USAID Haiti Training Session #3: Capacity Expansion

Cameron Weiner, National Renewable Energy Laboratory
Training Session #2 Exercise

1. How much capacity did the model build?

2. Was there unmet demand?

3. How much did it cost to operate the solar farm for one year?

1. Locations

2. Technologies

3. Nodes

4. Scenarios

5. Runs
1. How much capacity did the model build?
   1,000 kW or 1 MW, in line with what was configured for the solar PV technology

2. Was there unmet demand?
   Yes, during the hospital’s daily peaks indicating that solar was not enough to meet demand

3. How much did it cost to operate the solar farm for one year?
   $242,000

How can we cost optimally meet the hospital’s remaining demand using capacity expansion modeling?
Training Session #2 Exercise

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2. **Was there unmet demand?**

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Capacity Expansion Modeling

Models that simulate investment into new generation and transmission capacity, given assumptions about...

Future electricity demand

Fuel Prices

Technology cost and performance

Policy and regulation*

Capacity Expansion Modeling

Models that simulate investment into new generation and transmission capacity, given assumptions about…

Future electricity demand
Fuel Prices
Technology cost and performance
Policy and regulation*

...formule des optimisations autour du coût

* Definition borrowed from Department of Energy presentation by Erin Boyd at https://www.energy.gov/sites/prod/files/2016/02/f30/EPJSA_Power_Sector_Modeling_FINAL_021816_0.pdf
Future electricity demand
Fuel Prices
Technology cost and performance
Policy and regulation*

Questions for Capacity Expansion

1. What **operational and energy cost savings** could be anticipated by transitioning from a decentralized energy portfolio to a centralized one?
2. How does the **cost optimal system vary with constraints** on emissions, land use, and economic development goals?
3. What are the **high-level cost impacts** of alternative power sector policies?

Capacity Expansion Modeling

Models that simulate investment into new generation and transmission capacity, given assumptions about...

- Capacity expansion models are not **operational models**
  - Engage has **perfect foresight** when optimizing an energy portfolio
  - **Example:** Keeping batteries charged when it is sunny to meet demand when it will be cloudy in place of solar
  - **Implication:** Engage may build and dispatch technologies in ways that are operationally unrealistic

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**Future electricity demand**

**Fuel Prices**

**Technology cost and performance**

**Policy and regulation***

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Future electricity demand
Fuel Prices
Technology cost and performance
Policy and regulation*

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Calliope can run a model in “operation” mode to simulate limited foresight. https://www.calliope.ai/
Capacity Expansion Modeling

Models that simulate investment into new generation and transmission capacity, given assumptions about…

• Capacity expansion models often represent **power plants as one aggregate generator** even though they are commonly made up of individual units
  • **Example:** Individual generators at a power plant that have may have different operational parameters from another
  • **Benefit:** Less complex, shorter runtimes
  • **Implication:** Engage may overvalue or undervalue a power plant, which can lead to suboptimal investment decisions

Capacity Expansion Limitations

Future electricity demand

Fuel Prices

Technology cost and performance

Policy and regulation*

Capacity Expansion Modeling

Models that simulate investment into new generation and transmission capacity, given assumptions about…

- **Verify** Engage results and **think critically** about the model’s outputs
- Use capacity expansion models to **guide insight into energy sector planning**, such as identifying competitive technologies

**Future electricity demand**

**Fuel Prices**

**Technology cost and performance**

**Policy and regulation**

Capacity Expansion Modeling

Simulates how energy or commodities moves through a given system

- Supply
- Transmission
- Demand
- Storage
- Conversion

Supply → Transmission → Demand

Resource → Carrier$_{prod}$ → Carrier$_{con}$ → Carrier$_{prod}$ → Carrier$_{con}$ → Storage → Conversion → Carrier$_{prod}$ → Carrier$_{con}$ → Carrier$_{prod}$ → Resource
Storage Archetype

Supply

- Takes carriers in and stores them until later time intervals
- Serves system load but still requires a supply archetype

Storage Examples

- Electric batteries
- Potential (kinetic) energy (ex: water at a height)
- Electrochemical
- Fuel (natural gas, diesel)

Create a new technology and build “Storage” from scratch

Assign the storage technology a:
- Name
- Version Tag
- Color
- Electricity carrier
Storage Archetype

Supply

- Electric batteries
- Potential (kinetic) energy (ex: water at a height)
- Electrochemical
- Fuel (natural gas, diesel)

Storage

- C-rate
  - Indicates storage duration by describing the rate the technology can be discharged relative to its maximum capacity

<table>
<thead>
<tr>
<th>Battery Duration</th>
<th>C-rate / Storage Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Hour</td>
<td>50% / hour (1/2)</td>
</tr>
<tr>
<td>4-Hour</td>
<td>25% / hour (1/4)</td>
</tr>
<tr>
<td>6-Hour</td>
<td>~17% / hour (1/6)</td>
</tr>
<tr>
<td>10-Hour</td>
<td>10% / hour (1/10)</td>
</tr>
</tbody>
</table>

3 Populate for a four-hour duration
Storage Archetype

Supply

- C-rate

  Indicates storage duration by describing the rate the technology can be discharged relative to its maximum capacity.

