How Should the Public Utilities Commission Regulate the Hawaiian Electric Company for Better Integration of Renewable Energy?

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Identifying the Problem

- Policy Goal: Achieve Hawaii's renewable energy mandates at least cost to all consumers in the state
- Two policy challenges
  - Build and operate transmission and distribution network to support least system-wide cost of deployment of grid-supplied and distributed renewable energy
  - Price transmission and distribution network and grid-supplied electricity to cause least system-wide cost mix of grid-supplied and distributed renewable energy
    - Give all consumers have option to purchase from grid or install distributed solar capacity

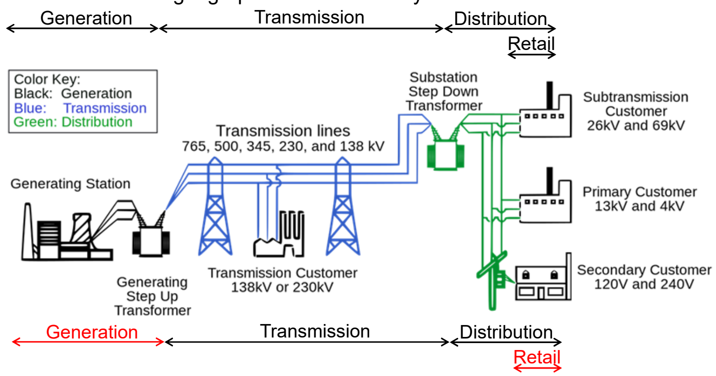
Outline of Talk

- Traditional Approach to Utility Regulation and Performance-Based Regulation
  - Isn't all regulation performance-based?
- Introducing Competition into Wholesale and Retail Markets
  - Is competitive market possible in Hawaii?
- Distributed Solar: A New Competitor for Grid-Supplied Electricity
  - What is inefficient bypass of grid-supplied electricity?
- Adapting Regulatory Process to the New Competitive Landscape
  - More competition? More regulation?
- Managing the Transition to the Renewable Future
  - How should HECO and Hawaii PUC adapt to green future?
- Concluding Comments

Traditional Approach to Utility Regulation and Performance-Based Regulation

Traditional Electricity Supply Industry

Vertically-integrated monopoly regime: One company owns generation, transmission, and distribution, and has legal right to sell energy to all consumers in its geographic service territory



Vertically-Integrated Monopoly Regime

- Given monopoly status and inelastic demand for product, firm can charge prices significantly in excess of average cost without losing customers
  - Customer has choice of buying from geographic monopoly or not getting grid-supplied electricity
- Solution: State-level regulation
  - Public Utilities Commission determines retail prices firm can charge to a consumers
  - Determines prudency of operating and investment decisions
- Hawaiian Electric Companies are regulated by Hawaii Public Utilities Commission (PUC)

Traditional Regulatory Process

- “Cost-of-Service Regulation” is a misnomer
  - Regulator does not allow utility to recover all costs of serving demand
  - More accurate to call it “output price regulation”
- Implicit “Regulatory Bargain”
  - Regulated firm agrees to serve all demand at price set by regulator
  - Regulator agrees to set price that allows utility the opportunity to recover all “prudently” incurred costs
- All US regulators do not allow recovery of “imprudently” incurred costs
  - Major point of contention in regulatory process is over what are “prudently” incurred costs

Setting Regulated Prices

- Cost-of-service regulatory process
  - P = price of output
  - Q = quantity of output
  - C(Q) = prudently incurred variable costs to produce output quantity Q
  - V = value of tangible and intangible property
  - D = accrued depreciation on tangible and intangible property
  - RB = rate base (V - D)
  - s = allowed rate of return on rate base
- Regulator sets Q*, output in future test year
- Then regulator sets P* so that

$$P^* = [C(Q^*) + s(RB)]/Q^*$$

Setting Regulated Prices

- [C(Q*) + s(RB)] = "revenue requirement"
- Both rate base, RB, and return of capital, s, are set by regulator
  - Regulator decides whether investment can be put in rate base (prudency review)
  - If so, firm is able to earn s on it for life of investment
- Note that P* > MC(Q*) = Marginal Cost at output quantity Q*
  - P* = AC(Q*) = Average cost at output quantity Q* (this recovers fixed costs)

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Setting Regulated Prices

- Once regulator sets output price, P*, profit-maximizing firm wants to minimize production cost
- Recall regulatory bargain—Firm must supply all demand a regulated price which implies firm has little or no control over its revenues which are equal to (P*) times realized Q
- Implication—Maximizing profits achieved by minimizing cost of production
- Quiz Question: Is regulatory challenge solved?

