<u>Understanding Energy Units in Energy Systems Modelling</u>

Quick Reference

- **Power** (rate of energy delivery): GW, MW, kW
- **Energy** (quantity of energy): PJ, GWh, MWh

Things become confusing as the units presented regarding rates and quantity in energy/power are often in contrast with what we are used to in terms of distance/speed

Understanding Power vs Energy (Car Analogy)

Think about the difference between speed and distance in a car:

- **Speed** (like **Power**):
    - Measured in mph (like GW)
    - Shows rate at any moment
    - Car's speedometer reading: "60 mph"
    - Power plant capacity: "2 GW (per second)"

Distance (like Energy):

- Measured in miles (like PJ or GWh)
    - 120 miles = 60 miles per hour × 2 hours
    - Similarly: 120 GWh = 60 GW × 2 hours
- Car's odometer might read "300 miles" after a journey
- Power plant production might read "50 PJ" or "60 GWh" (after a year)

Common Mistakes to Avoid

❌ **Incorrect Usage:**

- "The coal plant generated 500 GW last year"
    - Why wrong? Like saying "the coal plant drove 60 mph miles last year"
- "This wind power plant has a capacity of 300 PJ"
    - Why wrong? Like saying "car has a speed of 300 miles"
- The nuclear powerplant over there produces 2 GW of energy per hour"
    - Why wrong? GW is already a rate *(i.e. its GW per second, the 'per second' is always assumed but is not visible as a unit- unlike m**ph**)* - like mph is already a speed.

✅ **Correct Usage:**

- "The plant has a capacity of 2 GW"
  - Like: "The car has a top speed of 100 mph"
- "The plant generated 500 PJ last year"
  - Like: "The car drove 10,000 miles last year"
- "Energy consumption is 100 GWh per year"
  - Like: "Average driving distance is 1,000 miles per month"

Using Units in Energy System Models

Power (Capacity) Units:

- Use for:
  - Installing new capacity
  - Peak demand constraints
  - Operating limits
- Example: "Maximum solar capacity is 5 GW"

Energy Units:

- Use for:
  - Annual production
  - Consumption targets
  - Storage amounts
- Example: "Annual demand is 500 PJ"

Common Applications

1. **Power Plant Capacity**
   - Correct: "2 GW capacity"
   - What it means: Can deliver 2 gigawatts of power every second
2. **Annual Generation**
   - Correct: "50 PJ per year" or "50 PJ annually"
   - What it means: Total energy produced over a year
3. **Storage Systems**
   - Capacity (rate): "0.5 GW charging capacity"
   - Volume (quantity): "5 GWh storage capacity"

Quick Conversions Reference

- 1 GW running for 1 hour = 1 GWh
- 1 PJ ≈ 277.78 GWh
- 1 GW running for a year at full capacity ≈ 31.5 PJ

Remember:

- Power (GW) is about **capability** (like speed)
- Energy (PJ, GWh) is about **quantity** (like distance)
- Don't mix them up in calculations or constraints
- Always check if you need a rate or a quantity

Real-World Reference Values

Typical Power Plant Capacities (Power - GW)

- Nuclear Power Plant: 0.8 - 1.6 GW per unit
- Coal Power Plant: 0.3 - 2 GW
- Combined Cycle Gas Plant: 0.25 - 1 GW
- Hydroelectric Dam (large): 0.1 - 22 GW (Three Gorges Dam: 22.5 GW)
- Utility-Scale Solar Farm: 0.01 - 0.5 GW (1-500 MW)
- Offshore Wind Farm: 0.2 - 1.2 GW
- Onshore Wind Farm: 0.05 - 0.5 GW

Typical Annual Generation (Energy - GWh or PJ)

- 1 GW Nuclear Plant (at 90% capacity factor):
    - ~7,884 GWh/year
    - ~28.4 PJ/year
- 1 GW Solar Farm (at 20-25% capacity factor):
    - ~1,752-2,190 GWh/year
    - ~6.3-7.9 PJ/year

Household Energy Reference (UK typical)

- **Average Household Power Demand (instantaneous):**
    - Regular peak: 3-6 kW (when cooking/multiple appliances)

- Common appliances:
  - Electric shower: 7-11 kW
  - Electric oven: 2-2.5 kW
  - Kettle: 2-3 kW
  - Washing machine: 2-2.5 kW
  - AC (rare in UK): 1-3 kW

