Enabling and Motivating Consumers to Manage Their Energy Consumption

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Overview

- The Team
- Value Proposition
- System Concept
- Interface Concept
- Price Sensitivity
- Conundrums
- Future Research
The Team

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- William Rouse
Smart Grid Progress

- The need for an improved electric grid is widely recognized.
- Investment in Smart Grid infrastructure is significant and growing rapidly.
- The Smart Grid space has attracted many firms producing advanced hardware and software technologies.

Anticipated Smart Grid Revenue Growth

(Source: Pike Research)
Smart Grid technologies and standards are nearing maturity, but successful deployment requires consumer consent and participation.

Communities moving to install Smart Grid infrastructure are encountering resistance, as recently seen in California and Maryland.

Smart Grid proponents now recognize the importance of consumer education and communication, leading to efforts such as the Silicon Valley Smart Grid Task Force and the Smart Grid Consumer Collaborative.
Enabling and Motivating

There are many potential approaches to enabling and motivating consumer engagement; a successful solution must:

- Impart knowledge of opportunities created by Smart Grid technology and likely market outcomes
- Create financial and social incentives to engage in energy management activities
- Provide management tools that easily and efficiently communicate consumer preferences to Smart Grid systems

Before they will participate, consumers must be persuaded to accept the Smart Grid value proposition, outlined in the slides that follow
Primary Consumer Benefits

- The most salient benefit of Smart Grid systems is the potential to reduce consumption, leading to lower energy expenditures.
- Smart Grid technologies provide consumption information and management tools that make conservation easier.
- Pilot programs have demonstrated reduced consumption from 2-20%, depending on technology.
Other Consumer Benefits

- In addition to financial savings and ease of consumption management, Smart Grid systems deliver:
  - Social status and personal satisfaction associated with conservation
  - Reduced environmental impact from energy generation
  - Better electric service reliability and performance
  - Potential profit from distributed generation and supply
There are costs associated with Smart Grid systems, but these are tempered by the costs of continuing under the traditional system as energy demand increases:

The relative magnitude of costs is unknown, but consumers will likely fare better under a Smart Grid system, and will certainly have more flexibility to respond to evolving conditions.

<table>
<thead>
<tr>
<th>COST TYPE</th>
<th>SMART GRID COST</th>
<th>STATUS QUO COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial Burden</td>
<td>Consumer share of Smart Grid installation expenses</td>
<td>Consumer share of capacity expansion expenses, higher rates</td>
</tr>
<tr>
<td>Behavioral Accommodation</td>
<td>Adapting to new rate structures and learning to use management tools</td>
<td>Adapting to higher rates with little management flexibility</td>
</tr>
<tr>
<td>Personal Freedom</td>
<td>Concerns over privacy and data ownership</td>
<td>Lack of control over energy expenses and consumption</td>
</tr>
<tr>
<td>Future Market Uncertainty</td>
<td>Unknown future market conditions buffered by management tools</td>
<td>Unknown future market conditions with few alternatives</td>
</tr>
</tbody>
</table>
**Utility Benefits and Costs**

- **It is important for consumers to be aware of the value tradeoffs faced by utilities as Smart Grid systems are deployed:**

<table>
<thead>
<tr>
<th>TRADEOFF TYPE</th>
<th>UTILITY SMART GRID BENEFIT</th>
<th>UTILITY SMART GRID COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Requirements</td>
<td>Reduced need for future capacity expansion</td>
<td>Utility share of Smart Grid infrastructure investment</td>
</tr>
<tr>
<td>Operating Revenues</td>
<td>Gains from improved grid control, monitoring, maintenance, and repair</td>
<td>Reduced income due to consumer energy conservation</td>
</tr>
<tr>
<td>Business Model</td>
<td>Creation of new advanced energy services market</td>
<td>Disruption of established rate structures</td>
</tr>
<tr>
<td>Future Market Uncertainty</td>
<td>Improved alignment between energy prices and generation cost</td>
<td>Possible negative changes in customer relationships as market evolves</td>
</tr>
</tbody>
</table>