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Setting Regulated Prices

- Regulatory lag
  - Longer the regulated output price remains fixed, the longer is the time horizon over which the firm wants to minimize costs
  - The longer regulated output price remains fixed, the greater is the likelihood it will fail to recover the firm's cost of serving demand
- Performance-Based Regulation (PBR)
  - Goal is to provide stronger incentive for least cost production by regulated firm

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Performance-Based Regulation

- *Price cap regulation* is more sophisticated version of regulatory lag that is popular form of *Performance-Based Regulation*
- Price-cap regulation sets rule for evolution of prices:

$$\%\Delta P = \%\Delta CPI - X$$

  - %ΔP = annual percentage change in price
  - %ΔCPI = annual percentage change in consumer price index (CPI)
  - "X-factor" based on expected productivity and input price increases
- Output price does not depend on firm's actions, so its revenues are independent of its actions
  - Goal of price cap rule is a output price that evolves over time independent of firm's actions yet still obtains sufficient revenues to cover firm's costs in every year

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Performance-Based Regulation

- Caution--Performance-based regulation as implemented often resembles an inferior form of cost-of-service regulation
  - It all depends on how X-factors are set
  - Price cap regulation requires regulator to write an unenforceable contract with firm
- Examples from price-cap regulation
  - UK Regional Electricity Companies
  - UK National Grid Company
  - US Telecom Firms

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Regulation versus Competition

- Major problem with all forms of output price regulation
  - There are laws against confiscating a regulated firm's assets
    - Impossible to tell difference between regulator setting
      - Output prices that confiscate firm's assets
      - Output prices that provide strong incentives for least-cost production
  - Long history of legal disputes in US that attempt to define process for setting prices that do not confiscate firm's assets
  - Firm understands value of superior information about its demand and technology in regulatory price-setting process
    - For more on this issue, see Wolak (1994) "An Econometric Analysis of the Asymmetric Information Regulator-Utility Interaction," on web-site

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Performance-Based Regulation

- In theory, output price is set independent of firm's actions
  - Profit-maximizing firm has maximal incentive to minimize costs, because its revenues are exogenous
  - In reality X-factor often determined from a prospective measure of cost-of-service
- More important problem--Regulator finds it extremely difficult to maintain a given of X-factor when revenue constraint begins to affect adversely impact firm's profit level
  - Regulator cannot charge price that confiscates firm's assets
- Price-cap regulation becomes *de facto* cost of service regulation with the option to obtain very high profits if X-factor is set too low
  - Consumers likely to pay more on average than under cost-of-service
- The above logic applies to virtually all forms of performance based regulation
  - Promise firm upside in profits, but cannot generally enforce downside if firms profits are adversely impacted, and firm knows this

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Traditional Approach to Utility Regulation and Performance-Based Regulation

Key Points:

1) Regulated price set above short-run marginal cost of supply in order to recover fixed costs

2) Cost-of-service regulation is a form performance-based regulation

3) Performance-based regulation typically evolves into higher cost (for consumers) form of cost-of-service regulation

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Introducing Competition into Wholesale and Retail Markets

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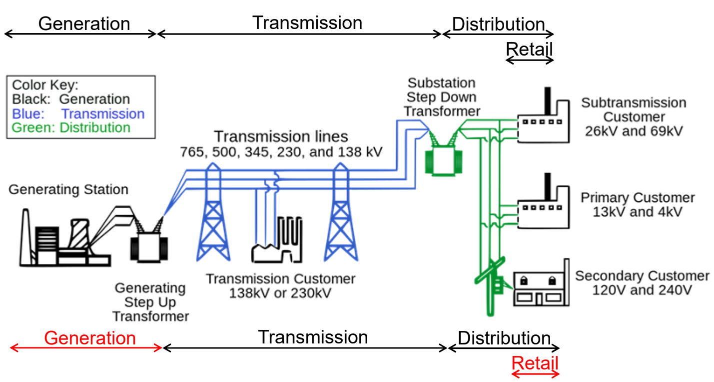
What is Restructuring?

- Starting in late 1990s a number of regions in the US embarked on restructuring process
  - Re-structuring ≠ Deregulation
- Replace explicit retail price regulation with market mechanisms to set prices and determine how electricity is supplied
  - Price-regulated open access to
    - Inter-state transmission network
    - Local distribution network
  - Market mechanism to set prices for wholesale power and determine which generation units produce energy
  - Market mechanism to set prices for retail electricity and determine which retailers sell electricity to final consumers

Traditional Electricity Supply Industry

Restructured regime: Generation and/or retail opened to competition



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Some Regulation Always Necessary

- Technology for delivering electricity implies
  - One transmission and distribution grid needed for a given geographic area
  - Competition among multiple networks would lead to single dominant network
    - Large fixed cost to construct network
    - Close to zero marginal cost to operate
- In all regimes, monopoly supplier of transmission and distribution services for each geographic area requires government oversight
  - Unregulated monopoly can set prices for use of network that extracts all monopoly profits from electricity supply