- **Average Household Electricity Consumption:**
  - Annual: ~3.7 MWh (0.0037 GWh)
  - Daily: ~10 kWh
  - Note: This is electricity only - typical UK home also uses gas for heating/cooking

UK City Scale References

- Medium City (1 million people):
  - Peak Electricity Demand: ~0.8-1.2 GW
  - Annual Electricity Consumption:
    - ~3,700 GWh/year
    - ~13.3 PJ/year

To Put it in Perspective

- One 1 GW power plant running for a year (at 90% capacity factor):
  - Can generate: 1 GW × 8760 hours × 0.90 = 7,884 GWh/year
  - This could power approximately:
    - 2.1 million UK homes (at 3.7 MWh/year each)
    - Or a city of about 2 million people (UK consumption patterns)

Capacity Factors (typical)

- Nuclear: 85-95%
- Coal: 70-85%
- Gas Combined Cycle: 50-70%
- Onshore Wind: 25-35%
- Solar PV: 20-25% (varies by location)
- Hydroelectric: 30-60% (varies by season and location)

Understanding Capacity Factors

What is Capacity Factor?

Capacity Factor = (Actual Energy Generated)/(Maximum Possible Energy Generation)

- Expressed as a percentage
- Shows how much of the time a plant operates at full capacity
- Helps convert between power (GW) and energy (GWh or PJ)

Simple Example:

If a 1 GW power plant running:

- At 100% capacity factor:
  - Would produce: 1 GW × 8760 hours = 8760 GWh/year
- At 25% capacity factor (like solar):
  - Actually produces: 8760 GWh × 0.25 = 2190 GWh/year

Why Aren't Capacity Factors 100%?

Different reasons for different technologies:

- Solar (20-25%):
  - No generation at night
  - Reduced output on cloudy days
  - Seasonal variations
- Wind (25-35%):
  - Wind speed variations
  - Seasonal patterns
- Nuclear (85-95%):
  - Planned maintenance
  - Refuelling periods
  - Very reliable and cost efficient once built
- Coal/Gas (50-85%):
  - Market demand variations (i.e. not needed when demand low)
  - Maintenance/repair periods
  - Economic dispatch decisions (i.e. only use when cheaper then alternatives)

Using Capacity Factors in Calculations

To get annual energy (GWh) from capacity (GW):

- Annual Energy = Power Capacity × Hours in Year × Capacity Factor
- Example: 1 GW × 8760 hours × 0.25 = 2190 GWh

To get required capacity (GW) from annual energy needed (GWh):

- Required Capacity = (Annual Energy)/(Hours in Year × Capacity Factor)
- Example: Need 2190 GWh/year with 25% CF:
    - Capacity = 2190 GWh ÷ (8760 × 0.25) = 1 GW

Common Mistakes with Capacity Factors

- Forgetting to include them in calculations
- Using nameplate (maximum) capacity for annual calculations
- Not accounting for seasonal variations in capacity factors (i.e. less daylight in winter for solar)

Pro Tips:

- Higher capacity factor = more energy from same capacity
- Low capacity factor ≠ unreliable or inefficient
- Capacity factors affect cost per MWh
- System planning needs to account for capacity factors

Understanding Power Generation graphs on the OSeMOSYS Cloud

Two power generation graphs are generated on the OSeMOSYS cloud after you upload your data file: 'power generation capacity' (in GW) and 'power generation' (in PJ).

"Power Generation Capacity (GW)":

- Shows how much capacity is INSTALLED
- Like "size of the power plants"
- Maximum possible output at any instant
- Think: "How big are my power stations?"
- Example: 2 GW solar capacity installed

Power Generation (PJ)":

- Shows how much energy actually PRODUCED over time
- Like "how much did they actually generate?"
- Accounts for capacity factors/actual operation
- Think: "What did my power stations actually deliver?"
- Example: Solar might produce 15 PJ/year from that 2 GW

Key differences in interpretation:

- Capacity (GW) graph:
  - Shows what you COULD generate at maximum
  - Doesn't show actual use
  - Important for peak demand/system size
- Generation (PJ) graph:
  - Shows what you DID generate
  - Accounts for actual operation
  - Important for understanding actual energy delivered

Example:

- Might see 2 GW of solar in capacity graph
- But much lower PJ in generation graph due to:
  - Only generates in daytime
  - Weather effects
  - Capacity factor (~25%)