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The Brattle Group

# Experimental Design for Behavior-Based Programs

**An AESP Webinar**

Presented by:

**Ahmad Faruqui, Ph.D.**
**Sanem Sergici, Ph.D.**

**08/25/2011**

# Agenda

1. **Overview of energy efficiency programs**
2. How do the behavior-based programs fit in?
3. How to design effective behavior-based programs?
4. How to obtain credible impact measurements from behavior-based programs?

# Importance of energy efficiency (EE) programs

- Grid reliability
- Difficulties with siting and building new transmission lines and power plants
- Environmental concerns about global warming
- Increase in electricity demand
- High energy prices and customer bills

# There are five major drivers of energy efficiency

1. **Codes and Standards**
   - Federal, state, and local building efficiency codes
   - Appliance and equipment standards, i.e., EISA of 2007
2. **Technological change**
   - Market transformation activities
   - Competition among manufacturers and builders
3. **Utility-based programs**
   - Rebates for efficient appliances
   - Financing for appliance and building retrofits
4. **Efficiency-inducing pricing designs**
   - Inclining block rates
5. **Behavior-based (or information feedback) programs**
   - Provision of information

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1. Overview of energy efficiency programs

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3. How to design effective behavior-based programs?

4. How to obtain credible impact measurements from behavior-based programs?

# In this presentation, we will focus on behavior-based energy efficiency programs

**There are two types of behavior-based programs:**

- ♦ Direct information feedback
  - Real-time information on energy usage and costs (through in-home displays)
- ♦ Indirect information feedback
  - Usage information that has been processed before reaching customers (detailed energy usage reports through paper reports, usage, online reports, and web-portals)

**These programs increase awareness of energy use and empower customers with knowledge to act upon**

# What is the information content?

- Comparison of historic usage to current month’s usage
- Comparison to similar homes in the same neighborhood
- Ability to set conservation goals and track performance towards these goals
- Quick tips on how to use energy more efficiently
- Ability to see consequences of actions taken and *turn electricity consumption into a controllable process*

# Many utilities around the country have discovered the power of behavior-based program

**Several pilots are underway to test the concept and measure the impacts**

**Several utilities have already rolled out (or have plans to roll out) these programs for their entire residential population**

**Several of these programs have reported energy savings in the range of 1% to 4 %**

***These programs must be designed and measured carefully to ensure credible results***

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4. How to obtain credible impact measurements from behavior-based programs?

# What are the “golden rules” of behavior-based program design?

1. Ensure internal and external validity
2. Determine sampling frame and program design approach
3. Determine impact evaluation method
4. Determine the sample design
5. Determine the data requirements

# 1. Ensure Internal and External Validity- I

**Internal validity means a true cause-effect relationship can be established between the treatments and the variable of interest**

- Treatment X (cause) yields Y percent conservation (effect)
- A *control group* is needed to ensure internal validity

**Without a control group, it is not possible to account for all non-treatment variables that change between pre-program and program periods, and hence truly measure the program impact**

# 1. Ensure Internal and External Validity- II

**External validity means that the program results can be extrapolated to the population of interest**

- A requirement in the case of a "pilot program" rather than a full-scale program

**It is important to determine how these programs will be deployed to the ultimate population of interest**

- Universal basis
- Default basis with opt-out
- Opt-in basis

***Different deployment strategies require different program design approaches***

# 2. Determine Sampling Frame and Program Design Approach- I

**A program design must clearly state:**

- Treatment (s) that will be tested
- Metric (s) that will be measured
- Sampling frame, a population about which inferences will be made

**After determining the sampling frame and considering the full-scale deployment strategy, the next step is to determine the <u>program design approach</u>**

- Most behavioral-based efficiency programs are likely to be offered on a universal basis to the entire residential customer population
- This makes the "randomized controlled trial" most suitable program design approach

# 2. Determine Sampling Frame and Program Design Approach- II

**In the randomized control trial (RCT) approach, customers from a sampling frame are randomly assigned into treatment and control groups**

- Pure random allocation to the T and C groups is the most straightforward way to meet internal and external validity criteria

**However, it is still good practice to compare the control and treatment group characteristics in the pre-program period**

# 3. Determine Impact Evaluation Approach

**It is important to determine the impact evaluation approach early in the program as it has implications for the sample sizes and data requirements**