- Storage capacity

  Represents total amount of carrier the technology can store (ex: kWh).

Storage

- Electric batteries
- Potential (kinetic) energy (ex: water at a height)
- Electrochemical
- Fuel (natural gas, diesel)

Storage Examples

- Populate a maximum storage capacity to signal capacity expansion
Linear Capacity Expansion

- Model **linearly expands** resource to the cost optimal point.

### Technology

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Capacity Expansion</th>
<th>Fixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply</td>
<td>Maximum production capacity</td>
<td>Production capacity</td>
</tr>
<tr>
<td>Transmission</td>
<td>Maximum carrying capacity</td>
<td>Carrying capacity</td>
</tr>
<tr>
<td>Storage</td>
<td>Maximum storage capacity</td>
<td>Storage capacity</td>
</tr>
<tr>
<td>Storage</td>
<td>Maximum c-rate</td>
<td>C-rate</td>
</tr>
</tbody>
</table>

**4. Populate a maximum storage capacity to signal capacity expansion**
Linear Capacity Expansion

- Maximum function

Model **linearly expands** resource to the cost optimal point

<table>
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<tr>
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<td>Maximum storage capacity</td>
<td>Storage capacity</td>
</tr>
<tr>
<td>Storage*</td>
<td>Maximum c-rate</td>
<td>C-rate</td>
</tr>
</tbody>
</table>

* Assumes that the cost of storage is also linear, which is often not the case
Linear Capacity Expansion

- **Maximum function**
  Model *linearly expands* resource to the cost optimal point.

- **Lifetime and amortization period**
  Relates to how Engage treats cashflows.
  Processes fixed and operating costs on an annualized basis.

- **Interest rate**
  To configuring the technology for capacity expansion, populate:
  - Lifetime and amortization period
  - Interest rate
Linear Capacity Expansion

- Maximum function
  - Model **linearly expands** resource to the cost optimal point

- Lifetime and amortization period

- Interest rate

$2,000,000$ for a 1 MW solar farm

- **20-year** technological lifespan
  - $\approx$ $100,000$
  - $\approx$ $160,000*$

* With 5% interest rate
Linear Capacity Expansion

Maximum function

Model \textit{linearly expands} resource to the cost optimal point \checkmark

Lifetime and amortization period

- Technological lifespan
- Contract period
- Maturity date of loan

Interest rate

- Cost of debt on loan
- Required rate of return
- Weighted average cost of capital (WACC)

1. Coax the model into generating \textit{cash flows} that will have the desired \textit{modeling impact}.
   - Critical for capacity expansion modeling

2. Be \textit{consistent} in representations.
   - Ex: consistent treatment of sunk costs, interest rates

**Modeling Reminders**

- Relates to how \textit{Engage treats cashflows}
- Processes fixed and operating costs on an \textit{annualized} basis
Annual Technology Baseline

Populated framework that identifies **technology-specific costs** as they relate to:
- Performance parameters under a robust set of modeling inputs that consider:
  - Electricity generation futures
  - Financial modeling scenarios

ATB uses assumption primarily focused within the United States market

**Historical cost data** for projects is always preferable since it considers **local conditions**

**Overnight capital cost (OCC):**
$1,715.50 / kW

**Fixed operation and maintenance (O&M):** $42.88 / kW

*Note: The ATB is displayed in English.*
Annual Technology Baseline

Populate costs from the ATB for:
- Cost of production capacity
- Annual Fixed O&M Costs

Note: The ATB is displayed in English.
Storage Archetype

C-rate
Indicates storage duration by describing the rate the technology can be discharged relative to its maximum capacity.

Storage capacity
Represents total amount of carrier the technology can store (ex: kWh).

One-way efficiency
Measures the loss in storing a carrier, whether on the charging or discharging side.

