OR LAB PROJECT

Group 10

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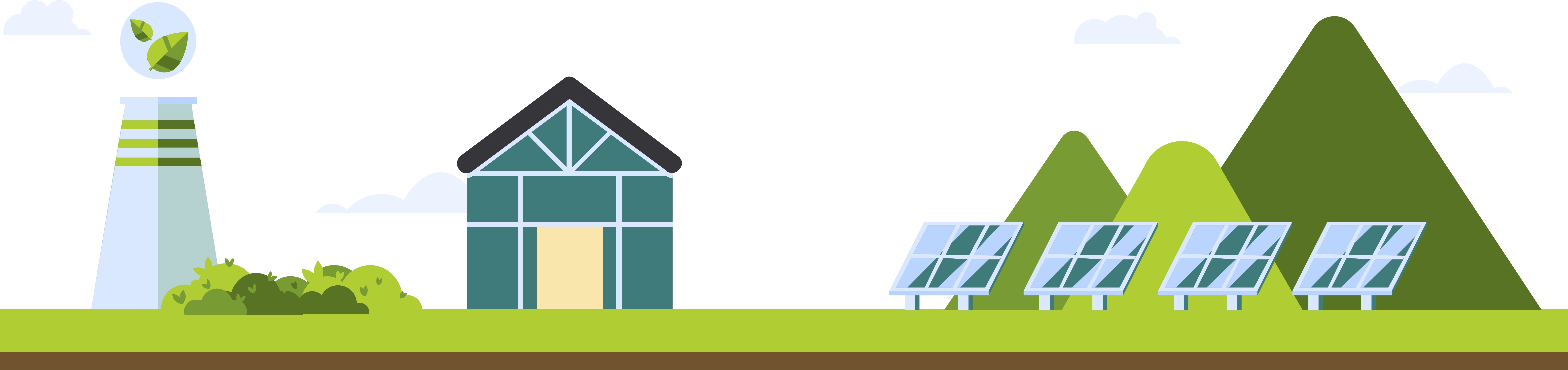
Energy Planning Optimization Problem



Problem Statement

An energy-reliant facility requires a continuous supply of power over a 24-hour period, with demand varying hourly between 65 MW and 150 MW. The facility aims to meet this fluctuating demand using a hybrid energy system composed of solar power, battery storage, and gas-based generation. As part of its sustainability strategy, the system must satisfy at least 88% of the total daily energy demand using renewable sources—namely solar generation and battery discharge powered by solar input

The solar energy potential varies significantly throughout the day, with zero availability during nighttime and peaking at midday. Battery systems must operate within constraints such as efficiency losses, charge/discharge limits, and capacity bounds. Gas generators provide the non-renewable share and act as a backup source, contributing at least 10% of the total demand.

Since no energy infrastructure currently exists on site, the problem involves determining the optimal installed capacities for solar panels, battery systems, and gas generators. The primary objective is to minimize the total investment and operational cost while ensuring that hourly energy demand is met, renewable energy targets are achieved, and land and technical constraints are satisfied.

Decision Variables

x_s in [0, Solar_Cap_Max]	Installed solar capacity (MW)
x_b in [0, Battery_Cap_Max]	Installed battery capacity (MWh)
x_g in [0, Gas_Cap_Max]	Installed gas capacity (MW)
E_solar[t]	Energy generated by solar (MWh)
E_battery[t] in R	Battery discharge (positive) or charge (negative)(MWh)
E_gas[t]	Energy generated by gas (MWh)
SOC[t] in R	Battery state of charge at time t (MWh)

Parameters

- Demand[t]: Energy demand at time t (MWh)
- A[t]: Solar availability at time t (0-1 scale)
- R: Minimum renewable energy share (e.g., 88%)
- alpha: Minimum solar share of demand (e.g., 82%)
- beta: Minimum battery share of demand (e.g., 4%)
- L_max: Maximum land available (acres)

