Future Grid

How to make decisions under uncertainty

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The factors affecting our future grid in 2050

Factor 1: Higher or lower **Temperature** relative to expected

Factor 2: Higher or lower relative cost of **Renewables**

Factor 3: More **Regional Grid** or less than expected

Factor 4: More or less **Load Growth** than expected
Temperature in 2050
Why **Temperature** as a factor?

Higher than expected **temperatures** mean:

- More AC Load
- Lower efficiency for solar, wind
- More powerful storms
- More fires and more severe fires
- Health effects

Resulting in increased costs
Lower Warming Range (3-5.5°F)

- 30-60% loss in Sierra snowpack
- 6-14 inches of sea level rise
- 3-6% increase in electricity demand
- 10-35% increase risk of large wildfires
California Temperature Scenarios?

Medium Warming Range (5.5-8°F)

- 70-80% loss in Sierra snowpack
- 14-22 inches of sea level rise
- 10% increase in electricity demand
- 55% increase risk of large wildfires
California Temperature Scenarios?

Higher Warming Range (8-10.5°F)

- 90% loss in Sierra snowpack
- 22-30 inches of sea level rise
- 20% increase in electricity demand
Relative Cost of Renewables by 2050
Why relative cost of **Renewables** as a factor?

- Will affect adoption
- Will affect the cost of meeting environmental targets
- Affects budget
Solar costs continue to decrease materially.
Wind costs continue to decrease materially.

Source: DoE
This year’s forecast from BNEF sees solar energy costs dropping a further 66% by 2040, and onshore wind by 47%, with renewables undercutting the majority of existing fossil power stations by 2030.

Source: Bloomberg June 15, 2017
Small-scale batteries installed by households and businesses alongside PV systems will account for **57% of storage worldwide by 2040**.

Battery costs are **decreasing** by 66% by 2030.

Source: Bloomberg Energy Finance
Regional Collaboration
Why Regional Collaboration as a factor?

More regional integration:

- Reduces costs balancing supply and demand
- Diversifies source and location of supply
- Enables broader transformation
- Increases reliability and resiliency

Possible cost reductions
Why **Regional Collaboration** as a factor?

Benefits by Level of Regional Coordination

- **Balancing area operations**
- **Sub-hourly economic dispatch**
- **Day-of operations and residual unit commitment**
- **Day-ahead trading and unit commitment**
- **Transmission planning and resource procurement**

**Regional Organization**

**Extended Day-Ahead**

**Energy Imbalance Market**
Load Growth
Why Load Growth as a factor?

Load Growth:

Due to sector switching

Due to temperature sensitive loads

Supply efficiency

Effects costs and provides possible opportunities
Demand for electricity is expected to increase as other sectors electrify to decarbonize.
How to generate forward looking scenarios
Factor Uncertainty

the past  factors today

temperature
renewables
regional grid
load
Factor Uncertainty

The past factors today factors in 2050

- temperature
- renewables
- regional grid
- load
Factor Uncertainty

The past factors today factors in 2050

- temperature
- renewables
- regional grid
- load

Distribution of possible deviations from expected temperature in 2050
How do we compute these distributions?

We use the sentiment of the “crowds” combined with scientists views. In future we will use AI/Machine Learning.
Studies indicate that by 2050 temperatures are expected to rise by approximately 4 degrees F. What do you predict the temperature change to be?
By 2050, the cost of renewable energy (without subsidies) compared to the cost of conventional resources will be...
By 2050, it is expected that regional collaboration across the West could evolve from the existing Energy Imbalance Market to an expanded participation in the Day-Ahead Market to full participation options with a single ISO/RTO in the West.

**What level of regional collaboration do you expect?**
By 2050, annual demand is expected to increase by approximately 60% compared to our current demand levels.

What do you expect the load growth to be?
How do we get values for the Scenario Tree?