Storage Examples
- Electric batteries
- Potential (kinetic) energy (ex: water at a height)
- Electrochemical
- Fuel (natural gas, diesel)

Populate one-way efficiency parameter by squaring the round-trip efficiency used in the ATB.
Conversion Archetype

- **Converts** one type of a carrier to another
- Appropriate for technologies where we would want to **track input carriers** used in the production of another carrier

**Conversion Examples**

- Combined cycle gas turbine (CCGT)
- Coal power plant
- Natural gas boiler
- Electric transformer
Conversion Archetype

- **Converts** one type of a carrier to another
- Appropriate for technologies where we would want to **track input carriers** used in the production of another carrier
- Conversion Plus archetype is ideal for modeling complex technologies with **multiple input** and **output carriers**

**Conversion Examples**
- Combined cycle gas turbine (CCGT)
- Coal power plant
- Natural gas boiler
- Electric transformer

**Conversion Plus Examples**
- Advanced gas turbines
- Air source heat pumps
- Combined heat and power (CHP)

Read more about Conversion Plus under the Calliope Documentation in Engage. [https://www.calliope.io/](https://www.calliope.io/)
Diesel Supply

- **Resource:** Supply/Demand
  - Represents **fuel availability** of diesel for backup generator

- **Carrier Production Cost**
  - Represents **fuel price** for diesel

### Go to the Carriers page and create a new carrier for diesel
Diesel Supply

Supply
- **Resource**: Supply/Demand
  - Represents **fuel availability** of diesel for backup generator
- **Carrier**: Production Cost
  - Represents **fuel price** for diesel

Conversion

Create a new technology and build “Supply” from scratch

Assign the supply technology a:
- **Name**
- **Electricity carrier**

Assume infinite supply of diesel with large number
Diesel Supply

Supply

- Resource: Supply/Demand
  Represents *fuel availability* of diesel for backup generator

- Carrier
  Production Cost
  Represents *fuel price* for diesel $3 per gallon
Diesel Supply

Supply

☑️ Resource: Supply/Demand

Represents fuel availability of diesel for backup generator

☑️ Carrier Production Cost

Represents fuel price for diesel

$3 per gallon
Diesel Supply

Supply

☑️ Resource: Supply/Demand

Represents fuel availability of diesel for backup generator

☑️ Carrier Production Cost

Represents fuel price for diesel $3 per gallon

Conversion

Tips on Unit Conversion

- Structure inputs in compatible or equivalent units to achieve target units
- Separate terms by spaces
- Use parentheses to indicate order of operations
- Search for existing unit conversions in Engage
- Converter does not handle currency conversions

5. Search for the energy density for diesel by volume and convert the $3 price per gallon into a kWh price
Backup Diesel Generator

1. Create a new technology and build “Conversion” from scratch.

2. Assign the conversion technology a:
   - Name
   - Version Tag
   - Color
   - Input carrier
   - Output carrier
Backup Diesel Generator

- **Unit cost**: Represents the **retail value** of the asset - $162,857 per unit

- **Unit production capacity**: Captures the **real power** of the diesel generator
  
  \[550 \text{ kVA} \times 80\% = 440 \text{ kW}\]
  
  Apparent Power × Power Factor

3. Populate unit parameters for cost and production capacity
Unit Capacity Expansion

- **Maximum number of units**
- Model **linearly expands** resource to the cost optimal point
- Model determines cost optimal **number of units**

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**Linear Expansion**

Set the maximum number of units needed to meet the hospital’s load:

\[
2,000 \text{ kWh} \div 440 \approx 5 \text{ units}
\]
Unit Capacity Expansion

- **Advantage**: Closer to real-world investment decisions with limited foresight
- **Challenge**: More algorithmically complex to the point of becoming computationally unsolvable

Set the maximum number of units needed to meet the hospital’s load:

\[ \frac{2,000 \text{ kWh}}{440} \approx 5 \text{ units} \]
Unit Capacity Expansion

- **Maximum number of units**
- **Model** linearly expands resource to the cost optimal point
- **Linear Expansion**
- **Model determines cost optimal number of units**
- **Unit Expansion**

- **Advantage**: Closer to real-world investment decisions with limited foresight
- **Challenge**: More algorithmically complex to the point of becoming computationally unsolvable

- Lifetime and amortization period
- Interest rate

Configure the technology for capacity expansion
Backup Diesel Generator

- **Unit cost**: Represents the *retail value* of the asset - $162,857 per unit
- **Unit production capacity**: Captures the *real power* of the diesel generator
  
  \[ 550 \text{ kVA} \times 80\% = 440 \text{ kW} \]
  
  \[ \text{Apparent Power} \times \text{Power Factor} \]