Parameters

- Battery_Efficiency in (0,1): Battery round-trip efficiency (e.g., 0.85)
- ChargeLimitRatio in (0,1): Max fraction of battery capacity per hour (e.g., 0.5)
- L_s: Land required per MW of solar capacity (acres)
- CAPEX and O&M costs per MW/MWh for all sourcest

Objective Function

Minimize total investment and operational cost

$$
\begin{aligned}
\text{Minimize:}\quad & x_s * (C_s + M_s) \\
& + x_b * (C_b + M_b) \\
& + x_g * (C_g + M_g)
\end{aligned}
$$

CONSTRAINTS

1. Power Balance (energy supply = demand):

$$E\_solar[t] + E\_battery[t] + E\_gas[t] = Demand[t]$$

2. Solar generation depends on installed capacity and availability:

$$E\_solar[t] \le x\_s * A[t]$$

3. Battery dynamics (discharge = reduction in SOC):

$$SOC[1] = -E\_battery[1]$$

$$SOC[t] = SOC[t-1] - E\_battery[t] \quad \text{for } t = 2 \ldots T$$

4. Battery capacity bounds:

$$0 \le SOC[t] \le x\_b$$

CONSTRAINTS

5.Charge/discharge rate cap:

$$(chargeLimitRatio * x\_b) \le E\_battery[t] \le (chargeLimitRatio * x\_b)$$

6.Battery discharge must be supported by solar input (efficiency-limited):

$$\max(0, E\_battery[t]) \le Battery\_Efficiency * E\_solar[t]$$

7.Renewable share constraint:

$$sum\_of\ (E\_solar[t] + \max(0, E\_battery[t])) \ge R * sum\_of\_Demand[t])$$

8.Solar share minimum:

$$sum\_of\_E\_solar[t] \ge alpha * sum\_of\_Demand[t]$$

CONSTRAINTS

9. Battery share minimum (count only discharges):

$$\text{sum\_of } (0, E\_battery[t]) \geq \text{ beta} * \text{sum\_t Demand}[t]$$

10. Minimum gas generation (whichever is greater):

$$\text{sum\_of } (E\_gas[t] \geq \max(Min\_Gas\_Backup, 0.1 * \text{sum\_of\_ Demand}[t])$$