Regulated versus Market Pricing

- Restructured regime restricts regulated portion of industry to smallest entity possible
  - Transmission and distribution are only regulated services in competitive regime
  - Generation and electricity retailing are open to competition
- Traditional regulated regime imposes regulatory process on all aspects of industry
  - Final output price of vertically-integrated monopoly is regulated
- Choice between regulation and competition depends which regime comes closer to achieving market design goals for each stage of production process
  - Choice between ***imperfectly competitive market versus imperfect regulatory process*** will depend on many region-specific factors

Wholesale Competition in Hawaii?
(Island of Oahu)

HAWAIIAN ELECTRIC

Customers: 304,948

Firm generation:

Hawaiian Electric plants

Kahe (oil) .... 650 MW
Waiau (oil) .... 500 MW
Campbell Industrial Park (biofuel) .... 120 MW
Schofield (biofuel/diesel) .... 50 MW

Independent power producers

Kalaeloa Partners (oil) .... 208 MW
AES-Hawai'i (coal) .... 180 MW
HPOWER (waste-to-energy) .... 68.5 MW
Airport Emergency Facility (biofuel) .... 8 MW

Total firm capacity .... 1,784.5 MW

Variable (as-available) generation:

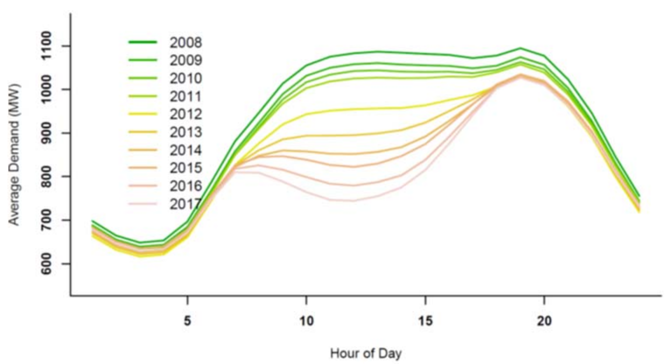
Independent power producers

Kawailoa Wind .... 69 MW
Kahuku Wind .... 30 MW
Wai'anae Solar .... 27.6 MW
Par Hawaii .... 18.5 MW
Island Energy Service .... 9.6 MW
Waihonu Solar .... 6.5 MW
Aloha Solar Fund 1 .... 5 MW
Kalaeloa Solar Two .... 5 MW
Kalaeloa Renewable Energy Park (PV) .. 5 MW
Kapolei Sustainable Energy Park (PV) .. 1 MW

Customer-sited solar** .... 460 MW

Approximate non-firm capacity:
.... 637.2 MW

Bid-Based Wholesale Market in Hawaii?



Bid-Based Wholesale Market in Hawaii?

- Difficult to see how a bid-based wholesale market as exists in continental US would be least cost solution for Oahu and other Hawaiian Islands
  - Annual peak demand in Oahu is ~1200 MWh
  - Minimum efficient scale for thermal generation unit is >200 MW
  - Ancillary services—Primary, Secondary Reserves, Spinning, Non-Spinning Reserves and other ancillary services
    - Meet supply and demand balance in real-time
    - Maintain frequency, Reactive power needs, Inertia
    - Black Start, Voltage control
- Preview of Recommendations: Alternative solution for small markets from international experience with electricity industry re-structuring

Introducing Competition into Wholesale and Retail Markets

Key Points:
1) Cannot eliminate need for regulation of transmission and distribution networks
2) Wholesale markets are susceptible to exercise of unilateral market power, particularly those with few suppliers
3) Wholesale and retail competition as practiced in continental US is impractical for size of efficient scale of generation units and level of demand in Oahu (and other islands)

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Distributed Solar: A Viable Competitor for Grid-Supplied Electricity

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Distributed Generation

- Distributed solar provides customer with ability to avoid purchases from grid
  - Consumer pays $/KWh charge only on electricity withdrawn from grid
  - Retail price is avoided cost of energy from distributed solar panels
    - P(retail) = P(Wholesale) + P(Trans) + P(Dist) + Other
    - Other = retailing margin, energy efficiency programs, above market cost of Renewables Portfolio Standard (RPS) energy, low-income energy programs, distributed generation and storage support mechanisms
- P(retail) is typically much greater than hourly marginal cost of grid-supplied electricity
  - MC(Grid,h) = P(Energy,h) + MC(Delivery,h)
  - MC(Delivery,h) = Hourly marginal cost of delivering electricity to customer's premises through transmission and distribution grid

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Example from California

- California has more than 7,000 MW of distributed solar installed
  - Most of it installed since 2007 under California Solar Initiative (CSI)
- CSI provided $2.167 billion to support distributed solar installations
  - CSI funded by electric ratepayers through higher retail prices
- California has 33% Renewables Portfolio Standard (RPS) by 2020 and 60% by 2030
  - Above-wholesale-market-price costs of qualified renewable energy included in retail price
- California energy efficiency programs cost approximately one billion dollars per year
  - Further raises retail prices
- All of these charges are recovered through a higher $/KWh retail price