- **Minimum operating level**: Requires a *minimum fraction* of the maximum production capacity to operate – 50%
Backup Diesel Generator

- **Unit cost**: Represents the retail value of the asset - $162,857 per unit

- **Unit production capacity**: Captures the real power of the diesel generator
  
  \[ 550 \text{ kVA} \times 80\% = 440 \text{ kW} \]

  Apparent Power × Power Factor

- **Minimum operating level**: Requires a minimum fraction of the maximum production capacity to operate – 50%

**Unit Advantage**: Capable of modeling real-world minimum operating conditions where technology is shut down if it cannot operate above a certain capacity

6. Populate the minimum operating level
Backup Diesel Generator

- **Unit cost**: Represents the retail value of the asset - $162,857 per unit
- **Unit production capacity**: Captures the real power of the diesel generator
  
  \[550 \text{ kVA} \times 80\% = 440 \text{ kW}\]
  
  Apparent Power $\times$ Power Factor

- **Minimum operating level**: Requires a minimum fraction of the maximum production capacity to operate – 50%

**Linear Challenge**: Interprets minimum operating levels as the required minimum operating capacity

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6. **Populate the minimum operating level**
**Backup Diesel Generator**

- **Unit cost**: Represents the retail value of the asset - $162,857 per unit.

- **Unit production capacity**: Captures the real power of the diesel generator. 
  
  \[550 \text{ kVA} \times 80\% = 440 \text{ kW}\]

  Apparent Power \times \text{Power Factor}

- **Minimum operating level**: Requires a minimum fraction of the maximum production capacity to operate – 50%.

  Linear Challenge: ✗
  
  Creates operating floor where technology operates between maximum and minimum level and never shuts off.

**Minimum Operating Level**

**Production Capacity (kW)**

**Linear**

**Unit**
Backup Diesel Generator

- **Unit cost**: Represents the retail value of the asset - $162,857 per unit
- **Unit production capacity**: Captures the real power of the diesel generator
  
  \[550 \text{ kVA} \times 80\% = 440 \text{ kW}\]
  
  Apparent Power \times Power Factor
- **Minimum operating level**: Requires a minimum fraction of the maximum production capacity to operate – 50%
- **Maximum ramp up rate**: Describes time needed before technology is at maximum capacity – 100% / hour
- **Conversion efficiency**: Measures the conversion rate between input and output carriers – 30% for diesel to electricity
- **Carrier production cost**: Represents variable operation and maintenance cost - $0.01 / kWh

Finish configuring the diesel generator with the:
- Maximum ramp up rate
- Carrier production cost
- Conversion efficiency
Model Building Process

1. Locations
2. Technologies
3. Nodes
4. Scenarios
5. Runs
Model Building Process

1. Create a new location called “Varreux”
2. Create new transmission technology called “Diesel Transport”

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2. Create a new transmission technology for “Diesel Transport”
1. Create a new location called “Varreux”

2. Create new transmission technology called “Diesel Transport”

3. Under Nodes tab, assign:
   - Diesel Supply to Varreux
   - Diesel generator to Solar PV and battery to Hospital
   - Diesel Transport to Varreux and Solar PV
1. Create a new location called “Varreux”
2. Create new transmission technology called “Diesel Transport”
3. Under Nodes tab, assign:
   - Diesel Supply to Varreux
   - Diesel generator to Solar PV and battery to Hospital
   - Diesel Transport to Varreux and Solar PV
4. Enable all nodes under the Scenarios page except for the lithium-ion battery
5. Click “Out of Date” under the Runs page

Click “Out of Date” and then “Run” to re-run the model

Enable all nodes in the model except for the lithium-ion battery
1. Create a new location called “Varreux”

2. Create new transmission technology called “Diesel Transport”

3. Under Nodes tab, assign:
   - Diesel Supply to Varreux
   - Diesel generator to Solar PV and battery to Hospital
   - Diesel Transport to Varreux and Solar PV

4. Enable all nodes under the Scenarios page except for the diesel generator

5. Click “Out of Date” under the Runs page

6. Enable all nodes in the model except for the diesel generator

7. Click “Out of Date” and then “Run” to re-run the model
Next Training Session

1. What was the cost optimal build of each technology?

2. How did the annual costs change under each technology?

3. Was there any unmet demand? If so, why?
Next Training Session

• Modeling renewable energy systems
• Resilience and power sector modeling scenarios
Thank you!

Contact engage@nrel.gov with any issues or questions.