Capacity Planning for PV and Battery Systems – Project Overview

This project involves **designing a photovoltaic (PV) system** and **battery storage solution** to optimize energy usage, reduce grid dependency, and minimize energy costs for a household. The aim is to determine the **appropriate sizes for the PV system and battery storage** by analyzing key factors such as **investment costs, energy demand patterns, electricity prices, and usage habits**.

Problem Statement

The world is shifting towards **renewable energy sources**, and PV systems with battery storage are becoming popular for **households** and **communities** to reduce their reliance on the grid. However, installing these systems requires **careful capacity planning** to balance:

- **Initial investment costs**
- **Energy production and consumption needs**
- **Electricity prices (including time-of-use tariffs)**
- **Usage habits** (such as peak consumption hours)

The goal is to find a **cost-effective balance** that ensures the system meets energy needs without being oversized or undersized.

Project Objectives

1. **Determine the Optimal PV Size**
    - Calculate how much solar power should be generated to meet the user's energy needs.
    - Avoid overproduction that would waste energy or underproduction that would increase reliance on the grid.
2. **Determine the Optimal Battery Size**
    - Ensure the battery can store excess energy generated during the day and supply power during peak demand or at night.
    - Consider factors like **battery degradation** and **charging/discharging cycles**.
3. **Optimize Costs**
    - Balance the **investment costs** of the PV panels and battery system with **long-term savings** on electricity bills.
    - Account for **electricity prices** (fixed tariffs, time-of-use tariffs, feed-in tariffs).
4. **Analyze Usage Habits**
    - Study **daily, weekly, and seasonal energy demand patterns** to optimize the system's performance.

- Consider **peak demand times** (e.g., mornings, evenings) and **weekend/holiday patterns**.

Key Data Requirements

To achieve the project's goals, you will need the following data:

Data Type	Description
Energy Demand Data	Household/community electricity consumption (hourly/daily).
Solar Generation Data	PV power production potential (based on location and weather).
Electricity Prices	Time-of-use tariffs, fixed tariffs, and feed-in tariffs.
Investment Costs	Costs of PV panels, inverters, battery systems, and installation.
Usage Habits	Patterns of electricity consumption across different hours, days, and seasons.

Methodology

1. **Analyze Energy Demand**
    - Calculate the household's or community's **load profile** using historical consumption data.
    - Identify **peak usage times** and seasonal variations in energy demand.
2. **Simulate PV System Performance**
    - Use **solar irradiance data** to estimate how much power the PV system will generate.
    - Factor in **weather patterns** and **panel efficiency**.
3. **Determine Battery Storage Requirements**
    - Calculate how much energy storage is needed to cover **nighttime consumption** and **peak demand** times.
    - Consider **battery degradation** and **discharge limits**.
4. **Optimize System Sizes**
    - Use **capacity planning models** to find the optimal size for the PV system and battery that minimizes costs while meeting energy needs.

- Factor in **electricity prices**, including **self-consumption savings** and **grid feed-in revenue**.

Cost Analysis

The project will evaluate:

1. **Capital Costs**
   - PV panels
   - Battery storage system
   - Inverters
   - Installation and maintenance
2. **Operating Costs**
   - System maintenance
   - Battery replacements (if needed)
3. **Savings and Returns**
   - Reduction in electricity bills
   - Earnings from selling excess energy to the grid (if applicable)

Challenges and Considerations

1. **Overproduction vs. Underproduction**
   - Oversizing the system results in wasted energy and higher costs.
   - Undersizing increases grid dependency, reducing savings.
2. **Battery Degradation**
   - Batteries degrade over time, which affects capacity and efficiency.
   - Proper sizing ensures the system remains effective over its lifespan.
3. **Time-of-Use Tariffs**
   - Electricity prices change depending on the time of day.
   - The system must account for **when energy is stored and used** to maximize savings.

Tools and Techniques

- **Python** for data analysis and simulation

- **Excel/Google Sheets** for basic calculations and visualizations
- **HOMER Pro** or similar software (optional) for detailed capacity planning
- **Data Visualization** tools for presenting results (e.g., Matplotlib, Plotly)

Expected Outputs

1. **Optimal PV and Battery Sizes**
    - PV system size (kW)
    - Battery storage size (kWh)
2. **Cost-Benefit Analysis**
    - Investment cost vs. long-term savings
    - Payback period and return on investment (ROI)
3. **Energy Usage Profile**
    - Detailed analysis of **energy production and consumption patterns**
    - **Self-consumption ratio** (how much of the generated energy is used directly)

Example Use Case

Imagine a household in **Torino, Italy**, considering the installation of a **5 kW PV system** and a **10 kWh battery**. By analyzing:

- **Energy demand data** from the household
- **Solar irradiance data** for Torino
- **Electricity prices** from their utility provider

The project will recommend the **most efficient sizes** for the PV system and battery, ensuring the household achieves:

- Maximum **self-consumption**
- Significant **electricity bill savings**
- A reasonable **payback period**

Why This Project is Important

With the **global shift towards renewable energy**, households and businesses must optimize their systems to achieve **cost-effective energy independence**. This project provides a practical solution for **reducing grid reliance**, **lowering energy costs**, and contributing to **sustainability goals**.