- **Utilities stand to gain from the introduction of Smart Grid systems, but these gains are not without costs, which must be balanced for utilities to participate**
To ensure that consumers engage and receive benefits, Smart Grid systems should provide compatible incentives:

- Engagement yields financial benefit
- Potential benefits are known
- Desired conservation strategy is easy to implement
- Social and competitive pressures to conserve are present
- Regulatory environment is trusted

<table>
<thead>
<tr>
<th>CONSUMER INCENTIVE</th>
<th>REQUIREMENT FOR REALIZATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engagement yields financial benefit</td>
<td>Utilities should design rate structures that adequately reward consumers for conservation</td>
</tr>
<tr>
<td>Potential benefits are known</td>
<td>Smart Grid proponents should initiate consumer education efforts and actively pursue communication of benefits</td>
</tr>
<tr>
<td>Desired conservation strategy is easy to implement</td>
<td>Consumption management tools should be flexible and intuitive</td>
</tr>
<tr>
<td>Social and competitive pressures to conserve are present</td>
<td>Management tools should make conservation visible to others where possible, and should provide rewards meaningful in other contexts</td>
</tr>
<tr>
<td>Regulatory environment is trusted</td>
<td>Data management and regulation should be transparent and consistently applied</td>
</tr>
</tbody>
</table>

Individuals are more likely to participate when these incentives are perceived to apply.
Utility Incentives

As with utility benefits and costs, it is instructive for consumers to be aware of utility incentives for Smart Grid participation:

**UTILITY INCENTIVE** | **REQUIREMENT FOR REALIZATION**
---|---
Peak and long-term demand is reduced | Smart Grid implementation and rate structures should allow utilities to reduce capacity expansion requirements
Grid operation parameters are improved | Implementation should provide utilities with improvements in grid control, monitoring, maintenance, repair, and security
New market mechanisms maintain profitability | The combined effects of Smart Grid should allow utilities to continue operating profitably

Utilities should not be expected to undertake Smart Grid investments or implement new rate structures without the presence of these incentives.
Integrated Approach

- When both consumers and utilities have incentives to participate, a Smart Grid can deliver mutual benefits.
- The extent and distribution of these benefits depends on implementation details.
- To maximize consumer engagement, an integrated approach must provide appropriate management tools and pricing schemes.
System Concept

- System Context Diagram
- Customer Engagement Dependencies
- Smart Grid System Diagram
- State of the Smart Grid
| Utility sends signal | Relevance of signal to consumer depends on latency of network infrastructure | Resolution is dependent on sampling apparatus i.e. Smart Meters | Customer Engagement is dependent on latency (relevance of signal), resolution, HAN requirements and interface devices, ancillary functionality as well as innate desire for engagement. | Processing time determines ‘age’ of data (relevance to utility) | Utility receives signal and the cycle continues. |

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The appropriate level of customer engagement is dependent on upstream investment that determines the latency and resolution of the network infrastructure.
Smart Grid System Diagram

UTILITY

Power Line  3G or WiMAX  Open IP  Private Network

Energy
Awareness Programs
Price signals. Information services.
Increasing Bandwidth. Cost.

Analytics

DATA

Feedback. Social Metrics. ‘Nudges’
Preferences

HAN communications standard

Link with HAN

Preferences

Feedback
The State of the Smart Grid

- Xcel Energy
- PG&E
- Google
- IBM
- Oracle
- Telvent
- Cisco
- Echelon
- SilverSpring Networks
- Opower
- Control4
- iControl Networks
- Comverse
- Energate
- Z-Wave
- Honeywell
- Landis+Gyr
- HomePlug
- ZigBee Alliance
- GE
- Whirlpool
- ecobee
- GroundedPower
- Rainforest Automation

Networks and Applications:
- Energy
- Awareness Programs
- Price signals
- Information services
- Bandwidth
- Cost
- Analytics
- Data
- Feedback
- Social Metrics
- ‘Nudges’
- Preferences
- Communications
- HAN

Technology and Standards:
- HAN communications standard

Connections and Interactions:
- Link with HAN
- Preferences
- Feedback
- Feedback
Interface Concept

