Social Psychological Approaches to Analyze Demand Response and Promote Energy Efficiency

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Overview of Research Projects

- Message Framing, Individual Difference and Intervention
- Public Acceptance of Smart Meters, EVs, SHWs and Policy
- Demand Response, Customer Segmentation and Social-psychological Factors
- Social-Technology: Occupant Behavioral Modeling, Building Technology, Norms and Networks
- Social Factors & Energy Efficiency Behaviors in Public Buildings
Today’s Topic

Message Framing
- Feedback and message framing affects energy attitude & behavior -> Understanding of individual differences and decision-making

Public Acceptance
- Public acceptance of smart meter, solar hot water heater, EV and renewable energy policy -> Identify social factors and barriers

Demand Response
- Costumer segmentation and social-psych factors -> Deeper understanding individuals’ decision-making process

Social-Technology
- Occupant behavioral modeling, social-psych factors, social rewards and network influence -> broader energy efficiency behaviors through network influence
Background: Individual-Level Factors

<table>
<thead>
<tr>
<th>Category</th>
<th>Factors/Variables</th>
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<tbody>
<tr>
<td>Behavioral Patterns</td>
<td>Heating/cooling, lighting, electronic devices usage and other curtailment habits, etc.</td>
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<tr>
<td>Awareness &amp; Knowledge</td>
<td>Appliances &amp; devices (items, types and ages), awareness of energy efficiency technologies and energy assistance programs, etc.</td>
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<tr>
<td>Social-psychological Factors</td>
<td>Energy saving attitudes, behavioral control, energy concern, social norms, sense of community, thermal comfort, money consciousness, trust, privacy concern, willingness to adopt new technologies, etc.</td>
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<tr>
<td>Demographics</td>
<td>Gender, income, race, education, political orientation, household size, number of children and seniors, household dynamics, areas, etc.</td>
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Strategies to Change Behaviors & Accept DR

• Feedback programs (direct vs. indirect)
• Social norms: descriptive and injunctive norms shape people’s behaviors; developing strategies in a social context
• Goal setting: define what people are trying to attain and be able to evaluate their progress
• Message framing: emphasizing a particular aspect of an object/activity while limiting emphasis on other aspects
• Commitments: help people to sure their actions are consistent with their ideals
Average Household Electricity Savings of Historical Program by Feedback Type

**Potential Resource Savings:** 20-35%

- **Real-Time Plus Feedback w/Smart Program:** 12.0%
  - Real-time info down to the appliance level
- **Real-Time Feedback:** 9.2%
  - Real-time premise level info
- **Daily/Weekly Feedback:** 8.4%
  - Household-specific info, advise on daily or weekly basis
- **Estimated Feedback:** 6.8%
  - Web-based energy audits with info on ongoing basis
- **Enhanced Billing:** 3.8%
  - Household-specific info, advice

**“Indirect” Feedback (Provided after Consumption Occurs)**

**“Direct” Feedback (Provided Real Time)**

*GARRISON INSTITUTE*
Social Norms Approach: Opower

Last Month Neighborhood Comparison

- **YOU**: 504 kWh*
- **EFFICIENT NEIGHBORS**: 596 kWh
- **ALL NEIGHBORS**: 1,092 kWh

Last month you used 15% LESS electricity than your efficient neighbors.

* kWh: A 100-Watt bulb burning for 10 hours uses 1 kilowatt-hour.
Message Framing and Electricity Saving

- **RQ1**: Which type of messages can 1) change attitudes toward electricity saving? 2) boost perceived efficacy (whether can I make a difference) on saving electricity?
- **RQ2**: How individual differences react to messages differently?

**Benefit framing:**
- Environmental vs. Money

**Temporal framing:**
- Long vs. Short-term
Condition 1, 2: Financial, Long-term/Short-term

According to the U.S. Department of Energy, an average household consumes 11,280 kWh in a year, leading to large electricity bills. There are a few ways proven to be effective in cutting down your bill, for example:

1. **Savings by using energy-efficient light bulbs**
   - **Standard Incandescent** → **Compact Fluorescent**
   - **Saves $6 per bulb in a year by using CFLs**

2. **Savings by insulating your house**
   - **Saves $75-170 in a year by insulating your house**

3. **Savings by switching computers to sleep mode**
   - **ON** → **SLEEP MODE**
   - **Saves $30 in a year by switching computers to sleep mode**

4. **Savings by increasing temperature by 2°F during summer**
   - **Saves $40-85 in a year by increasing by 2°F during summer**

According to the U.S. Department of Energy, an average household consumes 940 kWh electricity in a month, leading to large electricity bills. There are a few ways proven to be effective in cutting down your bill, for example:

- **Saves $.50 per bulb in the next month by using CFLs**

- **Saves $6-15 in the next month by insulating your house**

- **Saves $2.50 in the next month by switching computers to sleep mode**

- **Saves $3-7 in the next month by increasing temperature by 2°F during summer**
Condition 3, 4: Environmental, Long-term/Short-term

According to the U.S. Department of Energy, an average household produces 82,000 pounds carbon emissions per year, leading to polluted air and destructed ecosystems. There are a few ways proven to be effective in reducing your carbon emissions, for example:

- **STANDARD INCANDESCENT**
  - Reduces 660 pounds of carbon emissions per bulb in a year by using CFLs

- **COMPACT FLUORESCENT**
  - Reduces 2000 pounds of carbon emissions in a year by insulating your house

- **ON**
  - Reduces 3000 pounds of carbon emissions in a year by switching computers to sleep mode

- **SLEEP MODE**
  - Reduces 2000 pounds of carbon emissions in a year by increasing 2°F during summer

According to the U.S. Department of Energy, an average household produces 6,833 pounds carbon emissions per month, leading to polluted air and destructed ecosystems. There are a few ways proven to be effective in reducing your carbon emissions, for example:

- **STANDARD INCANDESCENT**
  - Reduces 55 pounds of carbon emissions per bulb in the next month by using CFLs

- **COMPACT FLUORESCENT**
  - Reduces 167 pounds of carbon emissions in the next month by insulating your house

- **ON**
  - Reduces 250 pounds of carbon emissions in the next month by switching computers to sleep mode

- **SLEEP MODE**
  - Reduces 167 pounds of carbon emissions in the next month by increasing temperature by 2°F during summer
Results of Message Framing

- **292** US residents
- Environmental messages, in general, are more effective than the financial benefits in producing positive attitudes toward energy saving.
- Short-term benefits boost perceived efficacy among people with lower environmental concern.

Theory of the Planned Behavior
(Icek Ajzen, 1991)
Social-Psych Factors Affecting the Use of Solar Water Heaters, EVs and Policy Support

* \( p < 0.05; ** \( p < 0.01, *** \( p < 0.001

\( \text{AT1} \rightarrow \text{Attitude} \)
\( \text{AT2} \rightarrow \text{Attitude} \)
\( \text{AT3} \rightarrow \text{Attitude} \)
\( \text{PBC1} \rightarrow \text{Perceived Behavioral Control} \)
\( \text{PBC2} \rightarrow \text{Perceived Behavioral Control} \)
\( \text{PBC3} \rightarrow \text{Perceived Behavioral Control} \)
\( \text{SN1} \rightarrow \text{Subjective Norm} \)
\( \text{SN2} \rightarrow \text{Subjective Norm} \)
\( \text{SN3} \rightarrow \text{Subjective Norm} \)
\( \text{DN1} \rightarrow \text{Descriptive Norm} \)
\( \text{DN2} \rightarrow \text{Descriptive Norm} \)
\( \text{DN3} \rightarrow \text{Descriptive Norm} \)
\( \text{KN1} \rightarrow \text{Knowledge} \)
\( \text{KN2} \rightarrow \text{Knowledge} \)
\( \text{KN3} \rightarrow \text{Knowledge} \)
\( \text{INT1} \rightarrow \text{Intention to use} \)
\( \text{INT2} \rightarrow \text{Intention to use} \)
\( \text{SP1} \rightarrow \text{Support for policy} \)
\( \text{SP2} \rightarrow \text{Support for policy} \)
\( \text{SP3} \rightarrow \text{Support for policy} \)

\( \text{AT1} \rightarrow \text{Perceived Behavioral Control} \)
\( \text{AT2} \rightarrow \text{Perceived Behavioral Control} \)
\( \text{AT3} \rightarrow \text{Perceived Behavioral Control} \)
\( \text{PBC1} \rightarrow \text{Subjective Norm} \)
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\( \text{SN2} \rightarrow \text{Descriptive Norm} \)
\( \text{SN3} \rightarrow \text{Descriptive Norm} \)
\( \text{DN1} \rightarrow \text{Knowledge} \)
\( \text{DN2} \rightarrow \text{Knowledge} \)
\( \text{DN3} \rightarrow \text{Knowledge} \)
\( \text{KN1} \rightarrow \text{Intention to use} \)
\( \text{KN2} \rightarrow \text{Intention to use} \)
\( \text{KN3} \rightarrow \text{Intention to use} \)
Public Acceptance of Smart Meters
(Extended Technology Acceptance Theory)

Sampled 817 U.S. residents across the U.S.
Social-Psych Factors, Segmentation and DR

• Traditional approach to promoting demand response (DR): economic approach – peak & off-peak pricing, dynamic pricing, additional financial incentives, etc.

• To what extent the financial incentives help customers to accept DR programs?

• Is the effect same for everyone?