11. Gas generation capacity limit:

$$E\_gas[t] \leq x\_g$$

12. Land constraint for solar installation:

$$x\_s * L\_s \leq L\_max$$

Cplex Code

```
// PARAMETERS
int T = ...; // 24 hours (or days if modeling per day)
float Demand[1..T] = ...; // Demand per hour/day (MW or MWh)
float SolarAvailability[1..T] = ...; // [%] Availability factor

float R = 0.88; // Relaxed renewable energy share (e.g., 88%)
float alpha = 0.82; // Solar share within renewables
float beta = 0.04;  // Battery share within renewables

float Min_Gas_Backup = 0.1 * sum(t in 1..T)(Demand[t]); // 10% backup

// CAPEX ($ per MW)
float C_s = 4000;
float C_b = 5500;
float C_g = 7500;

// O&M cost ($ per MW)
float M_s = 120;
float M_b = 110;
float M_g = 750;

// Total cost factors
float solarCapex = C_s + M_s;
float batteryCapex = C_b + M_b;
float gasCapex = C_g + M_g;

// Capacity constraints (MW or MWh)
float Solar_Cap_Max = 1500;
float Battery_Cap_Max = 800;
float Gas_Cap_Max = 1200;

// Battery parameters
float Battery_Efficiency = 0.85;
float chargeLimitRatio = 0.5; // Max 50% charge/discharge per hour

// Land constraint
float L_s = 10;
float L_max = 50000;

// DECISION VARIABLES
```

```
// DECISION VARIABLES
dvar float+ x_s in 0..Solar_Cap_Max; // Solar capacity
dvar float+ x_b in 0..Battery_Cap_Max; // Battery capacity
dvar float+ x_g in 0..Gas_Cap_Max; // Gas capacity

dvar float+ E_solar[1..T];
dvar float  E_battery[1..T]; // Discharge (+), charge (-)
dvar float+ E_gas[1..T];
dvar float  SOC[1..T]; // State of charge

// OBJECTIVE FUNCTION
minimize
  x_s * solarCapex +
  x_b * batteryCapex +
  x_g * gasCapex;

// CONSTRAINTS
subject to {
  // Power balance
  forall(t in 1..T)
    E_solar[t] + E_battery[t] + E_gas[t] == Demand[t];

  // Solar generation limit
  forall(t in 1..T)
    E_solar[t] <= x_s * (SolarAvailability[t] / 100);

  // Battery dynamics
  SOC[1] == -E_battery[1];
  forall(t in 2..T)
    SOC[t] == SOC[t-1] - E_battery[t];

  // Battery storage bounds
  forall(t in 1..T) {
    SOC[t] >= 0;
    SOC[t] <= x_b;
  }
```

```
  // Battery charging/discharging limit
  forall(t in 1..T) {
    E_battery[t] <= chargeLimitRatio * x_b;
    E_battery[t] >= -chargeLimitRatio * x_b;
  }

  // Battery efficiency limit
  forall(t in 1..T)
    maxl(0, E_battery[t]) <= Battery_Efficiency * E_solar[t];

  // Renewable share (solar + battery) >= R
  sum(t in 1..T)(E_solar[t] + maxl(0, E_battery[t])) >= R * sum(t in 1..T)(Demand[t]);

  // Solar share constraint
  sum(t in 1..T)(E_solar[t]) >= alpha * sum(t in 1..T)(Demand[t]);

  // Battery share constraint
  sum(t in 1..T)(maxl(0, E_battery[t])) >= beta * sum(t in 1..T)(Demand[t]);

  // Minimum gas generation
  sum(t in 1..T)(E_gas[t]) >= Min_Gas_Backup;

  // Gas capacity limit
  forall(t in 1..T)
    E_gas[t] <= x_g;

  // Land constraint
  x_s * L_s <= L_max;
}
```

DATA

T = 24;