- Types of Interfaces
- Current Interface
- Interface Requirements
- User Interface
- Feedback
Types of Interface

**Mobile**
- Interact with meters and provide information on how customers use their energy
- Helps to control home appliances anywhere anytime when mobile device is connected to communication network. (3G, Wi-Fi, and etc)

**In-home**
- Interact with meters to provide information on how customers use their energy

**Web**
- Develop solutions to encourage energy savings through social forces and demographic observations
- Interact with meters and provide information on how customers use their energy

**Paper**
- Provide information from utility providers on how customers used their energy weekly or monthly
Types of Interface

- Mobile: Control4, iControl, Tendril
- In-home: ecobee, HAI Smartgrid Solutions, Grounded Power
- Web: Google Powermeter, OPOWER, Microsoft Hohm
- Paper: Georgia Power, Southern Company
Current Interface

- Means of providing electricity usage information
  - Mobile devices
  - In-home devices
  - Web solutions
  - Paper bills

- Home automation systems already enable users to set rules and control appliances automatically

- Advanced metering infrastructure can measure customers’ energy usage and enable utilities to provide customers recommendations for managing energy consumption

- Users will be able to compare their usage with neighbors which, perhaps via social technology, may lead to sharing of energy conservation practices
Interface Requirements

- **Information Richness**: System provides real-time information on how much energy is being used, the cost of this energy, and the implications of switching appliances on or off.

- **Security**: System is secured against many different interruptions that can occur during communication or control of household appliances.

- **Privacy**: System requires personal data of users and outgoing information from users is protected by the system.

- **Simplicity**: Simple and comprehensible interfaces make users feel more comfortable using the system.

- **Controllability**: Interface elements allow users to communicate their preferences efficiently and accurately.
Interface Technologies

- Real-time information, e.g., of consumers’ usage
- Advanced graphical displays, including animation.
- Voice recognition, e.g., of consumers’ preferences
- Pattern recognition, e.g., of energy usage
- Predictive models, e.g., of costs of usage patterns
- Geographical information systems, e.g., weather forecasts
- Social technology, e.g., for sharing practices
## Feedback

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| **Direct Feedback** | * Real-time feedback on energy use and costs  
* Devices interface with utility electric meter | Users able to receive real-time feedback from their meter via a mobile monitor | Low willingness to pay relative to device cost |
| **Indirect Feedback** | * Processed feedback via mailed reports or online interface  
* Opportunity to incorporate comparative data/feedback | Provide comparative feedback, showing a customer’s performance relative to their neighbors; power of social norms | Utilities must be careful in targeting and crafting their messaging in order to minimize potential negative effects |
| **Dynamic Feedback** | * Protocols that allow for different rates to be charged based on time of use  
* Enabled by advanced metering infrastructure and two-way communication between the utility and customer | Utilities are better able to match prices to energy production and/or purchase costs | Costly infrastructure investment requiring substantial resources to install meters and develop integrated IT platforms |
Price Sensitivity

- Variable Pricing Strategies
- Consumer Price Elasticity
- Demand Response Models
- Recent Studies
Variable Pricing Strategies

- TOU (Time of Use) Only
- CPP (Critical Peak Pricing), CPP-F rate, CPP-V rate
- RTP (Real-Time Pricing or Dynamic Pricing)
- RCTOU (Time of Use + Critical Peak)
- DPP (Dynamic Peak Pricing)
- Peak Load Reduction Credits
- PTR (Peak Time Rebate)
- Regulated Price Plan
  - TOU (RPP TOU)
  - RPP TOU rates with a CPP component (TOU CPP)
  - RPP TOU rates with a Critical Peak Rebate (TOU CPR)
- Increasing-Block Pricing
Consumer Price Elasticity

- **Real-Time Pricing**

<table>
<thead>
<tr>
<th>Time of the Day</th>
<th>Elasticity Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daytime (8 a.m. to 4 p.m.)</td>
<td>-0.02</td>
</tr>
<tr>
<td>Late afternoon/evening hours (4 p.m. to midnight)</td>
<td>-0.03</td>
</tr>
<tr>
<td>Daytime+ High-Price Notification</td>
<td>-0.02</td>
</tr>
<tr>
<td>Late Daytime/Evening+High-Price Notification</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

