Detailed Step-by-Step Solutions and Reflection Points

for Case Studies in Sustainable Energy Systems

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

1. Energy Balance Calculation

The projected electricity demand for 2040 is 70 TWh/year. The domestic supply consists of:

$$\text{Hydroelectric Output} = 33\,\text{TWh/year}, \quad \text{Nuclear Output (reduced)} = 7\,\text{TWh/year}.$$

Thus, the total domestic supply is:

$$33 + 7 = 40\,\text{TWh/year}.$$

The shortfall that must be met by renewables and/or imports is:

$$\text{Shortfall} = 70 - 40 = 30\,\text{TWh/year}.$$

2. Scenario Analysis

Three scenarios are developed to fill the 30 TWh shortfall:

Scenario A: Maximum Renewable Deployment

- **Solar PV potential:** 8 TWh/year.
- **Wind potential:** 5 TWh/year.

Total renewable contribution:

$$8 + 5 = 13\,\text{TWh/year}.$$

Thus, the remaining requirement (to be met by gas-based imports) is:

$$30 - 13 = 17\,\text{TWh/year}.$$

CO_2 Emissions: Using an emission factor of 0.4 kg CO_2/kWh,

$$17\,\text{TWh} = 17 \times 10^9\,\text{kWh},$$

$$\text{Emissions} = 17 \times 10^9 \times 0.4 = 6.8 \times 10^9\,\text{kg CO}_2 \quad (6.8\,\text{Mt CO}_2).$$

Scenario B: Moderate Renewable Deployment (50% of Potential)

- **Solar PV:** 4 TWh/year.
- **Wind:** 2.5 TWh/year.

Total renewable contribution:

$$4 + 2.5 = 6.5\,\text{TWh/year}.$$

Import requirement:

$$30 - 6.5 = 23.5\,\text{TWh/year}.$$

CO_2 Emissions:

$$\text{Emissions} = 23.5 \times 10^9 \times 0.4 = 9.4 \times 10^9\,\text{kg CO}_2 \quad (9.4\,\text{Mt CO}_2).$$

Scenario C: Minimal Renewable Deployment Assume negligible renewable contributions; therefore, the entire shortfall is met by imports:

$$\text{Import Requirement} = 30\,\text{TWh/year}.$$

CO_2 Emissions:

$$\text{Emissions} = 30 \times 10^9 \times 0.4 = 12 \times 10^9\,\text{kg CO}_2 \quad (12\,\text{Mt CO}_2).$$

3. Sensitivity Analysis

To assess the influence of uncertainties in renewable output, consider a variation of $\pm 10\%$ in renewable potential.

For Scenario A:

- **If potentials increase by 10%:**

  $$\text{Solar} = 8 \times 1.1 = 8.8\,\text{TWh/year}, \quad \text{Wind} = 5 \times 1.1 = 5.5\,\text{TWh/year}.$$

  Total renewables:

  $$8.8 + 5.5 = 14.3\,\text{TWh/year}.$$

  Remaining import requirement:

  $$30 - 14.3 = 15.7\,\text{TWh/year},$$

  and CO_2 emissions become:

  $$15.7 \times 10^9 \times 0.4 = 6.28\,\text{Mt CO}_2.$$

- **If potentials decrease by 10%:**

$$\text{Solar} = 8 \times 0.9 = 7.2\,\text{TWh/year}, \quad \text{Wind} = 5 \times 0.9 = 4.5\,\text{TWh/year}.$$

  Total renewables:

$$7.2 + 4.5 = 11.7\,\text{TWh/year}.$$

  Remaining import requirement:

$$30 - 11.7 = 18.3\,\text{TWh/year},$$

  and CO_2 emissions become:

$$18.3 \times 10^9 \times 0.4 = 7.32\,\text{Mt CO}_2.$$

4. Integrated Strategy Proposal

Based on the above analyses, a hybrid strategy could include:

- Maximizing renewable deployment to the fullest technical potential.
- Integrating energy storage systems to manage intermittent renewable output. For example, if storage can effectively reduce imports by an additional 5 TWh, then under Scenario A the revised import requirement would be:

$$17 - 5 = 12\,\text{TWh/year},$$

  with emissions:

$$12 \times 10^9 \times 0.4 = 4.8\,\text{Mt CO}_2.$$

- Implementing demand-side management to shift consumption towards periods of high renewable generation.
- Proposing grid upgrades and policy measures that incentivize renewable installations.

Discussion and Reflection Points with Main Content Solutions

- **Impact of Renewable Variability:** A $\pm 10\%$ variation in renewable potential directly affects the gas-based import requirement. An increase in renewable output by 10% reduces imports from 17 TWh to approximately 15.7 TWh (reducing emissions by about 0.52 Mt CO_2), while a decrease increases imports to 18.3 TWh (raising emissions by 0.64 Mt CO_2). This demonstrates the sensitivity of the system to renewable performance.
- **Trade-offs Between Deployment and Import Reliance:** Maximizing renewables minimizes imports and emissions; however, technical constraints (e.g., grid capacity limited to an extra 10 TWh/year) and intermittency challenges must be considered. Moderate deployment leads to higher import reliance and higher emissions, but may be more feasible given current infrastructure limitations.

- **Additional Measures to Reduce Emissions:** Integration of energy storage (which could reduce imports by storing excess renewable generation) and demand-side management (to shift usage to match generation peaks) are effective measures. For example, if storage reduces imports by 5 TWh, emissions drop significantly as calculated above.