• How to predict acceptance from energy use habits, demographic variables, and social-psychological factors?
Financial Incentives & HVAC-Related DR

• **Goal:** more accurate estimation of adjustable loads a function of financial incentives and other individual (social-psych) household characteristics

• **Method:** Two online surveys across 48 states in the U.S.
  - 711 and 754 valid responses collected

Ex: How much monetary rewards do you expect in exchange for…?

• Adjusting AC setting by 2-3°F when at home
• Adjusting heater by 2-3°F when at home
• Adjusting AC setting by > 5°F or shutting AC down before leaving home
• Adjusting heater setting by > 5°F or shutting heater down before leaving home
Financial Incentives & HVAC-Related DR

Acceptance rates in respondents

- **Adjust AC for 2-3°F at home**
  - No incentive: 9.90%
  - <5% of monthly bill: 7.80%
  - 5%-10% of monthly bill: 5.30%

- **Adjust heater for 2-3°F at home**
  - No incentive: 9.10%
  - <5% of monthly bill: 8.00%
  - 5%-10% of monthly bill: 5.80%

- **Adjust AC for >5°F away**
  - No incentive: 11.30%
  - <5% of monthly bill: 7.10%
  - 5%-10% of monthly bill: 10.70%

- **Adjust heater for >5°F away**
  - No incentive: 11.70%
  - <5% of monthly bill: 6.00%
  - 5%-10% of monthly bill: 11.00%

- **Automation_AC**
  - No incentive: 12.60%
  - <5% of monthly bill: 9.80%
  - 5%-10% of monthly bill: 11.00%

- **Automation_Heater**
  - No incentive: 12.30%
  - <5% of monthly bill: 9.00%
  - 5%-10% of monthly bill: 13.30%
Preference on Incentive Type

- Amazon GC: 25.7%
- Grocery/Wholesale GC: 6.0%
- Dental/Health visit: 5.8%
- Cash: 2.2%
- Reduction on next month's bill: 0.5%
- Movie GC: 0.6%
- Restaurant GC: 0.2%
- Donation: 0.2%

Total: 100%
### Predictors of HAVC-Related DR

<table>
<thead>
<tr>
<th>Energy Use Info</th>
<th>Demographics</th>
<th>Social-Psychological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly Bill Average</td>
<td>Age</td>
<td>Energy Concern</td>
</tr>
<tr>
<td>Stay Home (9am-5pm)</td>
<td>Gender</td>
<td>Bill Consciousness</td>
</tr>
<tr>
<td>Light Use</td>
<td>Income</td>
<td>Frugality</td>
</tr>
<tr>
<td>Computer Sleep Mode</td>
<td>Education</td>
<td>Need for Comfort</td>
</tr>
<tr>
<td>Thermostat Settings</td>
<td>Political Orientation</td>
<td>Need for Convenience</td>
</tr>
<tr>
<td>Night Adjustments</td>
<td>House Sqft</td>
<td>Trust</td>
</tr>
<tr>
<td></td>
<td>Household Size</td>
<td>Subjective Norm</td>
</tr>
<tr>
<td></td>
<td>Weather Region</td>
<td>Perceived Control</td>
</tr>
</tbody>
</table>

- **Block 1**: Energy Use Info
- **Block 2**: Demographics
- **Block 3**: Social-Psychological
Hierarchical Regression results:

**Voluntarily Adjusting A/C settings by 2-3°F**

- **Step 1: habits**
  - Average bills in the summer
  - Use of sleep mode on computers
  - Age
  - Need for coolness
  - \( R^2 = 0.04 \)
  - \( R^2 = 0.07 \)
  - \( R^2 = 0.15 \)

- **Step 2: + demographics & house features**
  - Age
  - Income
  - \( R^2 = 0.06 \)

- **Step 3: + social-psychological variables**
  - Energy concerns
  - Frugality
  - Trust in the utility company
  - Need for coolness
  - \( R^2 = 0.18 \)

**Letting utility company adjust A/C by 2-3°F**

- **Step 1: habits**
  - Average bills in the summer
  - Use of sleep mode on computers
  - Age
  - Need for coolness
  - \( R^2 = 0.04 \)
  - \( R^2 = 0.06 \)

- **Step 2: + demographics & house features**
  - Age
  - Income

- **Step 3: + social-psychological variables**
  - Energy concerns
  - Frugality
  - Trust in the utility company
  - Need for coolness
  - \( R^2 = 0.18 \)
Differences in Acceptance Rates

Different clusters respond to no rewards or a reward <5% monthly bill
Example of Customer Segmentation

Characteristics of most cooperative group in voluntarily raising thermostat settings in summer

- Lower Comfort Need in Summer
- Lower Electricity Bills
- More Frugal
- Higher Concern for Environmental Impacts
- Smaller Homes