**All methodologies are essentially based on mean-comparison between T and C groups. Two main variations are:**

- Studies w/ a single measurement of the outcome
- Studies w/ repeated measurement of the outcome

***Studies w/ repeated measurements result in substantial increase in measurement efficiency and require much smaller sample sizes***

# 4. Determine the Sample Design

**Statistical power analyses must be conducted to achieve a pre-determined statistical precision level**

**The following factors determine the sample size in a repeated measurement study:**

- Significance level of the test (Type I error)
- Power of the test (1-Type II error)
- One-sided or two-sided hypothesis testing
- Ratio of treatment and control group sizes
- Number of the pre-treatment measurements
- Number of the post-treatment measurements
- Correlation between pre-treatment measurements
- Correlation between post-treatment measurements
- Correlation between pre-treatment and post-treatment measurements

# Sample Sizes: Single vs. Repeated Measurement (Statistical Power= 90%, Confidence Interval= 95%)

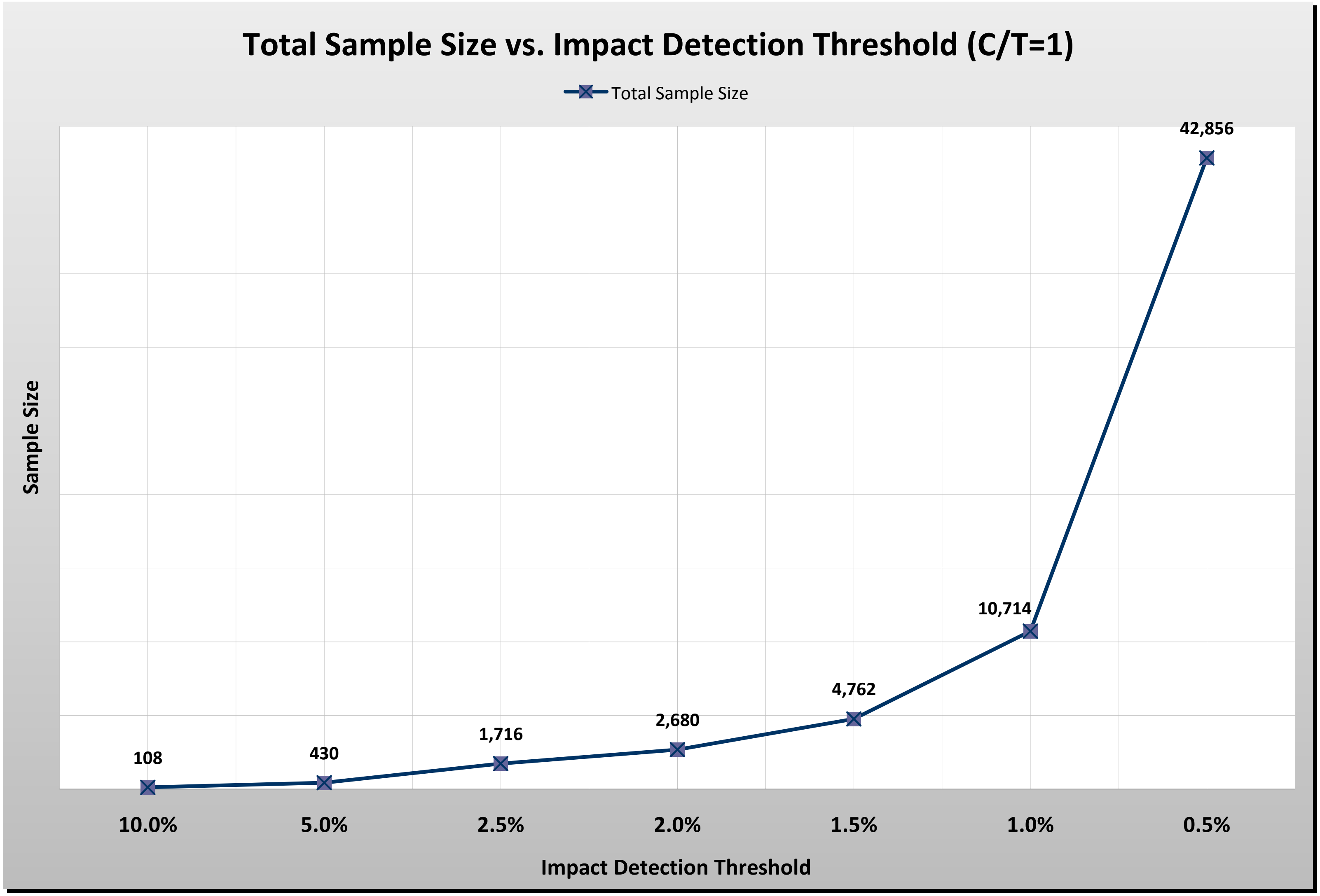
**One-sided Hypothesis Testing**

| Assumptions | Mean Usage (kWh/mo)=1,439 St. Deviation of Usage (kWh/mo)=779.2 Impact Detection Limit = 1% | | | | | |
|---|---|---|---|---|---|---|
| | **One-sided Test** | | | | | |
| | **C/T=1** | | **C/T=2** | | **C/T=1/2** | |
| | Treatment | Control | Treatment | Control | Treatment | Control |
| Pre=0, Post=1 | 50,220 | 50,220 | 37,665 | 75,330 | 75,330 | 37,665 |
| Pre=6, Post=6 | 7,701 | 7,701 | 5,776 | 11,552 | 11,552 | 5,776 |
| Pre=12, Post=12 | 5,357 | 5,357 | 4,018 | 8,036 | 8,036 | 4,018 |

**To detect changes in mean usage that are greater than or equal to 1%, with 90% statistical power and 95% confidence:**

- A single measurement study would require 50,220 T and C customers
- A repeated measurement study would require 5,357 T and C customers

# Smaller the impact detection threshold, the larger the sample size



# Determine Data Requirements

- Monthly kWh usage data for each of the T and C customers preferably 12 months *prior* to the treatment period
- Monthly kWh usage data for each of the T and C customers for at least 12 months *during* the treatment period
- Meter reading date for each of the customers if the billing is based on billing cycles
- Tariff designation
- Effective treatment start date