A clue comes from looking at the uncertainty in the factors.
Filling in the data needed to evaluate the tree

- **Probabilities**
  - **DOWN Probability (DOWN)**
  - **UP Probability (UP)**

- **Useful information embodied in the forward distribution**
Valuing Scenario Outcomes
Business as Usual case scenario 2°F

Prob. 0.4%
Cost* Reference Case
GHG reduction* Reference Case

It is 2050
Cost of meeting renewable targets are more than expected
A regional RTO has not formed.
Load growth lower than expected.

<table>
<thead>
<tr>
<th>Probability</th>
<th>$B</th>
<th>GHG MMTons</th>
</tr>
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<tbody>
<tr>
<td>24.8%</td>
<td>$32</td>
<td>3</td>
</tr>
<tr>
<td>21.2%</td>
<td>$24</td>
<td>(5)</td>
</tr>
<tr>
<td>5.1%</td>
<td>$37</td>
<td>5</td>
</tr>
<tr>
<td>4.3%</td>
<td>$27</td>
<td>(4)</td>
</tr>
<tr>
<td>4.7%</td>
<td>$45</td>
<td>23</td>
</tr>
<tr>
<td>4.0%</td>
<td>$32</td>
<td>7</td>
</tr>
<tr>
<td>1.0%</td>
<td>$58</td>
<td>28</td>
</tr>
<tr>
<td>0.8%</td>
<td>$40</td>
<td>10</td>
</tr>
<tr>
<td>12.8%</td>
<td>$(8)</td>
<td>(7)</td>
</tr>
<tr>
<td>10.9%</td>
<td>$(16)</td>
<td>(15)</td>
</tr>
<tr>
<td>2.6%</td>
<td>$(3)</td>
<td>(5)</td>
</tr>
<tr>
<td>2.2%</td>
<td>$(13)</td>
<td>(14)</td>
</tr>
<tr>
<td>2.4%</td>
<td>$5</td>
<td>13</td>
</tr>
<tr>
<td>2.1%</td>
<td>$(8)</td>
<td>(3)</td>
</tr>
<tr>
<td>0.5%</td>
<td>$18</td>
<td>18</td>
</tr>
<tr>
<td>0.4%</td>
<td>$-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Estimated values relative to reference are for illustration only.
**Expected case scenario 4°F**

- Prob. 21%
- Cost* $24 Billion
- GHG reduction* 5 MMTons

It is 2050

Renewable targets have been exceeded at lower cost.

A regional RTO has formed.

Load growth lower than expected.

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*Estimated values relative to reference are for illustration only*
**Worst** case scenario 4°F

Proba. 1%
Cost* $58 Billion
GHG increase* 28 MMTons

- It is 2050
- Cost of meeting renewable targets are more than expected
- A regional RTO has not formed.
- Load growth higher than expected.

*Estimated values relative to reference are for illustration only
Best case scenario $20F$

Prob. 11%
Savings* $16 Billion
GHG reduction* 15 MMTons

It is 2050
Renewable targets have been exceeded at lower cost.

A regional RTO has formed.

Load growth lower than expected.

*Estimated values relative to reference are for illustration only
Impact on the Grid

• Sea level rise will compromise coastal grid infrastructure

• Fires will threaten transmission lines

• Higher temperatures will increase demand and decrease supply

• Droughts will impact hydro availability
Drought Affects availability of Hydro Resources
Critical electric sector infrastructure could also be impacted by flooding.

**Table 3: Percent exposure of electric assets to 100- and 500-year FEMA flood zones**

<table>
<thead>
<tr>
<th>Electric Assets</th>
<th>FEMA 100-Year Flood Zone Exposure</th>
<th>500-Year Flood Zone Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution Lines</td>
<td>9%</td>
<td>13%</td>
</tr>
<tr>
<td>Distribution Transformers (Pad-Mount)</td>
<td>6%</td>
<td>17%</td>
</tr>
<tr>
<td>Transmission Lines</td>
<td>14%</td>
<td>18%</td>
</tr>
<tr>
<td>Substations</td>
<td>26%</td>
<td>39%</td>
</tr>
<tr>
<td>Power Generation Facilities</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Source: Pacific Gas & Electric
Wild Fires are becoming Fire Storms Threatening grid infrastructure