Smart Grid Demonstration Cost/Benefit Analysis

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Outline

A. Cost and Benefit Analysis (CBA) Defined
B. What constitute Smart Grid Benefits?
C. Measuring Smart Grid Impacts
D. Monetizing Smart Grid Benefits
E. The Cost to Realize Smart Grid Benefits
F. CBA Application to EPRI Smart Grid Demonstration
Cost and Benefit Analysis (CBA) – Design Principles

- Adaptable to all Smart Grid demonstrations
- Provides for a consistent and fair comparison of alternative Smart grid technologies and systems
- Adaptable to new findings and expanded applications
- Identifies all attributable benefits
- Minimizes redundancy in benefit attribution
- Distinguishes benefits according to:
  - Level (how much)
  - Distribution (who is the beneficiary)
  - Timing (when they are realized)
A Useful Semantic Distinction

- The first order, and therefore defining, impact of Smart Grid technology is a change in the technical performance of the electric system.
- The term benefit connotes a monetary result.
- A transformation function is required link the two.
- An important distinction is:
  - **Impact** (cause) = the first-order impact of the investment on the system (what aspect of service or performance changed?)
  - **Benefit** (effect) = the monetary equivalent of the impact.
Benefits 1st Order Distinction

- **Operating cost savings** that result from increased productivity attributable to the investment
- **Consumer cost avoidance** from reduced generation, transmission, and distribution investment or operational requirements
- **Societal Benefits** that inure to consumers, but in less obvious ways

- **Operating costs savings** (relative to what is incorporated into existing rates) provide a stream of funds that can be used by the utility to service the Smart Grid investment carrying costs.
- **Avoided capital and operating costs** result in rates that are lower than they otherwise would have been.
- **These benefits inure directly to consumers and are:**
  - Speculative, subjective, and challenging to monetize
  - Not necessarily evenly distributed among consumers

Many Benefits Originate at Wholesale and Flow to Retail

- **Energy efficiency**
- **Price-Based Demand Response**
  - TOU
  - DA-RTP
  - RTP
- **Induced Demand Response**
  - ICAP
  - KWH Bidding
  - Emer DR
  - I/C Load
  - DLC

Time scale:
- Years
- Months
- Day-ahead
- In-day

System management action:
- System planning
- Operational planning

RT balanced and regulated system
Smart Grid Benefits Categorization

Things that appear to be left out – based on typical list of benefits

**Impact on electricity markets**
- More efficiency operations
- Customer participation
- Flatter load profiles
- Reduced LMP/MC volatility

**Impact on System Operations**
- Integration or renewable generation resources
- Optimized PHEV charging/discharging
- Better unit operating efficiency

**Customer impacts**
- Lower electricity rates
- End-use and premise load control
- More consumer choices
- Lower electricity consumption

**Externalities**
- Lower emissions from renewable
- Achievement of RPS goals
Some Puzzlers

- Devices and controls specifically added to mitigate the adverse impact of distributed PV which itself is claimed as a benefit
  - Is that a benefit to consumers? or
  - A reduction in the value attributed to PV?
- Reduced cost of Smart Grid elements due to economies of scale
  - Is this attributable to the SG? or
  - Just the way of the world, a coincidental, not attributable, benefit?
- Improved perception of utilities, other entities – who gains from goodwill, and what is it worth to monopoly entity?
- Enabling more retail competition,
  - Is the real benefit measured already in induced kW and kWh changes?
- Horizontal and vertical expansion of utility economic activity
  - If utilities provide PHEV charging service, offer HAN systems, who gains and how, especially if those are regulated services? Does this restrict their competitive supply that might be cheaper or more robust?
Summary

• The DOE/EPRI CBA framework provides a foundation for consistent and credible evaluation of Smart Grid benefits
• Some adaptations improve its suitability
  – A functional definition of benefits
  – Methods for measuring the benefits by category
  – Monetizing the benefits
  – Clear linkage of cause and effect

Measuring Smart Grid Impacts
Metrics for Utility Expense Reduction

- Impacts that are direct measures of benefits:
  - Reduced expenses
    - Lower theft losses
    - Reduced outage restoration expenses
    - Lower maintenance expenses
    - Lower system dispatch costs
  - Increased net revenues (another source to offset investment costs)
    - Prepaid service enabled
    - Seasonal shut off
    - Reduced read-to-pay time
    - Fewer estimated bills
    - Faster account service initiation/termination
    - In-home device monitoring services

Data Sources
- Utility customer billing records
- Utility general accounts
- Department account records
- Cost of service studies
- Customer demographics
- Estimates of new service enrollment and usage