- For customers leaving the program, the date they left the program
- Socio-demographic and appliance data
- Weather data based on weather stations that are in the closest geographical proximity to the program customers

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# Our recommended approach is "panel data regression analysis technique"

**There are three main approaches that can be used:**

- Difference of Means or Analysis of Variance (ANOVA)
- Difference-in-Differences of Mean Values
- Panel Data Regression Analysis

**We recommend Panel Data Regression Analysis as it makes it possible to:**

- increase the efficiency and precision of the estimates using repeated measures on each program participant
- account for time-invariant unobservable variables that would otherwise lead to biased estimates

# An Example Model Specification- I

$$
\begin{aligned}
\ln\_kWh_{it} &= \alpha_0 + \alpha_1 Treatment_i + \alpha_2 Post_t + \alpha_3 TreatmentxPost_{it} \\
&+ \beta_1 HDD_t + \beta_2 HDDxTreatment_{it} + \beta_3 HDDxPost_{it} + \beta_4 HDDxTreatmentxPost_{it} \\
&+ \delta_1 CDD_t + \delta_2 CDDxTreatment_{it} + \delta_3 CDDxPost_{it} + \delta_4 CDDxTreatmentxPost_{it} \\
&+ v_i + u_{it}
\end{aligned}
$$

| | |
|---|---|
| $\ln\_kWh_{it}$ | : Natural logarithm of monthly average kWh/day for customer i and month t. |
| $Treatment_i$ | : Dummy variable that takes the value of 1 if customer i is a treatment customer. |
| $Post_t$ | : Dummy variable that takes the value of 1 if month t is in the treatment period. |
| $TreatmentxPost_{it}$ | : Dummy variable that takes the value of 1 if customer i is measured in the treatment period month t. |
| $HDD_t$ | : Heating degree days per day for month t |
| $HDDxTreatment_{it}$ | : Interaction of $HDD_t$ with $Treatment_i$ |
| $HDDxPost_{it}$ | : Interaction of $HDD_t$ with $Post_t$ |

# An Example Model Specification- II

| | |
|---|---|
| $HDDxTreatmentxPost_{it}$ | : Interaction of $HDD_t$ with $TreatmentxPost_{it}$ |
| $CDD_t$ | : Cooling degree days per day for month t |
| $CDDxTreatment_{it}$ | : Interaction of $CDD_t$ with $Treatment_i$ |
| $CDDxPost_{it}$ | : Interaction of $CDD_t$ with $Post_t$ |
| $CDDxTreatmentxPost_{it}$ | : Interaction of $CDD_t$ with $TreatmentxPost_{it}$ |
| $v_i$ | : Time invariant fixed effect term for customer i. |
| $u_{it}$ | : Independent and identically distributed random error term for customer i at month t. |