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Retail Price Increases: Reason I

- Fixed cost of transmission and distribution grid does not depend on how many KWh are withdrawn from grid
  - Very small hourly marginal cost of delivering 1 KWh through grid of less than one half of a cent/KWh
- As more customers install distributed solar, the same fixed cost must be recovered from fewer total KWh
  - $/KWh price must increase for cost recovery
- Higher $/KWh price increases incentive to install distributed solar
  - Avoid paying higher retail price of electricity

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Retail Price Increases: Reason II

- As more distributed solar is installed in a given distribution grid, upgrades may be necessary
  - Manage large surges of energy injections into grid during periods of the day with significant solar activity
  - Solar system sized to produce close to customer's monthly consumption produces more electricity than customer consumes during daylight hours
    - Capacity factor of California solar rooftop solar system is approximately 0.17 = (Annual Kwh)/(KW x 8760 hours)
- Grid upgrades raise fixed cost of grid, which further increases $/KWh retail price

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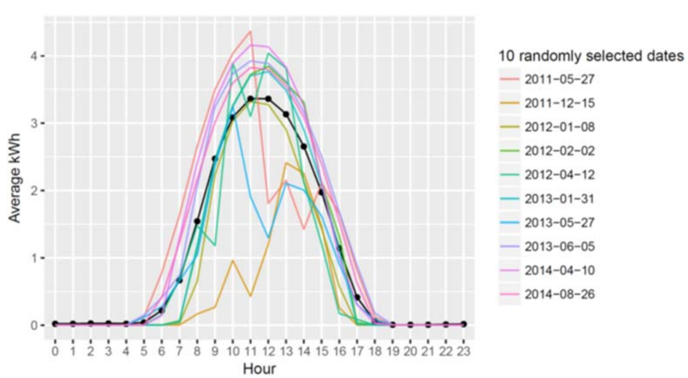
Fixed-Mount Daily Solar Energy Production



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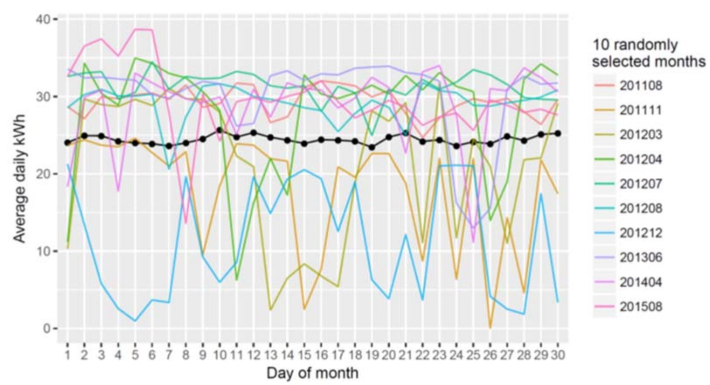
Fixed-Mount Monthly Solar Energy Production



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Inefficient Retail Pricing in CA

- Current average residential price in California is ~23 cents/KWh
  - All three investor-owned utilities have increasing block prices for retail electricity
    - Highest marginal price in PG&E territory is 40 cents/KWh
  - At $3.00/Watt installed, rooftop solar photovoltaic (PV) panels have a levelized cost equal to ~15 cents/KWh (at 3 percent real discount rate)
    - Going solar requires no subsidies to make it privately profitable for "average" California consumer
- Average wholesale cost of energy in California ISO in 2017 was 4 cents per KWh
  - Average hourly (Energy + Ancillary Services + Uplift) Charges per KWh of load served in California ISO control area
  - Socially unprofitable to invest in rooftop solar, because it is much cheaper for customer to get electricity from wholesale market

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Inefficient Retail Pricing in CA

- Divergence between privately optimal decision and socially optimal decision due to inefficient pricing
  - More than 18 cents/KWh = (23 – 4 – ~0.5) cents/KWh difference between average retail price and average hourly marginal cost of grid-supplied electricity
  - Economically inefficient bypass of grid-supplied electricity
  - Much cheaper on a system-wide basis to supply customer with ~4.5 cents/KWh electricity from grid rather than 15 cents/KWh from distributed solar
    - Customer chooses distributed solar because this avoids average price per KWh of 23 cents/KWh
- In world without distributed solar, inefficient retail pricing did not lead to bypass
  - Customer's bypass option was no electricity rather than electricity from solar PV capacity

