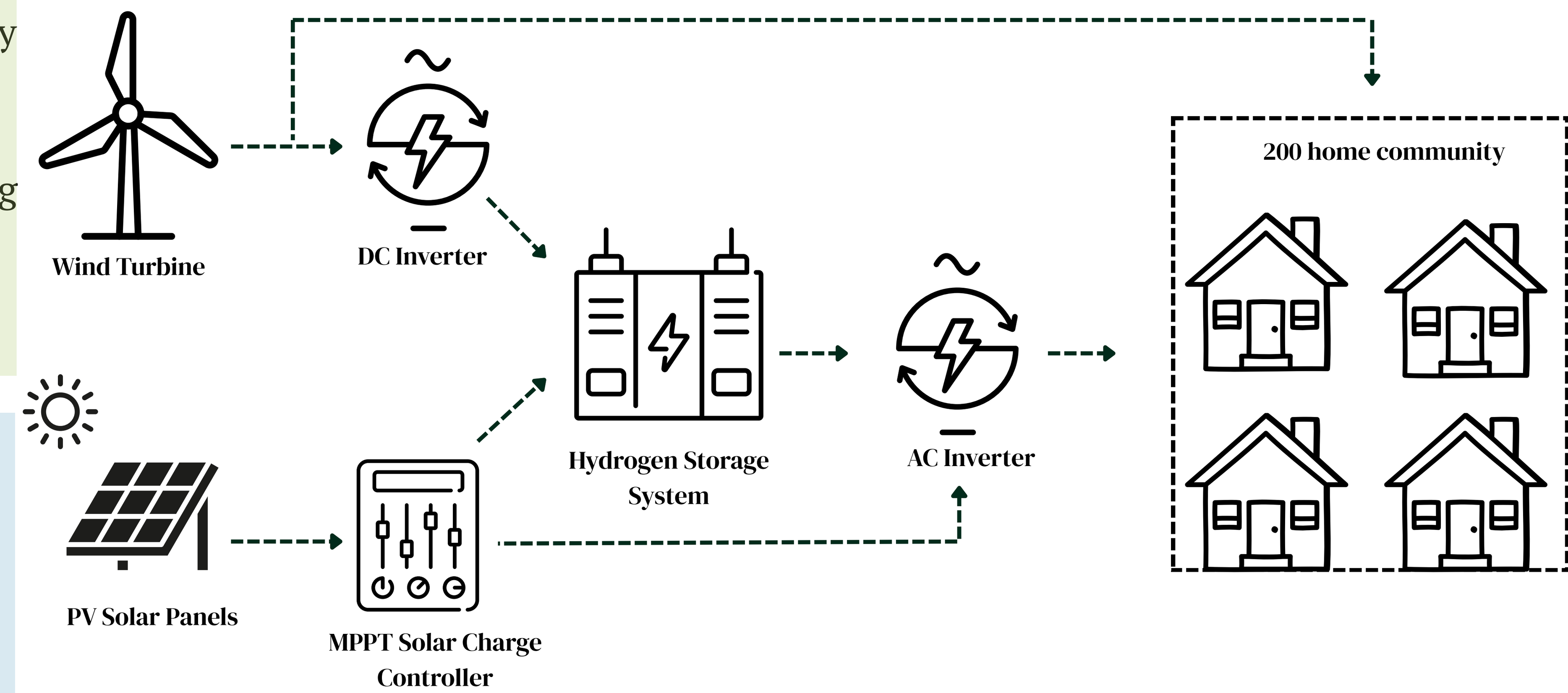

Figure 1. Grid-independent energy cycle

Discussion

Figures 2–9 illustrate key trends in energy supply and demand. On a daily scale, solar generation exhibits a pronounced midday peak, while wind generation remains relatively consistent, as shown in Figures 2 and 3. In contrast, the power demand profile follows what is commonly referred to as the "duck curve," characterized by a midday dip in demand followed by a steep evening increase (Figures 4 and 5). This pattern presents challenges for traditional power generation systems and highlights the growing need for greater grid flexibility.