# After estimating the model, it is straightforward to estimate the average program impact

$$\hat{ATI} = \hat{\alpha}_3 + \hat{\beta}_4 HDD_t + \hat{\delta}_4 CDD_t$$

**Where $HDD_t$ and $CDD_t$ are the average values of the *actual* weather terms in the treatment period.**

**It is also possible to estimate a confidence interval for this average impact:**

$$\hat{ATI} \pm c * se(\hat{ATI})$$

**For a 95% confidence interval, c is the 97.5th percentile in a $t_{df}$ distribution and $df = n - k - 1$**

# Concluding Remarks

**Behavior-based energy efficiency programs hold the key to increasing customer awareness and unlocking the energy efficiency potential**

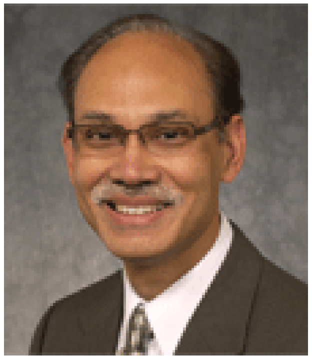
**A statistically valid program design and a strong impact evaluation approach will yield reliable impact metrics**

**Different M&V approaches have important implications for sample sizes**

**For more information, please see *The Brattle Group*, "Measurement and Verification Principles for Behavior-Based Efficiency Programs," May 2011, prepared for OPOWER.**

**http://www.brattle.com/_documents/UploadLibrary/Upload955.pdf**

# Speaker Bio and Contact Information



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Dr. Ahmad Faruqui has advised utilities in two dozen states on smart grid issues involving the customer and testified before a dozen state and provincial commissions and legislative bodies. He has designed and evaluated some of the best known pilot programs involving dynamic pricing and enabling technologies. The author, co-author or editor of four books and more than 150 articles, papers and reports, he holds a doctoral degree in economics from the University of California at Davis and undergraduate and graduate degrees from the University of Karachi, Pakistan.

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Sanem Sergici is a Senior Associate of *The Brattle Group* with expertise electricity markets, industrial organization and applied econometrics. At *Brattle*, the focus of Dr. Sergici's work has been on assisting electric utilities, regulators, research organizations and wholesale market operators in the development of innovative demand response and energy efficiency portfolios and strategies. Dr. Sergici has expertise in the design and evaluation of dynamic pricing pilot programs, development of load forecasting models, and design of innovative rates for electric utilities. Her recent engagements include assisting the utilities in Michigan, Connecticut, Illinois and Maryland in the design and impact evaluation of their pricing and technology pilots. Dr. Sergici is a member of a Technical Advisory Group (TAG) for Smart Grid Investment Grant projects that was formed by the U.S. Department of Energy (DOE) and Lawrence Berkeley National Laboratory (LBNL). She has spoken at several industry conferences and published in several industry journals.

Dr. Sergici received her Ph.D. in Applied Economics from Northeastern University in the fields of applied econometrics and industrial organization. She also holds an M.A. in Economics from Northeastern University, and B.S. in Economics from Middle East Technical University (METU), Ankara, Turkey.

# About *The Brattle Group*

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# Questions???

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# Experimental Design for Behavior-Based Programs