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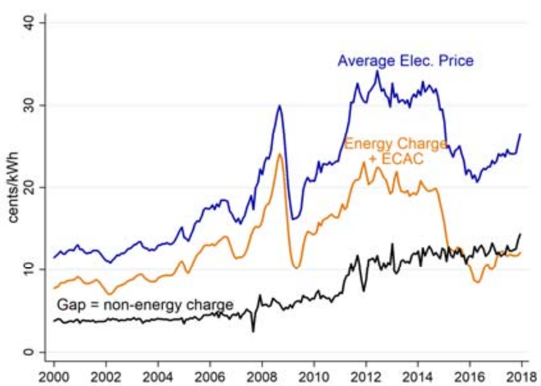
Inefficient Retail Pricing in Hawaii



More than 10 cents/KWh difference between average retail price and average variable cost of grid-supplied electricity in Hawaii creates incentive for inefficient bypass that raises total cost of supplying electricity in Hawaii

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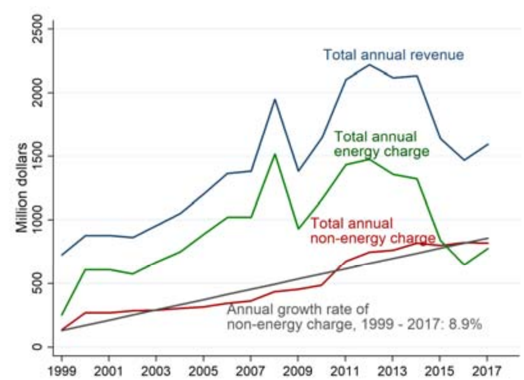
Inefficient Retail Pricing in Hawaii



Substantial economic benefits to Hawaiian electricity consumers from more efficient retail pricing

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The "Utility Death Spiral"

- Two reasons for increase in $/KWh retail price due to solar PV installations
  - (1) Mechanical—Less electricity withdrawn from grid on annual basis (same total cost divided by less electricity withdrawals)
  - (2) Grid integration costs—Upgrades of distribution network to accommodate more distributed solar (increases distribution costs)
- "Utility Death Spiral"
  - Higher prices lead to more rooftop solar, which leads to less withdrawals, which leads to higher prices and more rooftop solar and less withdrawals, which leads to higher prices...
- Wolak (2018) "Evidence from California on the Economic Impact of Inefficient Distribution Network Pricing" available on web-site
  - Roughly 1/3 of $/KWh increase in average retail prices since 2003 due to "Mechanical" effect
  - Roughly 2/3 of $/KWh increase in average retail prices since 2003 due to "Grid Integration Costs" effect

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Distributed Solar: A New Competitor for Grid-Supplied Electricity

Key Points:

1) Inefficient bypass—Privately profitable action that raises system-wide costs of supply because of economically inefficient pricing

2) Because of viable competitor for grid-supplied electricity, inefficient network pricing leads to inefficient bypass of grid-supplied electricity by installing rooftop solar PV

2) Two options for meeting renewable energy goals, grid-supplied renewables and distributed renewables and inefficient retail pricing favors distributed renewables even if they are significantly higher cost system-wide basis

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Adapting Regulatory Process to the New Competitive Landscape

When the Facts Change, I Change My Mind. What Do You Do, Sir?
--Attributed to John Maynard Keynes

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Sunk Cost Recovery

- Urgent problem--There is no guarantee that a utility receives cost recovery for an obsolete investment
  - "Utility only guaranteed an opportunity to earn a fair return" (Justice Brandeis)
  - Superior competitive technology that renders past investments obsolete makes cost recovery unlikely
- Ultimate outcome unclear because rooftop solar does not render transmission or distribution network obsolete
  - It is unnecessary only certain times of the day
- Increasing distribution costs associated with accommodating distributed solar makes addressing question even more urgent
  - Utility may not receive full cost recovery for investments to accommodate distributed solar capacity

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A Proposed Solution

- How to reform Hawaiian Electric Companies (HECO) and Hawaiian PUC regulatory process to facilitate least cost transition path to Hawaii's renewable energy goals
  - Reform retail electricity pricing based on concepts of cost causation and ability to pay
  - Introduce cost-based short-term market for wholesale electricity to set hourly wholesale price of electricity
  - Plan transmission and distribution network expansion to support least-cost, on system-wide basis, deployment of distributed and grid-scale renewables and storage technologies
- If interval meters (meters that can measure consumption at high level of temporal resolution) are deployed for all customers, can introduce retail competition
  - Hourly metering should be a regulated service provided by HECO

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Improving Efficiency of Retail Pricing

- Set retail prices based on cost causation and willingness-to-pay principles
  - Set HECO's hourly price of grid-supplied energy equal to *hourly marginal cost* of grid-supplied energy plus *hourly marginal cost* of delivering energy to customer
  - Remainder of HECO's fixed of costs recovered in monthly fee based on customer's willingness to pay
    - Retail electricity supply charges look much more like cable television bill (Monthly fixed cost + pay per view)
    - Customer pays $/month fixed fee for right to purchase grid-supplied electricity at hourly price
- Fixed monthly charge set based on customer's willingness to pay
    - Wolak (2018) "Evidence from California on the Economic Impact of Inefficient Distribution Network Pricing" describes mechanism for computing monthly fixed charge based on willingness-to-pay