Metrics for Avoided Costs

- **Avoided capital costs**
  - Reflect the reduction in the cost to serve load
    - Generation plant investments
    - T&D investments
  - Generally measured in terms of kW avoided

- **Avoided energy costs**
  - Reflect the cost of operating the generation unit that otherwise would have been dispatched

- **Measurement issues**
  - How is capacity adequacy affected (kW impact)?
  - What generation units are not built
    - Peaking
    - Base load
    - Cycling
  - How is total dispatch effected?
  - Are ancillary services requirement affected?
  - Impact of market structure
Baselines

- A baseline establishes:
  - For a specific impact
  - The level of impact that would have otherwise realized
  - But for the Smart Grid investment
  - Need to forecast outcomes (baseline) over the SG investment lifetime to account of base dynamic influences

- Perspective
  - Marginal perspective- how did things change
  - Measures temporal and spatial changes
  - Historic data generally used to establish the basis for impact measurement, but may have to model the baseline in some cases
  - Dynamic adjustments if investments system usage changes would been made (occurred) anyway

Baseline for Measuring Impacts Attributable to Smart Grid Investments

- Asset performance
  - Measures of currently generation efficiency (unit and portfolio)
  - Measure of today’s T&D system performance

- Consumer behavior
  - What would consumption otherwise have been?
  - What is today’s level of reliability? Service quality?

- Economic activity
  - Oil consumption for generation
  - Character of electricity sector
    - Expenditures by sector
    - Labor multipliers
Who is Responsible for, or Concerned about, Demand Response EM&V Protocols?

North American Energy Standards Board
National Association of Regulatory Utility Commissioners
Curtailment Service Providers
ISO/RTO Council
Public Service Commissions
Federal Energy Regulatory Commission
Lawrence Berkeley National Laboratory
Efficiency Valuation Organization

How demand response product performance is measured

Deemed Device Response

FPL

Pre-Specified CBL

Event-Driven CBL
Metrics for Improved Reliability

- **Outage Mitigation**
  - Fewer outages
  - Shorter duration outages
  - Increased outage notice

- **Power Quality Improvement**
  - Reduced voltage sags and spikes
  - Harmonic stability

- **Measurement issues**
  - What constitutes an outage?
  - Impacts of sags on premise service
  - Spatial and temporal measurement requirements
    - Premise
    - Circuit
    - Network

Metrics for Better Societal Resource Utilization

- **National security**
  - Reduced imported oil consumption for generation

- **Better environment**
  - Lower net emissions from electricity generation

- **Efficient economy**
  - Employment
    - Net job creation, character of the jobs
    - Wages
  - Economic output – GNP
  - Social welfare
    - Economic measure of resource productivity

Most are difficult to quantify, but methods have been developed
Monetizing Smart Grid Benefits

All Roads Lead to Demand Response

On Average, 34% of Attributed Smart Meter Benefits are Societal (Customer)

Operational and Societal Benefits (%) Attributed to Smart Metering

Household-level Benefits of Demand Response
What is the Value of Demand Response?

- Demand response is a change in the consumption of electricity due to a change in the price paid, or another inducement to do so.
- The value of such changes depend on:
  - Economic outcomes
    - Market price changes
    - Dispatch costs
  - Reliability conditions
    - Value of reliability
- Net demand response benefits

Lots of Demand Response Already
DR Resources by Type

Distribution of Demand Response Resources by Category

- ISO/RTO Total (23,129 MW)
- United States (20,864 MW)
- Canada (2,265 MW)
IRC Estimates of DR Resources as Percentage of Peak

How DR Generates Value

• Product design determines how the demand response program is activated and produces benefits
  – **Autonomous.** The consumer decides at what price it changes consumption
  – **Directly dispatched.** An external entity has the ability to curtail a device’s usage
  – **Self-dispatched** the consumer controls the response decision
• Market or enterprise circumstances determine when an event is manifested
  – Prevailing energy prices
  – Level of system operating reserves
  – Demand response provider’s internal value
• Value is determined by how markets and consumers are impacted
  – Wholesale value is transparent
  – Vertically integrated utility value is like administratively determined
Modified NERC and NAESB characterization to accommodate retail pricing structures

- Demand-Side
  - Demand Response
  - Energy Efficiency
    - Dispatchable Resource
    - Customer Choice & Control
      - Fully Hedged
        - Uniform Price
        - Time-of-day Schedule
        - Step Rates
        - Demand & Energy

- Reliability
- Economic
- Energy
- Bids
- Dynamic Pricing
- Energy Efficiency
- Ancillary Services
- Capacity
- Emergency
- Real Time
- Day Ahead