- **Time-of-Use Pricing**

<table>
<thead>
<tr>
<th>Type</th>
<th>Season</th>
<th>Peak Own Price Elasticity</th>
<th>Peak to Shoulder Cross Price Elasticity</th>
<th>Peak to Off-Peak Cross Price Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>Summer 2006</td>
<td>-0.30 to -0.38</td>
<td>-0.07</td>
<td>-0.04</td>
</tr>
<tr>
<td></td>
<td>Winter 2006</td>
<td>-0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business (less than 40 MWh)</td>
<td>Summer 2006</td>
<td>-0.16 to -0.18 (ns)</td>
<td>-0.03</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Winter 2006</td>
<td>-0.2 (ns)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business (40 MWh to 160 MWh)</td>
<td>Summer 2006</td>
<td>-0.03 to -0.13 (ns)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Winter 2006</td>
<td>-0.02 to -0.09 (ns)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Demand Response Models

CES (Constant Elasticity of Substitution) Demand System

\[
\ln \left( \frac{Q_p}{Q_{cp}} \right) = \alpha + \sigma \ln \left( \frac{P_p}{P_{cp}} \right) + \delta (CDH_p - CDH_{cp}) + \sum_{i=1}^{N} \theta_i D_i + \varepsilon
\]

\[
\ln (Q_d) = \alpha + \eta_d \ln (P_d) + \delta (CDH_d) + \sum_{i=1}^{N} \theta_i D_i + \varepsilon
\]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_p$</td>
<td>average energy use per hour in the peak period for the avg. day</td>
</tr>
<tr>
<td>$Q_{cp}$</td>
<td>average energy use per hour in the off-peak period for the avg. day</td>
</tr>
<tr>
<td>$Q_d$</td>
<td>average daily energy use per hour</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>elasticity of substitution between peak and off-peak energy use</td>
</tr>
<tr>
<td>$P_p$</td>
<td>average price during the peak pricing period</td>
</tr>
<tr>
<td>$P_{cp}$</td>
<td>average price during the off-peak pricing period</td>
</tr>
<tr>
<td>$P_d$</td>
<td>average daily price (e.g., a weighted average of the peak &amp; off-peak)</td>
</tr>
<tr>
<td>$\delta$</td>
<td>measure of weather sensitivity</td>
</tr>
<tr>
<td>$CDH_p$</td>
<td>cooling degree hours per hour during the peak pricing period</td>
</tr>
<tr>
<td>$CDH_{cp}$</td>
<td>cooling degree hours per hour during the off-peak pricing period</td>
</tr>
<tr>
<td>$CDH_d$</td>
<td>cooling degree hours per hour during the day</td>
</tr>
<tr>
<td>$\theta_i$</td>
<td>fixed effect coefficient for customer $i$</td>
</tr>
<tr>
<td>$D_i$</td>
<td>binary variable equal to 1 for the $i$th customer, 0 otherwise</td>
</tr>
<tr>
<td>$\eta_d$</td>
<td>price elasticity of demand for daily energy</td>
</tr>
</tbody>
</table>
Demand Response Models

VES (Variable Elasticity of Substitution & Other Customer Characteristics)

\[
\ln \left( \frac{Q_p}{Q_{op}} \right) = \alpha + \sum_{i=1}^{N} \theta_i D_i + \sigma \ln \left( \frac{P_p}{P_{op}} \right) + \delta (CDH_p - CDH_{op}) + \lambda (CDH_p - CDH_{op}) \ln \left( \frac{P_p}{P_{op}} \right) \\
+ \phi(CAC) \ln \left( \frac{P_p}{P_{op}} \right) + \varepsilon
\]

Other customer characteristics, such as income, household size, and number of people in the household, may also influence the elasticities in the CES model. They can be included in the specification by introducing additional price interaction terms in a similar manner to the CAC and weather terms shown:

\[
\ln \left( Q_D \right) = \alpha + \sum_{i=1}^{N} \theta_i D_i + \eta \ln \left( P_D \right) + \rho (CDH_D) + \chi (CDH_D) \ln \left( P_D \right) \\
+ \xi(CAC) \ln \left( P_D \right) + \varepsilon
\]

\[
ES=\sigma + \lambda (CDH_p - CDH_{op}) + \phi(CAC)
\]