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Improving Efficiency of Retail Pricing

- Use a cost-based short-term market on Oahu to set hourly marginal cost of grid-supplied energy
  - Many small countries have wanted to capture economic benefits of short-term market mechanisms
  - Cost-based short-term market allows all resources—HECO owned and IPPs--to compete to produce energy
    - Least cost dispatch of units based on regulator-determined start-up and marginal cost of production
  - Cost-based markets exist in Chile (since 1980), Bolivia, Peru, throughout Central America, and Mexico
- Cost-based short-term markets focus on realizing major source of benefits of competition
  - Foster the development of an competitive forward market for energy
  - Countries with these markets have enabled enormous demand growth fueled by long-term power purchase agreements (PPAs) and cost-based short-term market to clear imbalances relative forward contract quantities

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Improving Efficiency of Retail Pricing

- What does clearing imbalances mean?
  - Suppose supplier sells PPA for 100 MWh each hour of the day for 10 years
    - There will be hours when plant does not produce or plant produces more than 100 MWh
    - With cost-based short-term market, supplier can purchase shortfall from short-term market or sell excess energy in short-term market
  - The existence of option to buy and sell in short-term market at cost-based price reduces risk to supplier of signing PPA
    - Reduces price consumers pay for a PPA

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Fostering Forward Market

- Forward market for energy very competitive at time horizons in advance of delivery greater than time needed to construct new capacity
  - Time horizon to delivery greater than two years
- Hawaii PUC can manage forward contract procurement process for grid-supplied energy
  - Maximize benefits of competition for meeting Hawaii's renewable energy goals
- Cost-based short-term market provides more certainty on imbalance charges loads and generators will be liable for relative to their forward contracts
  - Easier to forecast future short-term energy prices
  - Reduces cost of new investment—Forward contract to attract new investment
  - Makes it easier to sell standardized forward contracts for energy

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Cost-Based Market

- All generation units, HECO-owned and IPPs, have Hawaii-PUC approved costs
  - MC = Heat rate x Fuel Cost + Variable O&M
    - Heat rate = MBTU/MWh
    - Fuel price = $/MMBTU
    - Variable O&M = variable operating and maintenance cost
  - SC = start-up and no-load cost in dollars
- On day-ahead basis, HECO would take information from all generation unit owners and other resources and find least cost (total variable cost + total start costs) combination of resources to meet energy and ancillary services demands for all 24 hours of following day
  - Respect all relevant operating constraints on grid in computing energy production and consumption schedules for following day
- Process yields an hourly market-clearing price of wholesale energy
  - Price transmission congestion and losses using locational marginal pricing and set market-clearing price equal to quantity-weighted average locational marginal price

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Multi-settlement Cost-Based Market

- All generation units, HECO-owned and IPPs, have Hawaii-PUC approved costs
  - MC = Heat rate x Fuel Cost + Variable O&M
    - Heat rate = MBTU/MWh
    - Fuel price = $/MMBTU
    - Variable O&M = variable operating and maintenance cost
  - SC = start-up and no-load cost in dollars
- Cost-based multi-settlement locational marginal pricing (LMP) market
  - The day-ahead before actual operation, HECO finds least cost (total variable cost + total start costs) combination of generation units to operate to meet energy and ancillary services demand subject to all relevant operating constraints on grid
- Process yields an hourly energy and ancillary services schedules for all loads and generation units and prices at all locations in grid for energy and ancillary services
  - Can set market-clearing price that all loads pay equal to quantity-weighted average locational marginal price

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Multi-settlement Cost-Based Market

- Day-ahead market allows market model to incorporate start-up costs, ramping constraints, scheduling limitations (combined cycle natural gas-fired units) in determining energy schedule all hours of following day
  - Reduces cost of serving demand at all locations in grid
- Supplier receives revenue from day-ahead forward market sales *regardless of real-time output of its generation unit*.
  - Sell 40 MWh at a price of $25/MWh receive $1,000 for sales.
  - Any deviation from day-ahead generation schedule is cleared in real-time market.
  - If supplier only produces 30 MWh, it must purchase 10 MWh of day-ahead commitment from real-time market at real-time price
- Buyer pays for day-ahead forward market purchases *regardless of real-time consumption of energy*
  - Buy 40 MWh at a price of $25/MWh and pay $1,000 for energy
  - Any deviation from day-ahead load schedule is cleared in real-time market
  - If buyer only consumes 30 MWh, it sells 10 MWh of day-ahead commitment in real-time market at real-time price

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Multi-settlement Cost-Based Market