Jeff Haase

AESP Webinar | August 25, 2011

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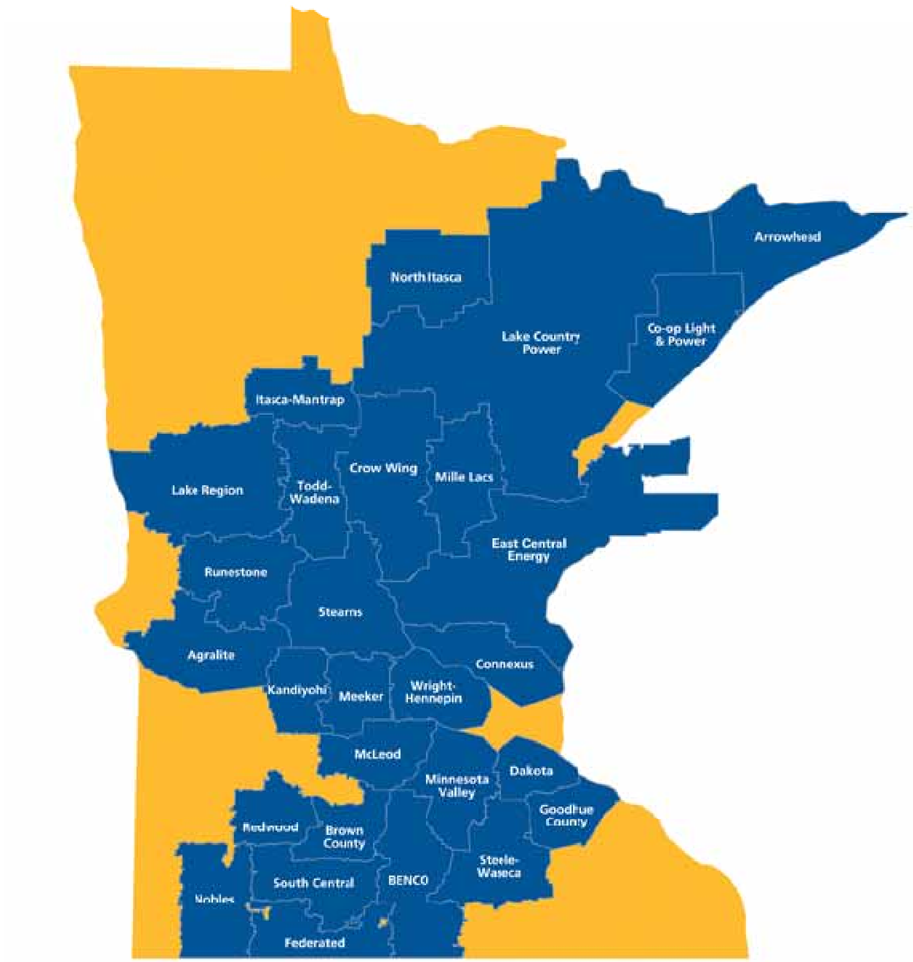
# Great River Energy




- Not for profit generation & transmission cooperative providing wholesale electricity to 28 distribution cooperatives in Minnesota and into Wisconsin.
- Second largest utility in Minnesota, our member cooperatives distribute electricity to families, farms and businesses servings almost 1.7 million people.



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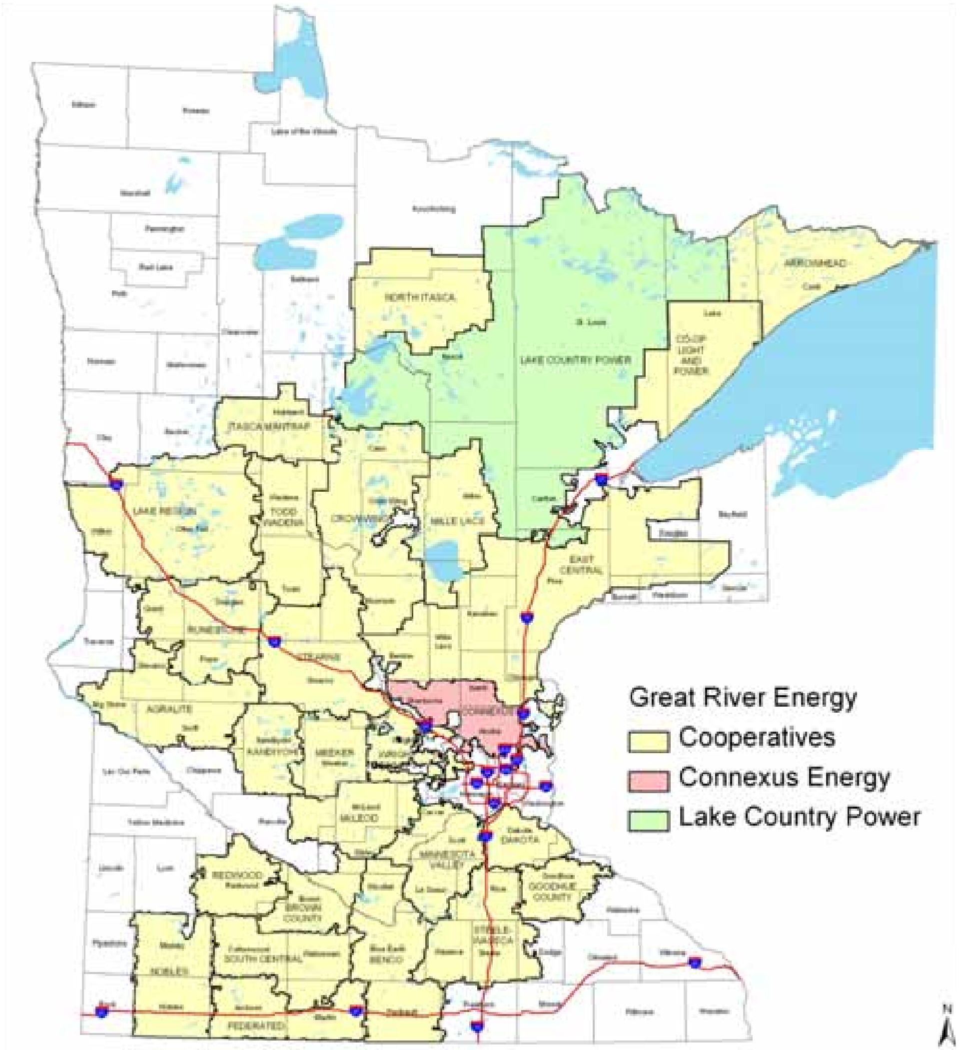
# Minnesota Energy Conservation Goal