Most Cooperative Cluster
Predicting HAVC-DR (Segmentation)

• Accepting automation at home in summer

Features of most cooperative group:
- Higher thermostat settings generally
- Lower electricity bills
- More Democrats
- Higher energy concerns
- More frugal
- Lower comfort needs
- Lower needs for convenience
- Positive energy-saving attitudes

Hierarchical logistic regression results:

Features of least cooperative group:
- Lower thermostat settings generally
- Higher income
- Lower energy concerns
- Lower money consciousness
- Lower trust
- Poorer energy-saving attitudes
Social-Psych & Demographics Factors Predicting DR Programs

Structure equation modeling results:

Environmental concern
Bill consciousness
Comfort needs Summer
Comfort needs Winter
Perceived inconvenience
Trust
Rent
Home size

Demanded reward Adjust HVAC at home
Demanded reward Adjust HVAC away
Demanded reward Auto
Demanded reward Emergency

Solid lines: significant relationships, α = .05
General Findings

• **Finding 1**: Social-psychological variables enhanced the predictive power of the overall model.

• **Finding 2**: The amount of the requested incentives did not have a linear relationship with certain factors.
  - E.g. Small homes -> smaller amount of requested incentives to lower thermostat setting in winter, large homes is not associated with higher requested incentives.
Ongoing Project: With an Eye on the Market

• How attractive are current DR programs in the market?
  - Automatic A/C cycling
  - Automatic A/C shut down
  - Automatic thermostat adjustment
  - Voluntary A/C adjustment

• How specific features of DR programs affect attractiveness?
  - Frequency, duration, etc.
  - Level of control (e.g., opt out options)
  - Rewards (one-time vs. consumption-dependent)

• Predictable by energy use habits, demographics and social-psychological variables?
What are the factors affecting your preference of DR programs? Please drag the left factors and drop them into the appropriate blocks on the right.

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>WILL CONSIDER AS THE MOST IMPORTANT FACTOR(S)</th>
<th>WILL CONSIDER AS IMPORTANT FACTOR(S)</th>
<th>MAY OR MAY NOT CONSIDER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which behaviors/devices are targeted, e.g., A/C, water heater, etc.?</td>
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<td>How uncomfortable it may become?</td>
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<td>Would it be convenient to do?</td>
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<td>What is the time of the events, e.g., before or after 5 pm?</td>
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<tr>
<td>How much financial benefit would I get?</td>
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<tr>
<td>How much environmental benefit it would bring?</td>
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<tr>
<td>How would the rewards be provided, e.g., bill credits, gift cards, etc.?</td>
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<tr>
<td>Can I control how to use my devices, e.g.,</td>
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<td>Is my utility company trustworthy?</td>
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<td>What are my neighbors’ choices?</td>
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<tr>
<td>Other, please describe.</td>
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Future Work: Time Use, Behavioral Pattern and Attitudes

1) the Residential Energy Consumption Survey by the U.S. Energy Information Administration,
   RECS collected data including residents’ energy characteristics on the housing unit, usage patterns, and demographics. (Potential Capacity)

2) the American Time Use Survey (ATUS) by the U.S. Department of Labor,
   ATUS representative estimates of how, where, and with whom Americans spend their time, and is the only federal survey providing data on the full range of nonmarket activities. (Ongoing Activity)

3) the Survey of Customers’ Reactions to Financial Incentives (SCRFI) in DR by CURENT.
   SCRFI collects self-reported data from U.S. residents across 48 states in 2013. And, it estimates the adopting rates of major DR behaviors as a function of the financial incentives. (Willingness)
Future Work: Integration of Social-psych Approaches and Technology

1. National Representative Survey: Determine patterns and barriers

2. Test-Bed Study:
   Test social-technological interventions: Real-time
   Prepare for the field experiment

3. Field Experiment:
   Find out the most effective Intervention
### Test-Bed Pilot Study: Four Households

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<tbody>
<tr>
<td>Real-time Energy Monitoring</td>
<td>1</td>
<td>1 2</td>
<td>1 2 3</td>
<td>1 2 3 4</td>
<td>1 2 3 4 5</td>
<td></td>
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<tr>
<td>Mobile Technology</td>
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<tr>
<td>Energy Impact Estimation-Based Modeling</td>
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Conclusions

• Human beings are not always rational.
• Information programs (e.g., energy saving programs) may be effective in changing attitudes but may not be effective in changing behaviors.
• Financial incentive is not the only factor to adopt DR programs or reduce energy consumption.
• The approaches of social norm, social networks and message framing could be effective.
• Don’t assume people will automatically adopt DR programs; need to consider different type of individuals (customer segmentation) and situations.
• Energy use in public domain relates largely to social matters, not individual ones.
• Integration of social-technological approaches are needed for persistent behavioral change and technology adoption.