On a monthly scale, Figures 6 and 7 demonstrate that wind generation experiences greater variability, whereas solar generation remains comparatively stable. Finally, Figures 8 and 9 indicate seasonal differences in supply and demand balance, with July showing a more even alignment between supply and demand, while January exhibits a surplus of energy supply relative to demand.

Results

Using a 400 kW wind turbine, an optimal solar PV area of 2,082 m² was determined to maximize the community's energy efficiency. Equation 1 is used to calculate the energy produced by the PV system, while Equation 2 is used to determine whether the system is operating in a surplus or deficit of stored energy.

References:

ERCOT, 2024, https://www.ercot.com/gridinfo/generation

Michaelides, E. E. (2018). *Energy, the Environment, and Sustainability.* CRC Press.

Michaelides, E. E. (2025). *Energy Efficiency and the Transition to Renewables*—Building Communities of the Future. Energies

Wilcox, S., 2012, National Solar Radiation Database 1991–2010 Update: User's Manual; Technical Report NREL/TP-5500-54824, https://www.nrel.gov/docs/fy12osti/54824.pdf

Data Tables/Results of Power Supply and Demand in North Texas

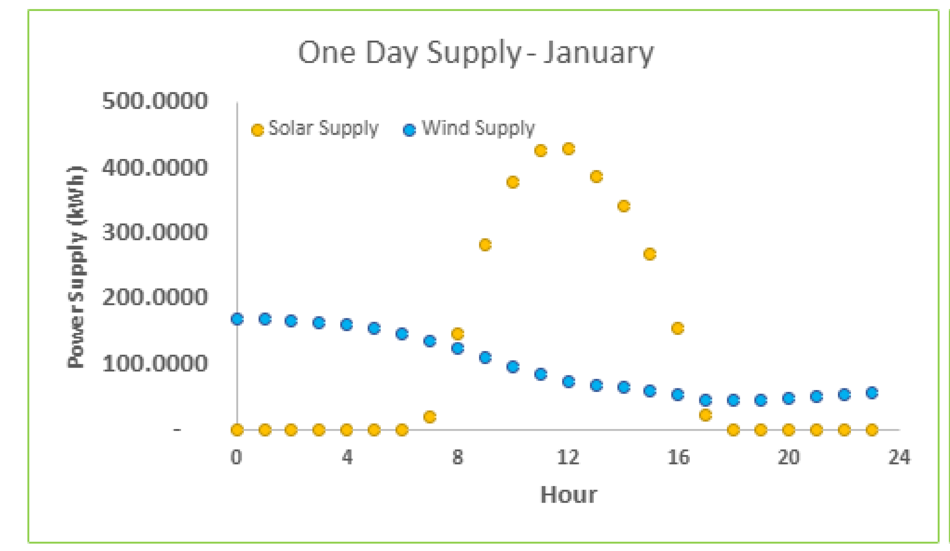

Figure 2. Daily wind and solar supply in January

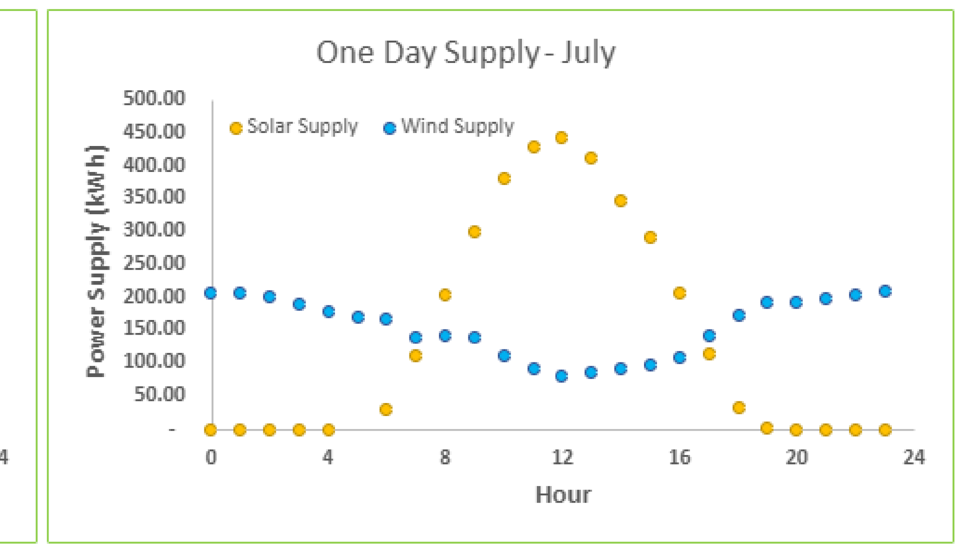

Figure 3. Daily wind and solar supply in July

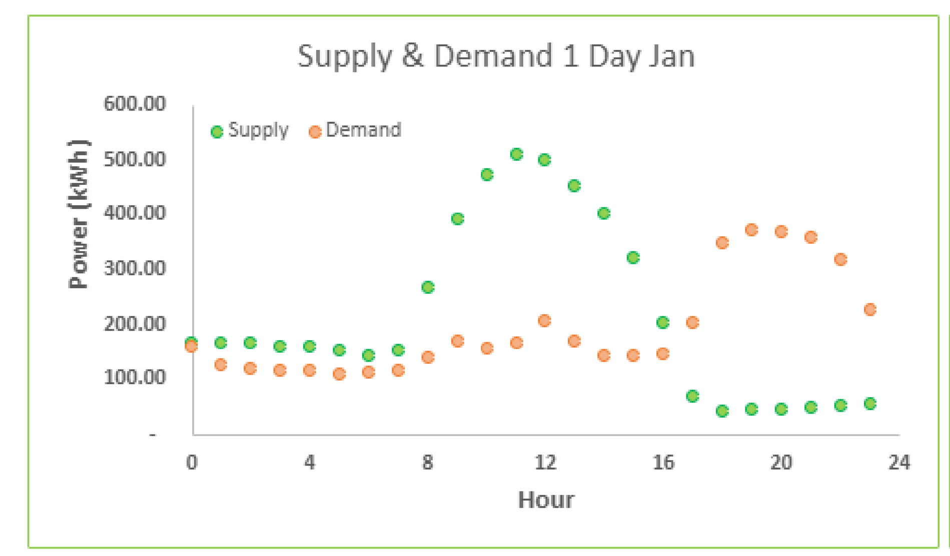