**Minnesota Statutes §216B.2401**
**ENERGY CONSERVATION POLICY GOAL**

It is the energy policy of the state of Minnesota to achieve annual energy savings equal to 1.5 percent of annual retail energy sales of electricity and natural gas directly through energy conservation improvement programs and rate design, such as inverted block rates in which lower energy prices are made available to lower-usage residential customers, and indirectly through energy codes and appliance standards, ***programs designed to transform the market or change consumer behavior***, energy savings resulting from efficiency improvements to the utility infrastructure and system, and other efforts to promote energy efficiency and energy conservation

# Participating Cooperatives




Lake Country Power
A Touchstone Energy® Cooperative

- 42,551 Members
- 612 Million kWh Sales (2010)

CONNEXUS® ENERGY
Your Community Energy Partner

- 125,341 Members
- 2.2 Billion kWh Sales (2010)

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# Experimental Design

- Connexus Energy
  - Home Energy Report System Pilot Program launch in February 2009
    - 40,000 households received the reports
    - 40,000 households were selected to serve as the control group

| | Control | Test | Difference | p-value |
|---|---|---|---|---|
| Size of home | 1690 sqft | 1692 sqft | 0.1% | 0.62 |
| Age of home | 31.4 years | 31.5 years | 0.5% | 0.43 |
| % with electric heat | 8% | 8% | 0.4% | 0.88 |
| % renters | 17% | 17% | 0.1% | 0.63 |
| % of single-family homes | 96% | 96% | -0.1% | 0.68 |
| Average kwh/year | 10,998 | 11,014 | 0.0% | 0.70 |

# Experimental Design

- Lake Country Power
  - Home Energy Report System Pilot Program launch in May 2009
    - 10,016 households received the reports
    - 7,983 households were selected to serve as the control group

| | Control | Test | Difference | p-value |
|---|---|---|---|---|
| Size of home | 1690 sqft | 1692 sqft | 0.1% | 0.62 |
| Age of home | 31.4 years | 31.5 years | 0.5% | 0.43 |
| Has parcel data | 34.3% | 34.2% | 0.1% | 0.86 |
| % with electric heat | 30.1% | 31.3% | 1.2% | 0.08 |
| % renters | 4.5% | 4.7% | 0.2% | 0.48 |
| Average kwh/year | 14,234 | 14,581 | 2.4% | 0.02 |
| Homes with electric heat | 23,889 | 24,101 | 0.9% | 0.49 |
| Homes without electric heat | 10,071 | 10,232 | 1.5% | 0.08 |

# Top energy savings programs

| Program | Energy Savings (kWh) | Percent of Total Energy Savings |
|---|---|---|
| Residential Lighting | 29,638,551 | 19.8% |
| Comm. Lighting | 20,134,718 | 13.4% |
| GSHPs | 17,724,829 | 11.8% |
| Appliances | 15,284,509 | 10.2% |
| ASHPs | 5,978,073 | 4.0% |
| Air Conditioning | 1,630,582 | 1.1% |
| Load Management | 804,584 | 0.5% |
| **Total** | **91,195,846** | **60.8%** |

- Measurable behavioral savings programs resulted in almost 10,000,000 kWh in savings for the 2010 program year.
- These results place it in GRE's top five programs, with only 2 cooperatives participating.