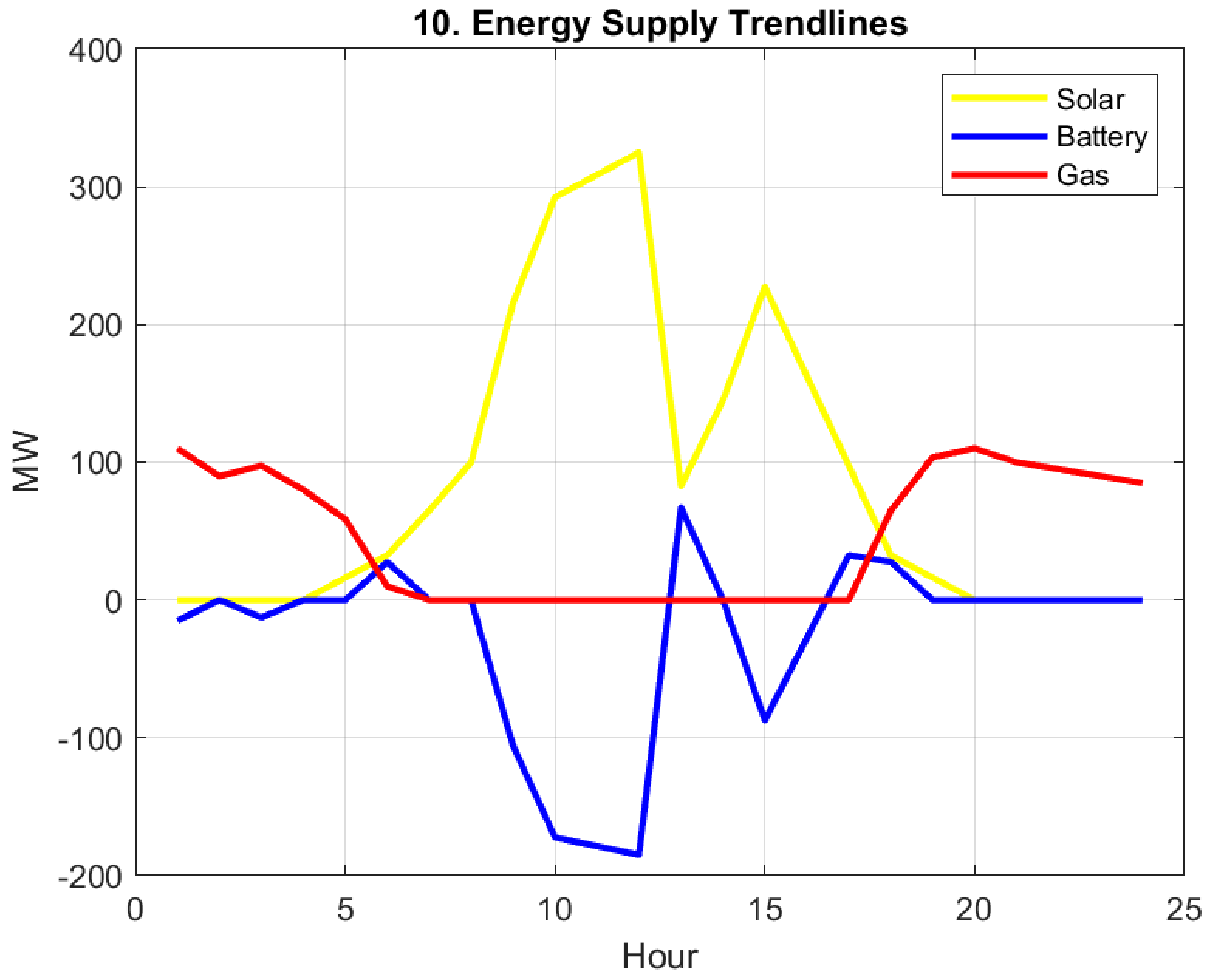
DEMAND = [95, 90, 85, 80, 75, 70, 65, 100, 110, 120, 130, 140, 150, 145, 140, 135, 130, 125, 120, 110, 100, 95, 90, 85];