DR Program Features

Plan Features and Provisions

Product Features
- Term
- Caps and floors on enrolled load
- Instrumentation requirements

Event Characteristics
- Notice
- Duration
- Frequency
- Total Exposure/yr, /contract period
- CBL determination

Benefits
- Option/availability payment (+)
- Event performance payment (+)
- Overall performance payment (+)
- Non-compliance penalties (-)
- Transaction costs (-)

Participation
- Number of Customers and their load basis

Response
- Load reduction undertaken (MW, MWH)

Valuation ($/MW, $/MWH)
Dynamic Pricing Participation

- Residential Dynamic Pricing
  - EDF = 75% or more on dynamic TOU rate
  - Salt River and APS + 20% or more on TOU rate schedule
  - Gulf Power = 30% of target on TOU/CCP
  - CA pilots estimate
    - ~30% predicted acceptance
    - 5% actual participation
  - Pilots report 20-25% subscription rates for pilots
    - Target recruiting
    - Participation incentives

Simulated DR Plan Participation Rates
Potential Benefits Attributable to Residential RTP

Reliability Improvements

- Smart Grid provides for more localized measurement of individual premise service status
- If this information is integrated into restoration systems, the duration of outages may be reduced, which translates into more value to consumers
- Such an analysis requires:
  - Identifying changes in CAIDI that would be attributable to Smart Metering
  - Estimating customer outage costs

\[
\text{Change in Outage Duration} \times \text{Outage Cost} = \text{Smart Metering Premise-level Reliability Value}
\]

<table>
<thead>
<tr>
<th>OUTPUT</th>
<th>Residential</th>
<th>Small Commercial</th>
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<tr>
<td>Baseline Cost per Outage</td>
<td>$5.73</td>
<td>$295 - $475</td>
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<tr>
<td>Marginal Cost per CAIDI Minute</td>
<td>$0.01</td>
<td>$5.45</td>
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Improved Utilization Efficiency - Feedback

- A wide variety of studies have been conducted over the past 20 years to quantify the impact of information on electricity consumption:
  - Indirect feedback – provides consumers with more detailed and in-depth analyses of billing information
  - Direct feedback – provides consumers direct access to the meter contents
- The reported impacts over both feedback types, reductions in total kWh consumed, range from zero to 25%
- Electronic display results also exhibit a wide range of energy reduction values
- Most studies involved only very few (under 150) participants for a year or less.

Feedback Impacts

Metastudies
- Darby 2001, 2006
- Fischer 2007
- Abrahamse, et al., 2005

Pilots
- Before and after 2000
- Direct vs. indirect
- Slow vs. fast feedback
- North America, Europe
Feedback Hierarchy

- Darby provided an important distinction; indirect vs. direct
- EPRI added a functional hierarchy

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<th>Feedback Hierarchy</th>
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<td>Estimated Feedback</td>
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<td>Tailor audits and advice</td>
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<td>Daily/Weekly Feedback</td>
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<td>Periodic reports on actual usage</td>
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"Indirect" Feedback provided after consumption occurs
"Direct" Feedback provided as consumption occurs

Information availability
Low
Cost/Effort to Implement
High

Smart Grid & Smart Pricing - Example Application

- Thermostat receives day-ahead hourly prices
- Consumer sets upper and lower limits
- Thermostat “learns” thermal, consumer and weather impacts

[Image of a Smart Grid & Smart Pricing example application diagram]
Smart Charging: Key to Reducing PHEV Impacts

July 27th 2007 24 hr: Total Loading for the Feeder Under Study

- Added peak load without PHEV charging integration
- Added off-peak load with smart PHEV charging
- Off-peak load

Comparison of DR Plan Event Impacts

- Differences among pricing structures are largely due to event price differences, not elasticity differences
- Participation levels and sustainability is highly speculative
Valuing Demand Response Benefits - An Elemental Method

**Basic Program Characterization**

- Participation rate
- Reference load profiles for target customers
- Price change
  - Event prices, penalties
  - Reference price
- Price response
  - Event load
  - Level of price response
  - Event/Peak coincidence
- Avoided cost
  - Energy
  - Capacity
- Reliability benefit
- Costs of program implementation

**For Smart Metering business cases, the frame of reference is incremental; how does Smart Metering enhance the levels of key parameters?**

An Illustrative Example

- An example of a specific demand response product illustrates the assumptions required and their implications for the resulting level of benefits
- The Peak Time Rebate (PTR) serves to illustrate the methods and implications
- PTR is assumed to be deployed to reduce coincident peak demand and thereby reduce capacity costs
- PTR Events are declared each year to coincide with the system peak load