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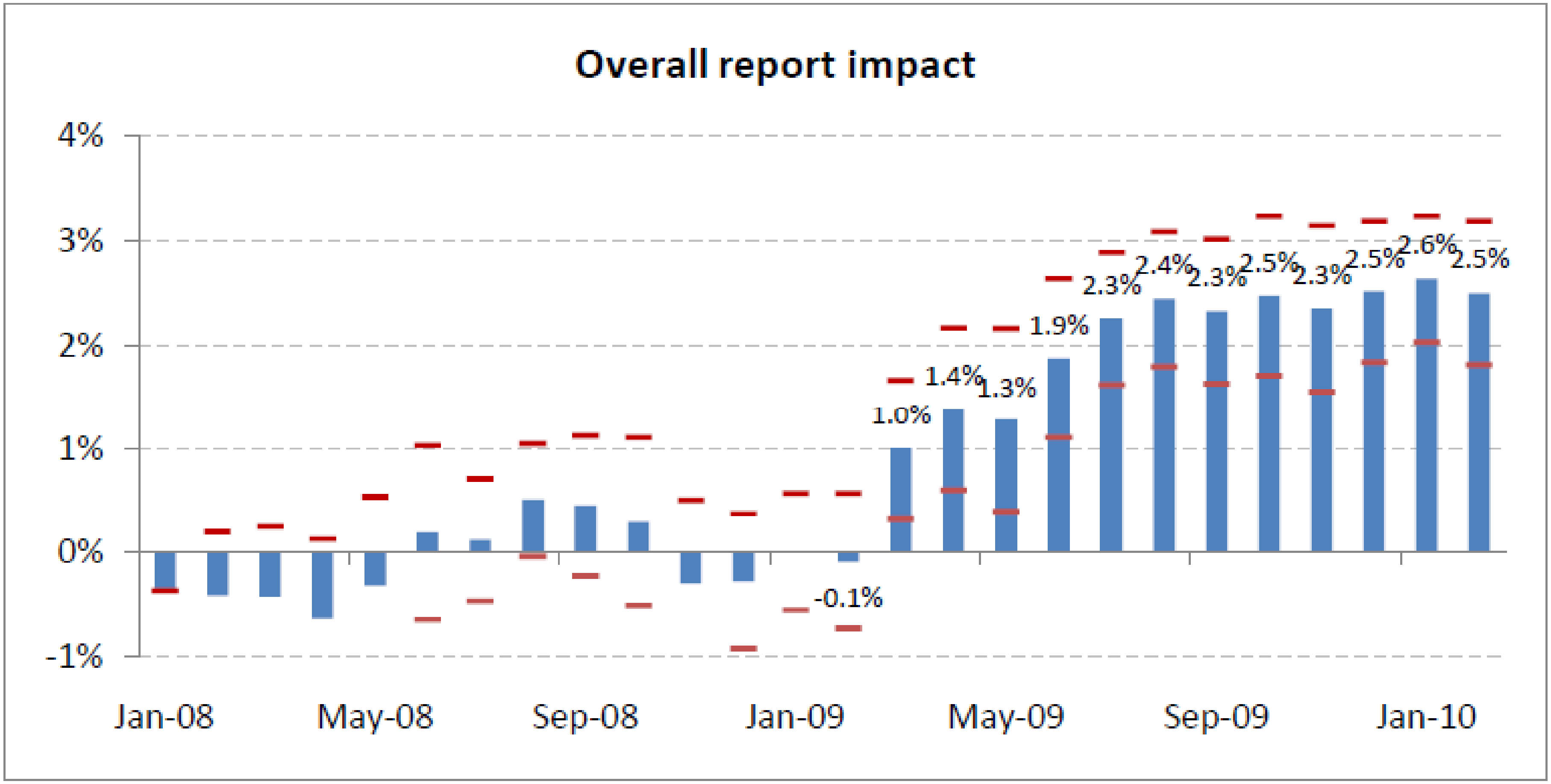
# Connexus Energy Results