Figure 4. Daily energy supply and demand in January

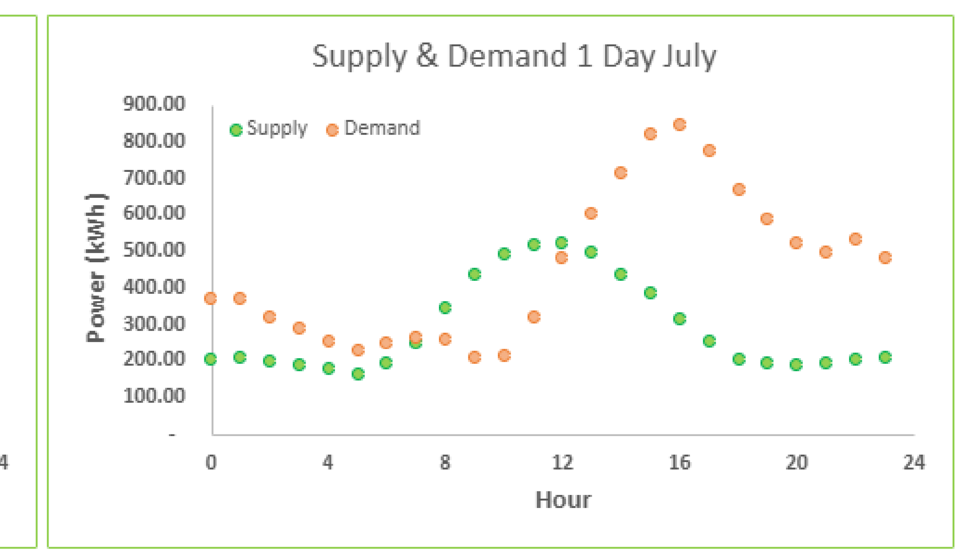

Figure 5. Daily energy supply and demand in July

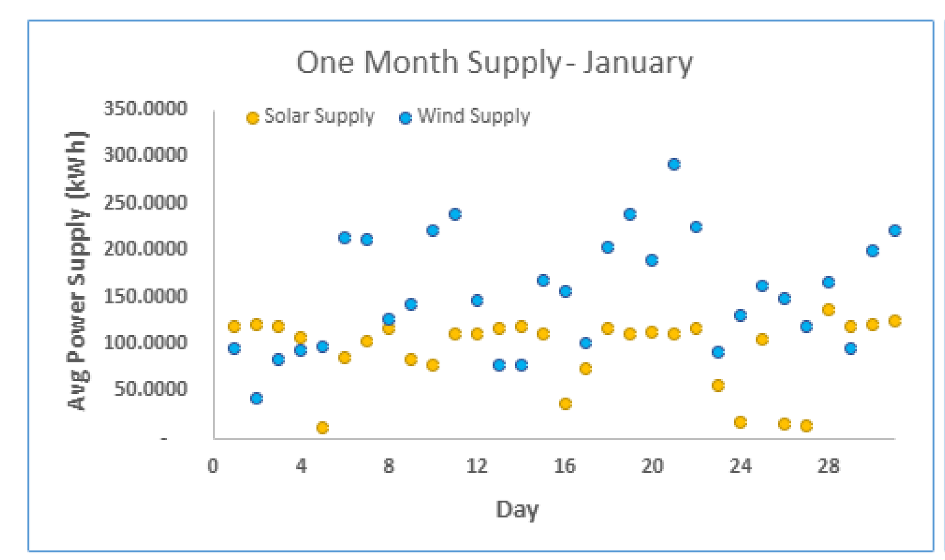

Figure 6. January wind and solar supply

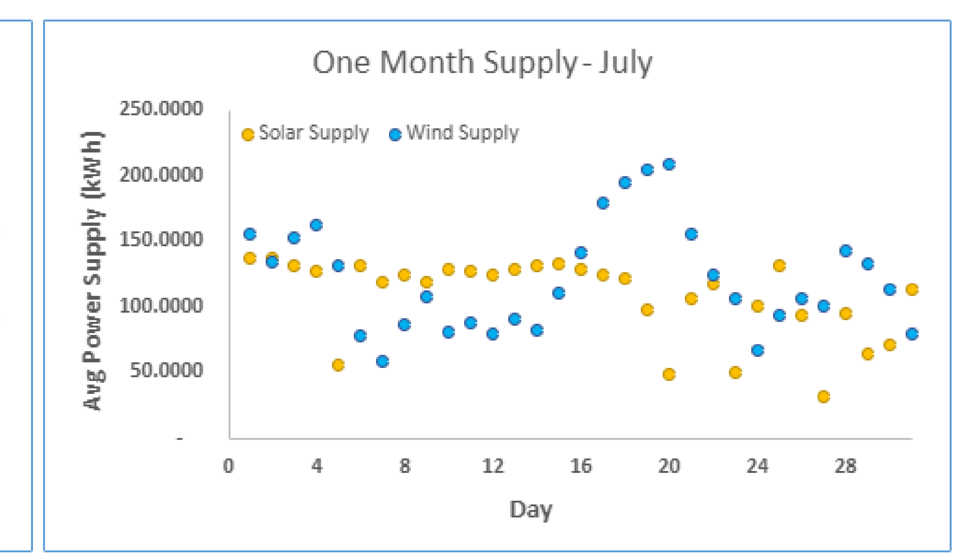

Figure 7. July wind and solar supply

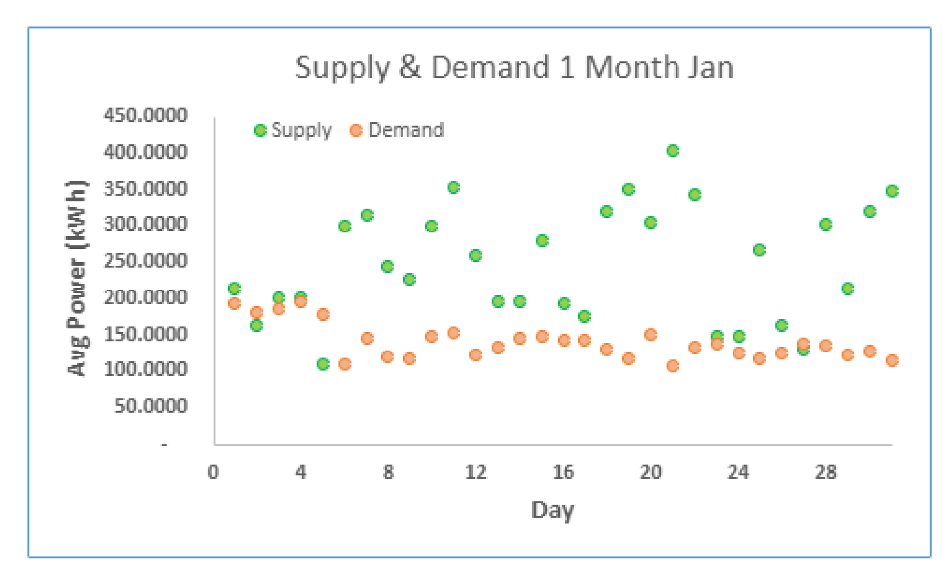

Figure 8. January energy supply and demand

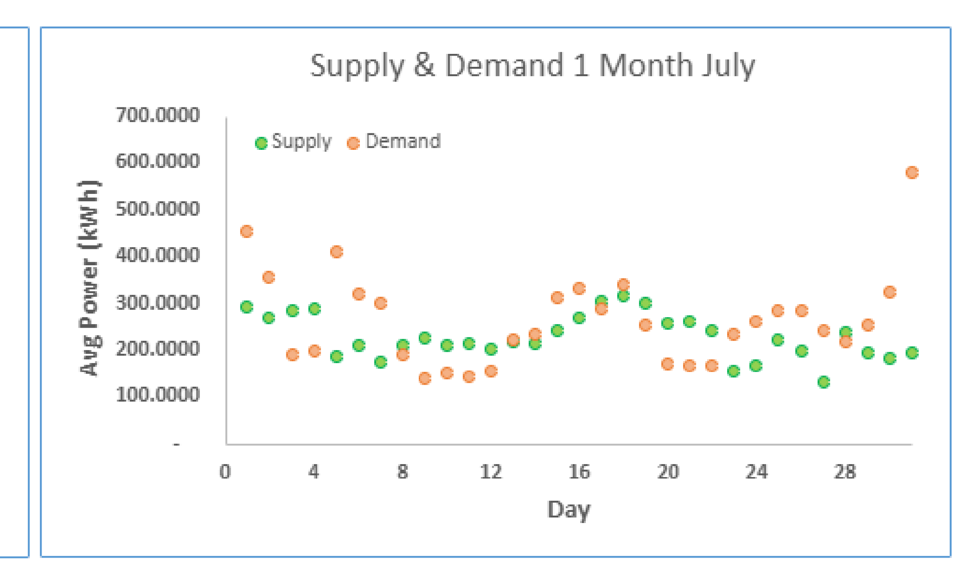

Figure 9. July energy supply and demand