**Assumptions**

- Perfect foreknowledge of when the system peak occurs
- Avoided capacity cost = $100/kW year
- 20 year lifetime for Smart Metering
- 100,000 households
- Average 14,000 kWh/yr
- 65% coincidence of peak energy and system peak kW
- System cost - $20 million (NPV)
NPV 20-Year Value at Higher Buy-back Rebate

- Lightly shaded (green) cells exceed the Smart Metering capital cost of $20 million.
  - Participation rate of at least 30% (corrected value)
  - Elasticity of at least 0.10

- The dark shaded (black) cells exceed the capital cost plus the participant incentives
  - Participation of at least 50% (corrected value)
  - Elasticity of at least 0.175

Values assume that only one event is called per year to achieve the peak reduction. If more events are required, then the net benefits are less.

NPV 20-Year Value at Buy-back Rebate 8 times Standard Rates

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<th>0.025</th>
<th>0.05</th>
<th>0.10</th>
<th>0.15</th>
<th>0.175</th>
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<td>$1,746,205</td>
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<td>$5,238,986</td>
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<td>20%</td>
<td>$1,746,205</td>
<td>$3,492,411</td>
<td>$6,984,822</td>
<td>$10,471,233</td>
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<td>$17,452,055</td>
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<td>40%</td>
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<td>50%</td>
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<td>60%</td>
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<td>100%</td>
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<td>$34,904,110</td>
<td>$52,356,164</td>
<td>$61,082,192</td>
<td>$78,534,247</td>
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Participation

- Elasticity

NPV 20-Year Value at Higher Buy-back Rebate

What some pilots exhibited

- Lightly shaded (green) cells exceed the Smart Metering capital cost of $20 million.
- Participation rate of at least 30% (corrected value)
- Elasticity of at least 0.10

Not yet demonstrated

- The dark shaded (black) cells exceed the capital cost plus the participant incentives
- Participation of at least 50% (corrected value)
- Elasticity of at least 0.175

Values assume that only one event is called per year to achieve the peak reduction. If more events are required, then the net benefits are less.

Externalities

- Externalities are costs associated with economic activity that are not included in the price paid by consumers
- As a result, resources are not used optimally from a societal perspective
- Smart Metering may enable changes that reduce externalities
  - Reduced kWh usage that is oil-based reduces reliance on imports, which may have implications for national security
  - Reduced kWh usage that reduces generation carbon emission reduces costs associated with the associated adverse environmental impacts
- Externalities are sometimes associated with market failure – the missing cost element in the good is an indication that the market is not functioning properly
- But, in the absence of a market, how are such costs monetized?
  - Cicchetti- implied national security adder = $.057 to $.014/kWh
  - Synapse – implied CO2 emissions = $.016 to $.018/kWh
Different Average Emissions Approaches Yield Different Results

![Bar chart showing different average emissions approaches and their results.]

Source: U.S. EPA eGrid Database

Macroeconomic Impacts

- Disruptive changes in sector spending behaviors can trigger beneficial changes in the economy:
  - Expanded regional economic activity
  - Increased employment and wages
- Smart Grid may be the source of such changes arising from:
  - Changes in utility expenditures
  - Changes in consumer expenditures associated with
    - Reduced electricity costs (if applicable)
    - Purchase of other products and services
- Characterizing and quantifying them involves economic sector macroeconomic (Input/Output) modeling:
  - Requires using very specialized and generally expensive modeling techniques
  - The expenditure changes associated with Smart Metering may not involve substantial changes in expenditure
The Cost to Realize Smart Grid Benefits

Issues to Resolve

• What is the purpose of the CBA?
  – Calculate demonstration project net benefits
  – Estimate the net benefits for the project
    • Under repeated applications at the same scale
    • Scaled-up applications

• What costs need to be measured?
  – All project costs
  – Distinguish R&D (one-time) from project requirements costs
  – Today’s cost or cost at full scale and scope
  – Collateral costs

• Access to pertinent data
  – Utility
  – Vendor/contractor
Step-wise process

1. Characterize project outcomes
2. Map goals to impacts
3. Monetize estimated impacts
4. Estimate costs
5. Establish performance tracking requirement
   1. Cost reporting
   2. M&V protocols
   3. External variable measurement
Next Steps

• Develop operational manual to guide protocol application
• Test out protocols on one or more projects
• Revise and document protocols
  – Application guides for EPRI Smart Grid (and Energy Efficiency) demo
  – Coordinate with DOE
    • Coordinate development of protocols
    • Share experiences
• Develop analytical tools