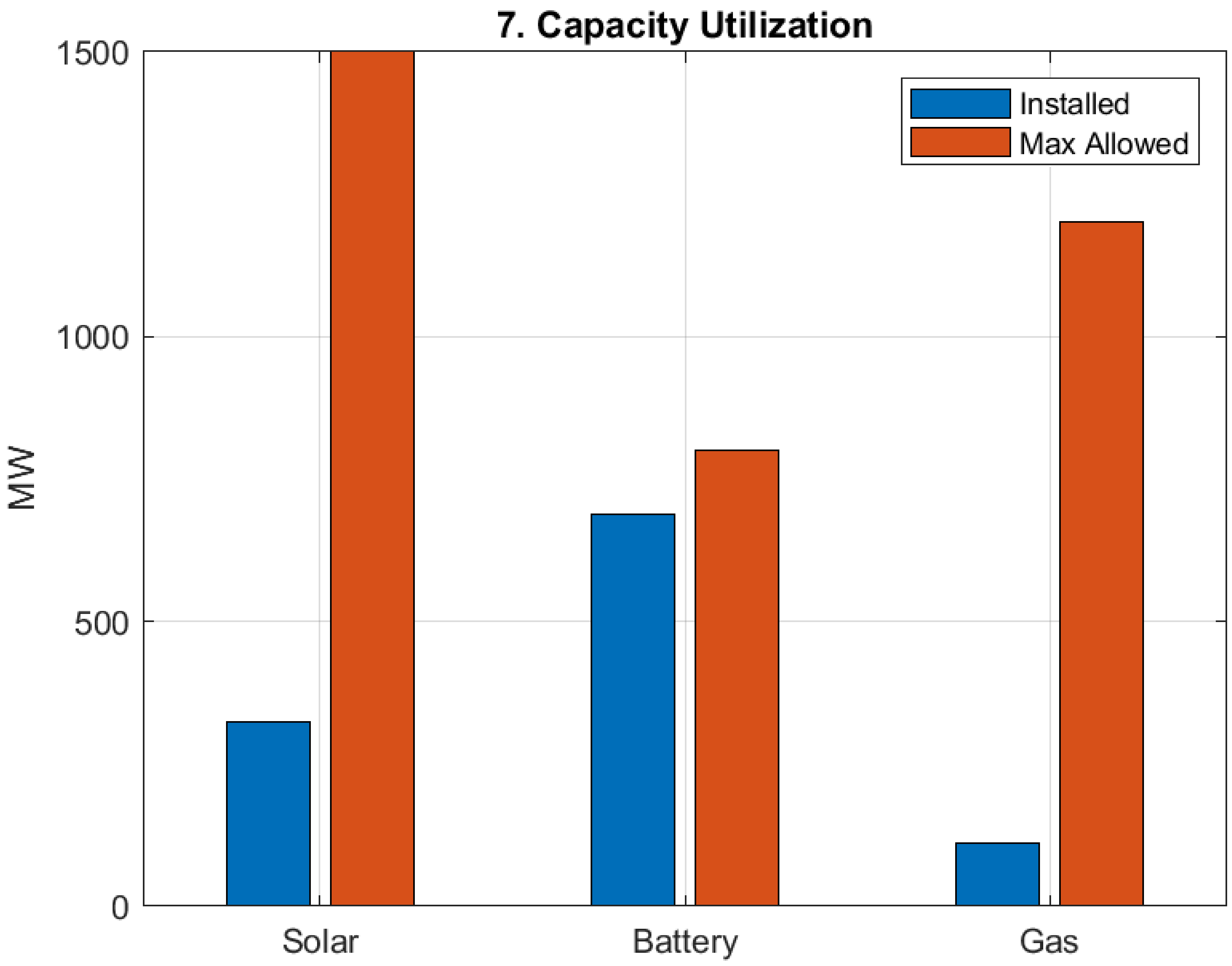
SOLARAVAILABILITY = [0, 0, 0, 0, 5, 10, 20, 50, 70, 90, 95, 100, 95, 85, 70, 50, 30, 10, 5, 0, 0, 0, 0, 0];