The composite daily price elasticity in this model is a function of three terms:

\[
\text{Daily} = \eta + \chi(CDH_D) + \xi(CAC)
\]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \chi )</td>
<td>the change in daily price elasticity due to weather sensitivity</td>
</tr>
<tr>
<td>( \xi )</td>
<td>the change in daily price elasticity due to the presence of central air conditioning</td>
</tr>
<tr>
<td>CAC</td>
<td>if a household owns a central air conditioner, 0 otherwise</td>
</tr>
</tbody>
</table>
Recent Studies

- Fifteen recent empirical studies of the residential dynamic pricing programs found that usage response depends on:
  - Magnitude of the price increase
  - Presence of central air conditioning
  - Availability of enabling technologies
    - For example, two-way programmable communicating thermostats that allow multiple remote end-use control
- Measured usage responses:
  - TOU induced a drop in peak demand from 3 to 6 percent
  - CPP induced a drop in peak demand between 13 to 20 percent
  - CPP plus enabling technologies induced a drop of 27 to 44 percent
- Demand response programs that blend together customer education initiatives, enabling technology investments, and carefully designed time-varying rates can achieve substantial demand impact
## Conundrums

<table>
<thead>
<tr>
<th>Conundrum</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost &amp; Profit</td>
<td><strong>Who Pays:</strong> Utility Companies, 3rd Party companies, Government, Customers: who pays for required Smart Grid investments?</td>
</tr>
<tr>
<td>Utility Companies Engagement</td>
<td><strong>Why Change:</strong> Inertia to change in the utility industry vs. the need for consistent regulation and innovation in energy offerings. Distributed generation forces utilities to decentralize yet extend transmission infrastructure to energy source.</td>
</tr>
<tr>
<td>Market &amp; 3rd party Companies</td>
<td><strong>Who Wins:</strong> Variety of Smart Grid related devices, software, technologies and companies, dynamic market vs. Interoperability and standardization. Competing and overlapping standard protocols must be standardized. Who will survive? Why?</td>
</tr>
<tr>
<td>Customers Engagement</td>
<td><strong>Why Play:</strong> Different types of consumers, e.g., price-sensitive, energy-conservative, how to get them all involved? Consumers reluctant to pay upfront costs for uncertain benefit while efficiency and conservation are anti-business model for utilities.</td>
</tr>
<tr>
<td>Security</td>
<td><strong>When Safe:</strong> Grid optimization allows more points of entry for breaches of security to grid. Smart Grid devices and communication infrastructure bear the risk of being attacked vs. Infrastructure complexity and investment.</td>
</tr>
<tr>
<td>Privacy</td>
<td><strong>Who Knows:</strong> Dynamic pricing and optimal energy saving strategies vs. Energy usage data can invade privacy creating a backlash against Smart Grid implementation</td>
</tr>
<tr>
<td>Storage</td>
<td><strong>Where Stored:</strong> Peak demand reduce, renewable resource vs. energy storage feasibility, stability and cost</td>
</tr>
</tbody>
</table>
Future Research

- Market Simulation
- Consumer Modeling
- Token Economies or Games
Smart Grid firms can benefit from simulations that assume a variety of consumer agents and predict the outcome of pricing schemes and market conditions.

Data generated by pilot programs allow validation and refinement of simulation results.

Given preferences generated by the tool on the next slide, accuracy of agent models can be improved.
Consumer Modeling

- Need for tools that interact with consumers to build personalized preference models
- Preference models can drive automated conservation management algorithms
- Potential use in simulations that inform users of likely individual benefits from energy consumption management
- Could help persuade consumers to accept Smart Grid if available free on the web
**Token Economies or Games**

- Use of token economies or games to motivate additional engagement
- Pseudo currency conservation rewards redeemable in a virtual marketplace
- Game advancement and bonuses tied to conservation performance
- Visibility and competition through real-time integration with social networks
Summary

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