Planning a Transition to 100% Renewable Power in Hawaii

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Hawaii adopted 100% RPS by 2045 in 2015

• What is the least-cost plan to achieve this transition?
• What factors do we need to get right to keep costs down?
• Can we make a plan that is robust against uncertain fuel prices?

The challenges Hawaii faces will also need to be addressed by market-based power systems as the cost of renewable power falls.
Levelized Power Costs (Oahu)

- Levelized cost per MWh (2017$)
- Year

Exis-ng Steam Plants
- Internal combustion
- Combined Cycle
- AES (coal/biomass)
- Offshore Wind
- Onshore Wind
- Distributed PV
- Tracking PV

fossil / biofuel plants
wind / solar
Challenges in Planning for 100% Renewable Power

Power Production or Consumption (MW)

Too much power in the day.
Too little power at night.
Too much energy most of the year.
Too little energy part of the year.

Options:
- batteries
- pumped storage hydro
- demand response
- biofuels
- hydrogen storage

Solar Power
Wind Power
H-POWER
Electricity Demand

[4]
“Switch” Capacity Expansion Model for High-Renewable Power Systems (up to 100%)

Mixed-integer linear program, open-source software (http://switch-model.org)

Decision variables (co-optimized)
- **Investments every 5 years**: How much capacity to add in each potential project
  - Options include wind and solar farms, thermal and hydro power plants, battery storage and hydrogen equipment
- **Operation on sample days**: unit commitment and dispatch, storage, demand response
  - 12 sample days are modeled with hourly detail during each period, using synchronized profiles for wind, solar and load
  - Follow-up stage can test and refine plans using 8760+ hours

**Objective**
- minimize NPV of costs (capital recovery, fuel, O&M, emission taxes)

**Constraints**
- physical limits of equipment, weather, demand response
- provide enough electricity and reserves every hour
- meet RPS target
Input Data for Switch-Hawaii

- Hourly production profiles for all possible wind and solar resources
  - Land-use screens, Google Maps roof images, meteorological models, National Solar Radiation Database
- Hourly loads for sample days in future years
  - From FERC Form 714 filings for 2007-08, adjusted to match peak and average forecasts from PSIP
- Costs for generators, batteries and other equipment
  - Hydrogen from U.S. DOE studies
- Fuel price forecasts
  - US EIA Annual Energy Outlook, indexed to Hawaii
- Demand response potential (10%) and EV adoption (55% by 2045)
  - from PSIP
Projected Costs for Equipment and Fuel

- **Capital Cost (2017$/kW)**
  - Offshore Wind
  - Onshore Wind
  - Distributed PV
  - Tracking PV
  - Combined Cycle
  - IC Barge

- **Fuel Cost (2017$/MMBtu)**
  - Biodiesel
  - Diesel
  - LSFO
  - Pellet Biomass
  - Coal
Switch chooses the optimal mix of resources to build, based on cost and hourly behavior.
RESULTS
Least-Cost Transition to 100% Renewable Power

Installed Capacity (MW)

Renewable Energy Share

Average Production Cost ($/kWh)

- Dist PV
- Large PV
- Wind
- Hydrogen
- Reserve Batteries
- Bulk Batteries
- Oil
- Coal/Biomass
- Waste

Renewable share (solid line)
RPS target (dashed line)

Average Production Cost:
- $0.00 in 2020
- $0.05 in 2025
- $0.10 in 2030
- $0.15 in 2035
- $0.20 in 2040
- $0.25 in 2045
Hourly Energy Balance in Reference Plan ($139/MWh)

Hourly Power Production (MW)

Hourly Power Consumption (MW)
Hourly Energy Balance in Reference Plan ($139/MWh)

Hourly Power Production (MW)

Hourly Power Consumption (MW)

Curtail Wind
Curtail Solar
Discharge Batteries
Solar
Wind
Diesel
LSFO
Hydrogen
Biodiesel
Pellet-Biomass
Coal
Waste to Energy

Charge Batteries
Liquify Hydrogen
Produce Hydrogen
Charge EVs
Responsive Demand
Nominal demand
Energy Balance with No Hydrogen ($139/MWh)

Hourly Power Production (MW)

- Curtail Wind
- Curtail Solar
- Discharge Batteries
- Solar
- Wind
- Diesel
- LSFO
- Hydrogen
- Biodiesel
- Pellet-Biomass
- Coal
- Waste to Energy

Hourly Power Consumption (MW)

- Charge Batteries
- Liquify Hydrogen
- Produce Hydrogen
- Charge EVs
- Responsive Demand
- --- Nominal demand
No Demand Response ($150/MWh)

Hourly Power Production (MW)

Hourly Power Consumption (MW)
20% Demand Response ($131/MWh)

Hourly Power Production (MW)

Hourly Power Consumption (MW)

Curtail Wind
Curtail Solar
Discharge Batteries
Solar
Wind
Diesel
LSFO
Hydrogen
Biodiesel
Pellet-Biomass
Coal
Waste to Energy

Charge Batteries
Liquify Hydrogen
Produce Hydrogen
Charge EVs
Responsive Demand
Nominal demand
Cost Summary (in 2045)

Electricity Production Cost in 2045 (2017$/MWh)

- No new renewables: $153
- Reference Plan: $139
- No Hydrogen: $139
- No demand response: $150
- Double demand response: $136
- No wind: $159

Technology Scenario
Optimal Transitions for Different Oil Prices

Brent Crude Oil Price (2017$/bbl)

- Historical
- AEO 2018 High Forecast
- AEO 2018 Reference Forecast
- AEO 2018 Low Forecast

Optimal Renewable Power Share

- High oil prices
- Ref oil prices
- Low oil prices
- RPS

Historical, AEO 2018 High Forecast, AEO 2018 Reference Forecast, AEO 2018 Low Forecast

Brent Crude Oil Price (2017$/bbl)

- Historical
- AEO 2018 High Forecast
- AEO 2018 Reference Forecast
- AEO 2018 Low Forecast
Robust Planning for Different Oil Prices

- **Average Production Power Cost, 2020–2045**
- **Oil Price Scenario**
  - Low
  - Base
  - High

**Portfolio**

<table>
<thead>
<tr>
<th>Portfolio</th>
<th>Average Prod. Cost Across all Scenarios ($/MWh)</th>
<th>Max. Regret Across all Scenarios ($/MWh)</th>
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</thead>
<tbody>
<tr>
<td>High RE</td>
<td>$126</td>
<td>$22</td>
</tr>
<tr>
<td>Ref. RE</td>
<td>$122</td>
<td>$9</td>
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<tr>
<td>Low RE</td>
<td>$131</td>
<td>$39</td>
</tr>
</tbody>
</table>

Reference plan has "least regret" across all oil price scenarios.
Findings from Switch–Hawaii (Oahu-Focused)

• 100% renewable power is possible at reasonable costs
  – optimal plan is above RPS through 2040
  – optimal plan is 55% renewable by 2020

• Optimal designs only move about 15% of energy through storage

• Wind and demand response are important for keeping costs down

• Reference plan minimizes expected cost and regret in the face of higher or lower oil prices

• Future work: directly optimize first-stage plan for multiple cost scenarios for fuel and equipment, with adaptation in later stages
Implications for Market Design

• ISOs could (should?) use Switch-like models for capacity markets
  – non-discriminatory selection among different resource options
  – no need for simplifying/biasing statistics (“capacity value”)
  – long-term markets would provide secure finance

• Challenge: long-term planning requires forecasts
  – cost of future projects, not bidding today
  – future cost of fuels
  – who should carry the risk that the forecast is wrong?