- Each time the LMP market is run, the system operator's best estimate of real-time configuration of grid is used to price transmission congestion and other operating constraints
  - Day-ahead market uses system operator's best guess real-time configuration of transmission network
  - Ensures physical feasibility of dispatch and load schedules, which eliminate need for re-dispatch process
- In real-time market minimizes same marginal and start-up cost to meet real-time demand subject to all relevant operating constraints using real-time configuration of grid
  - Can operate real-time cost-based LMP market every 5-minutes
  - Sets 5-minute prices and dispatch levels for all dispatchable resources—generation units, loads, batteries, etc.
  - 5-minute real-time markets reduces scope and size of ancillary services markets

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Multi-settlement Cost-Based Market

- Multi-settlement market rewards suppliers for reliability of supply, yet still pays same LMP to all resources at same location in both day-ahead and real-time markets
  - Very important feature of market design for regions with ambitious intermittent renewable energy goals
- Consider a market with significant intermittent resources
  - Supply of intermittent resources typically highly correlated
    - Wolak (2016) "Level versus Variability Trade-offs in Wind and Solar Generation Investments: The Case of California," The Energy Journal (available at http://www.Stanford.edu/~wolak)

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Multi-settlement Cost-Based Market

- Suppose that a dispatchable thermal unit sells 100 MWh at price of $50/MWh in day-ahead market and intermittent resource sells 80 MWh in day-ahead market at same price
- In real-time, significantly less wind is produced than was scheduled
  - Wind produces 50 MWh, so must purchase 30 MWh from real-time imbalance market at $90/MWh
- Thermal unit supply must maintain supply and demand balance, which explains high real-time price
  - Sells 30 MWh at real-time at $90/MWh
- Average price paid to thermal and intermittent units
  - $59.23 = 100 MWh*$50/MWh + 30 MWh*$90/MWh)/130 MWh)
  - $26 = (80 MWh*$50/MWh – 30 MWh*$90/MWh)/50 MWh
  - Dispatchable unit rewarded with higher average price than intermittent unit

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Multi-settlement Cost-Based Market

- Case of unexpectedly high intermittent resource output yields a similar outcome of rewarding dispatchable resource with higher average price
  - Intermittent resource sells only 50/MWh in day-ahead market and thermal unit sells 130 MWh, both at $50/MWh
  - Intermittent resource produces 80 MWh, which implies that it sells 30 MWh in real-time market at $20/MWh
    - Low real-time price because of unexpectedly large intermittent output
  - Thermal resource buys back 30 MWh in real-time at $20/MWh
- Average prices paid to thermal and intermittent units
  - $59 = (130 MWh*$50.MWh – 30 MWh*$20/MWh)/100/MWh
  - $38.75 = (50 MWh *$50/MWh + $30 MWh*$20/MWh) /80 MWh

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Multi-settlement LMP Market

- Wolak (2011) "Measuring the Benefits of Greater Spatial Granularity in Short-Term Pricing in Wholesale Electricity Markets" *American Economic Review*
  - Finds ~3 percent reduction in variable operating cost of operating thermal units from transition to multi-settlement LMP market from multi-settlement zonal market design in California
  - Roughly $110 million in annual operating cost savings associated with introduction of LMP market
- Even larger savings seem possible for Hawaiian market and markets with significant amounts of intermittent renewables
  - Accounts for configuration of transmission network and other operating constraints in energy and ancillary services procurement
  - Eliminates need for re-dispatch, only need to respond to changes in demand, supply and grid configuration
  - Frequent settlement in real-time limits size and scale of ancillary services markets

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Multi-settlement Cost-Based Market

- For more information on multi-settlement LMP mechanism, see Wolak (2017) "Efficient Pricing: The Key to Radical Innovation in Electricity Sector" on web-site
- Computing marginal cost of delivering energy through distribution grid can be computed
  - Simple models exist now—primarily price losses
  - More complex models can be developed (active area of research)
- Implementing cost-based short-term market far less costly than implementing bid-based short-term market
- Cost-based multi-settlement LMP short-term market provides ideal mechanism for batteries, other storage technologies, load-shifting technologies and active demand-side participation
  - Rewards these resources for the "dispatchability" of their energy, similar to above case of thermal resources

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Locational Marginal Pricing (LMP)

- Prices all relevant network and other operating constraints
  - Minimize as-bid cost to meet demand at all locations in network subject to all relevant network and other operating constraints
    - Ramp rates, minimum run-times, minimum down-times, etc.
  - Limits divergence between financial market that prices and physical realities of grid operation
- All US markets currently operate bid-based LMP markets
  - New Zealand and Singapore do as well
- Cost of not pricing all relevant transmission and other operating constraints grows with amount of intermittent renewables control area
  - Many jurisdictions in Europe are exploring LMP market designs for this reason