RESULT

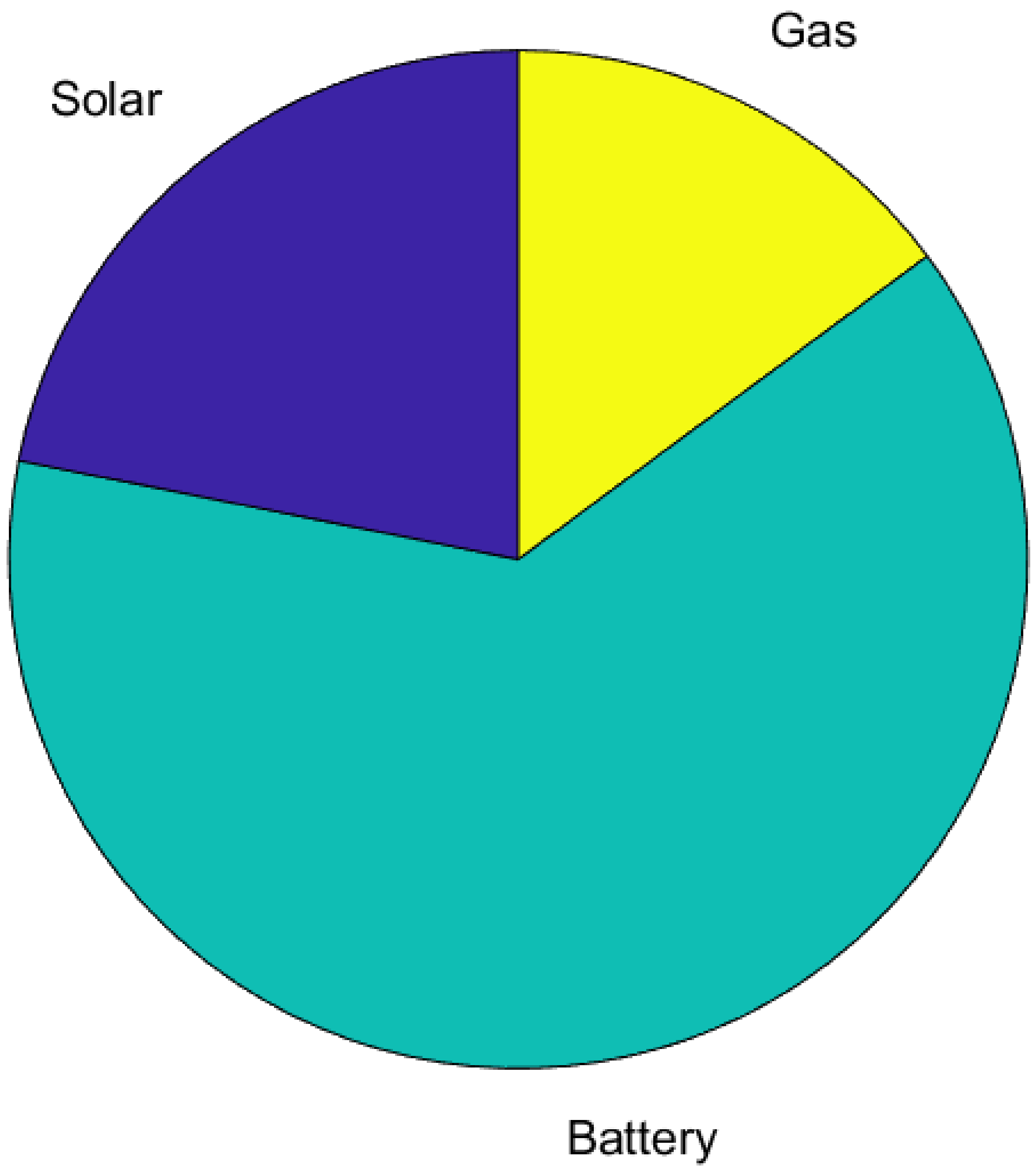
- solution (optimal) with objective 6115717
- x_s = 325;
- x_b = 689.7;
- x_g = 110;
- E_solar = [0 ,0 ,0 ,0 ,16.25, 32.5, 65 ,100 ,215.8, 292.5, 308.75 ,325 ,82.65, 145, 227.5, 162.5, 97.5 ,32.5, 16.25 ,0 ,0 ,0 ,0 ,0];
- E_battery = [-15 ,0 ,-12.625 ,0 ,0 ,27.625, 0 ,0 ,-105.8, -172.5 ,-178.75, -185, 67.35, 0 ,-87.5, -27.5, 32.5, 27.625, 0 ,0 ,0 ,0 ,0 ,0];
- SOC = [15, 15, 27.625, 27.625, 27.625, 0 ,0 ,0 ,105.8, 278.3, 457.05, 642.05, 574.7, 574.7, 662.2, 689.7, 657.2, 629.57, 629.57, 629.57, 629.57 ,629.57, 629.57 ,629.57];
- E_gas = [110, 90, 97.625 ,80 ,58.75, 9.875, 0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,64.875, 103.75, 110, 100, 95, 90, 85];

Graphical Analysis


10. Energy Supply Trendlines
400
300
200
100
0
-100
-200
MW
0
5
10
15
20
25
Hour
Solar
Battery
Gas


7. Capacity Utilization
1500
1000
500
0
MW
Installed
Max Allowed
Solar
Battery
Gas

9. CAPEX Cost Breakdown



THANK YOU!