Exercise Set: Case Studies in Sustainable Energy Systems

Towards Sustainable Energy Futures

General Instructions

This document presents a series of real-world case studies designed to bridge lecture theory and project work. Each case study offers an immersive scenario based on Switzerland's energy transition challenges and includes extensive context, detailed data tables, and a list of tasks. You are expected to research, model, and analyze the provided scenarios using the EnergyScope tool and your preferred analytical methods. No solutions or calculation steps are included here; you must derive and document your own methods, assumptions, and results. Use the additional data (often more than needed) to guide your analysis and to explore the sensitivity of your models.

Each of these case studies is designed to help you integrate theoretical knowledge with practical analysis, preparing you for the final project. Your reports should demonstrate a deep understanding of energy system challenges and present innovative, data-driven strategies for achieving sustainable energy futures in Switzerland.

Case Study 1: Swiss Energy Future — Balancing Demand and Supply

Introduction and Context

"Energy is the cornerstone of sustainable development." In the heart of Europe, Switzerland faces a defining challenge: transitioning from a system historically dominated by hydroelectric and nuclear power to a future based on diversified renewable sources. With nuclear energy scheduled for a major phase-out and electricity demand projected to rise from 60 TWh/year to 70 TWh/year by 2040, energy planners must develop a resilient strategy that ensures security of supply, economic viability, and environmental sustainability.

In this case study, you will assume the role of an energy systems analyst charged with designing Switzerland's 2040 energy mix. You will assess current trends, evaluate the potential of renewable technologies, and propose a comprehensive strategy that integrates additional measures such as energy storage and demand-side management. You are encouraged to consider the broader context—including cost constraints, grid limitations, and historical shifts in energy use—and to propose an innovative configuration that meets both energy and emission targets.

Background: Switzerland's current energy profile is undergoing rapid transformation. Hydroelectric power remains a stable source at 33 TWh/year, but nuclear output is set to decline from 21 TWh/year to 7 TWh/year. Meanwhile, renewable energy sources such as solar PV and wind have significant potential to fill the gap. However, these potentials must be evaluated in the context of technical, economic, and environmental constraints.

The table below summarizes key current and projected data:

Energy Source	Current Output (TWh/year)	Projected 2040 Output (TWh/year)
Hydroelectric	33	33
Nuclear	21	7
Gas-based Imports	6	—

Additional renewable potentials for 2040 are provided in the table below:

Renewable Type	Potential Output (TWh/year)	Capacity Factor
Solar PV	8	12%
Wind	5	25%

Other Relevant Data:

- Total projected electricity demand in 2040: 70 TWh/year.

- Emission factor for gas-based imports: 400 g CO_2/kWh.
- Cost Data (help yourself):
- Grid capacity constraints: The current grid can accommodate up to an additional 10 TWh/year of renewable generation without major upgrades.
- Historical trends indicate that significant energy transitions are accompanied by shifts in public policy and large-scale investments.

Problem Description: Your task is to develop a comprehensive energy strategy for 2040 by:

1. Analyzing the domestic energy supply (hydroelectric and nuclear) and calculating the shortfall relative to the 70 TWh/year demand.
2. Developing at least three scenarios:
   - Scenario A: Maximum deployment of renewables (full use of the 8 TWh and 5 TWh potentials for Solar and Wind, respectively).
   - Scenario B: Moderate renewable deployment (using 50% of the available renewable potential).
   - Scenario C: Minimal renewable deployment (high reliance on gas-based imports).
3. Estimating the gas-based import requirements and associated CO_2 emissions for each scenario.
4. Performing a sensitivity analysis by considering variations in renewable capacity factors (e.g., ±10%).
5. Proposing an integrated energy strategy that includes supplementary measures (energy storage, demand-side management) and outlining policy recommendations.

Additional Data for Analysis:

Parameter	**Value**	**Unit**	**Notes**
Total Demand (2040)	70	TWh/year	Projected demand
Hydroelectric Output	33	TWh/year	Constant
Nuclear Output (2040)	7	TWh/year	Reduced
Solar PV Potential	8	TWh/year	Maximum potential
Wind Potential	5	TWh/year	Maximum potential
Emission Factor (Gas)	0.4	kg/kWh	400 g CO_2/kWh
Grid Capacity Constraint	10	TWh/year	Additional renewables

Your discussion points should be focused and compromise on:

- A clear energy balance analysis.
- A detailed description of each scenario with justification.
- Estimates of gas-based import needs and associated CO_2 emissions.
- A sensitivity analysis addressing key uncertainties.
- An integrated energy strategy with policy and operational recommendations.

Step-by-Step Instructions

1. Energy Balance Analysis
Calculate the domestic supply by summing hydroelectric (33 TWh) and nuclear (7 TWh) outputs. Determine the shortfall relative to the projected 70 TWh/year demand.

2. Scenario Development
Develop three scenarios:

- **Scenario A (Maximum Renewables):** Utilize the full renewable potential (Solar = 8 TWh, Wind = 5 TWh).
- **Scenario B (Moderate Deployment):** Employ 50% of the renewable potential (Solar = 4 TWh, Wind = 2.5 TWh).
- **Scenario C (Minimal Renewables):** Assume negligible renewable contribution, relying entirely on imports.

3. Import and Emission Calculations
For each scenario, compute the remaining import requirement (shortfall minus renewable contribution) and then calculate the associated CO_2 emissions using the emission factor (0.4 kg/kWh).

4. Sensitivity Analysis
Vary renewable capacity factors by $\pm 10\%$ and assess the impact on energy generation and emissions.

5. Integrated Strategy Proposal
Propose an integrated energy strategy incorporating additional measures (e.g., storage, demand-side management) and provide policy recommendations to optimize the energy mix.

Reflection and Discussion Points

- How do changes in renewable potential influence overall system performance?
- What are the primary trade-offs between cost, emission reduction, and grid stability?
- Which additional measures could further reduce the reliance on gas-based imports?