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Cost-Based Market

- Regulating HECO in cost-based market regime is not significantly different from current regime
  - Set HECO's revenue requirement and allow recovery through combination of monthly fixed charges to customers and price of delivered energy
- Cost-based model has been very successful at delivering significant benefits to consumers throughout Latin America relative to former vertically-integrated monopoly regime
  - Facilitates competition in forward market without downside of market power in short-term market
- For more on cost-based markets
  - Wolak (2018) "Electricity Market Design and Renewables Integration in Small Markets," on web-site

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Transmission and Distribution Network

- Recommended retail pricing change addresses problem of inefficient bypass of grid-supplied electricity
  - Many customers may now decide to obtain their renewable energy from the grid rather than install rooftop solar
- Transmission and distribution network planning process becomes much more important
  - As experience from California demonstrates, integrating significant amounts of distributed solar capacity can significantly increase distribution network costs
  - However, Hawaii PUC likely to want to provide all customers with option to install distributed solar
- Transmission and distribution network planning process should balance these two competing goals
  - Least cost mix of grid-supplied and distributed energy to meet Hawaii's renewable energy goals
  - Provide all customers with the option to install distributed solar

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Transmission and Distribution Network

- Many of the challenges with regulating HECO could be addressed through financial separation
  - HECO Transmission and Distribution
  - HECO Generation
  - HECO Retailing
  - HECO Cost-Based Market/System Operator
- HECO Cost-Based Market/System Operator would operate cost-based market and electricity grid
- HECO Transmission and Distribution would build and maintain transmission and distribution grid
- HECO Generation owns and operates all HECO generation units
- HECO Retailing serves all retail consumers
- Could use separate revenue cap regulation for each entity
  - Makes HECO Transmission and Distribution indifferent to investments in grid-supplied versus distributed energy

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Transmission and Distribution Network

- New role for transmission and distribution network under proposed solution
  - Transmission and distribution network facilitates competition between resources that provide electricity to final consumers when they want to consume it
    - Grid-scale and distributed generation, storage (distributed and grid-scale), load-shifting technologies, etc.
- Under revenue cap, HECO Transmission and Distribution must interconnect all distributed solar resources consumers demand and all new grid-scale generation projects that result from power purchase agreements signed by HECO Retailing

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Adapting Regulatory Process to the New Competitive Landscape

Key Points:

1) Charge hourly price of grid-supplied electricity and monthly fixed charge to recover remaining fixed costs from retail customer (Welfare improving and supports state's broader green goals)

2) Cost-based multi-settlement locational marginal pricing short-term market to reduce total cost of serving demand in Hawaii, set hourly price of grid-supplied electricity and foster competition in forward market for energy

3) Enhance transmission and distribution planning process and financially separate HECO to improve effectiveness of regulatory process and balance goals of least cost path to meeting Hawaii's renewable energy goals and provide option for all customers to install distributed solar

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Managing the Transition to the Renewable Future

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Evolutionary Change at HECO

- Unlikely that customers will disconnect from grid for both reasons of expense and convenience
  - HECO will still be needed to build, operate, and maintain transmission and distribution grids
  - HECO can continue to own and operate generation resources under cost-of-service revenue recovery
- Short-term pricing of distribution grid likely to become increasingly important with distributed solar, storage, automated response technologies
  - Locational marginal pricing of distribution network pricing losses, congestion and other operating constraints (important area for research)

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Evolutionary Change at PUC

- PUC process for determining regulated marginal and fixed cost for all generation units in Hawaii is straightforward and familiar
- Additional expertise in transmission and distribution network planning and costing and pricing techniques important to develop
  - PUC builds network that facilitates competition between all resources that supply energy services to consumers
- Refine and implement methods for determining
  - Monthly fixed charge for all classes of customers
  - Methods for setting hourly prices for energy
  - Methods for setting hourly prices for use of distribution network

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Concluding Comments I

- Inefficient retail electricity pricing in Hawaii (and California) leading to inefficient bypass of grid-supplied electricity and substantially higher costs of supplying all electricity consumed
- Establishing cost-based short-term market allows more efficient retail pricing, increases competition for power purchase agreements from renewable and conventional resources
- Transmission and distribution planning process at Hawaii PUC must become more sophisticated in order to balance competing goals of least cost achievement of Hawaii's renewable energy goals and providing all customers with option to install rooftop solar

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Concluding Comments II

- More efficient retail pricing increases likelihood that least cost mix of distributed and grid-scale renewables will be built to meet Hawaii's renewable energy goals
  - Supports electrification of Hawaii's vehicle fleet
- Cost-based market has been successfully implemented in regions with significantly less technical expertise and less sophisticated regulatory institutions
- More efficient pricing and operation transmission and distribution network can yield significant operating cost saving
- Hawaii can serve as global example for how small countries and regions wanting to "green" their energy sector, which fits with major industries in state

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Questions/Comments?

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