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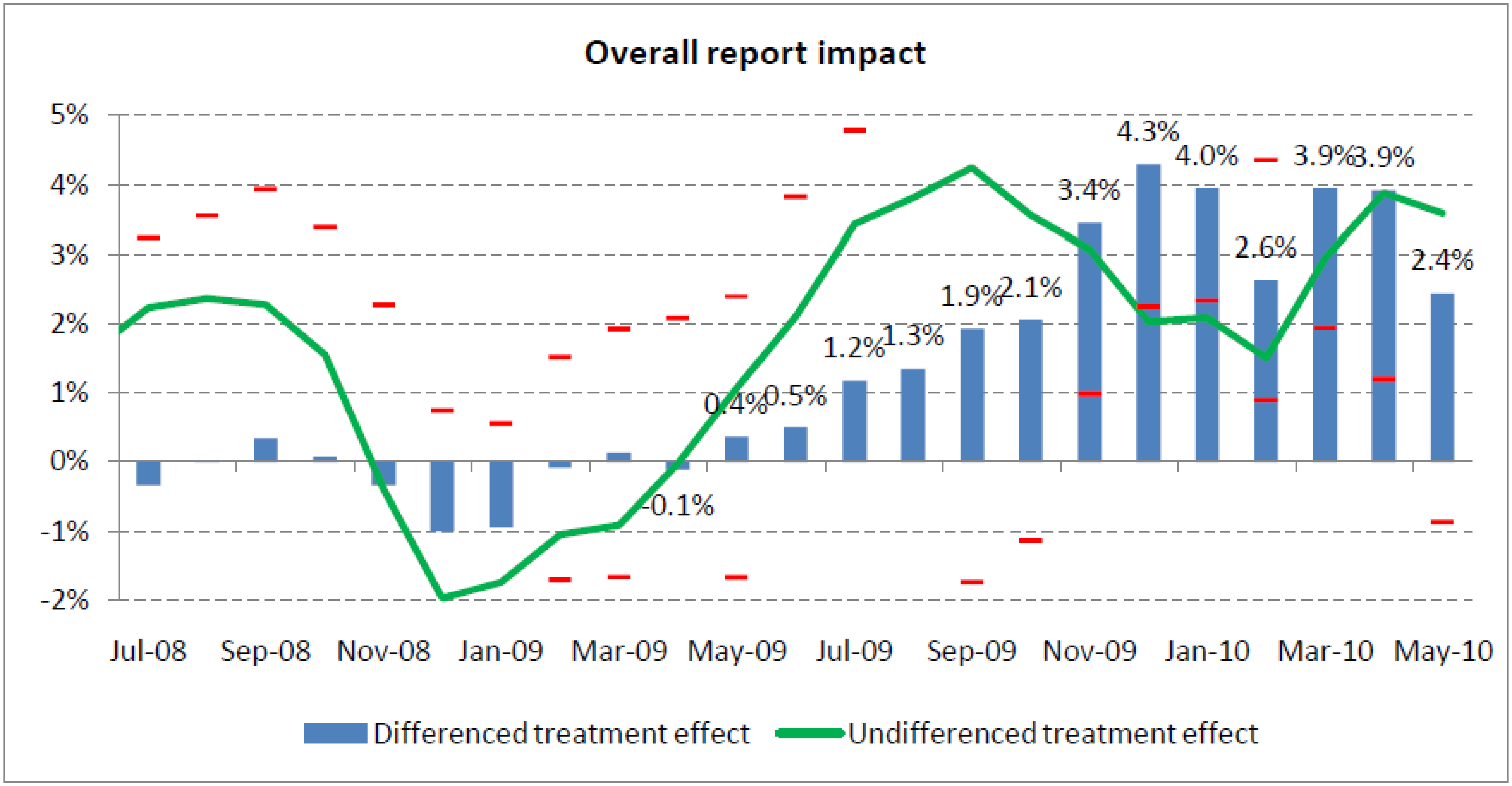
# Lake Country Power Results



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# Final Pilot Program Results

- Connexus Energy
  (February 2009 – March 2010)
  - 2.2% average savings per household per year
  - 8,354 MWh in total energy savings
  - 1.3% Opt-out rates (500)

- Lake Country Power
  (May 2009 – May 2010)
  - 2.9% average savings per household per year
  - 3,692 MWh in total energy savings
  - 1.4% Opt-out rates (139)



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# Third Party Evaluation

- Power Systems Engineering (PSE) conducted the evaluation.

  – Data provided to PSE included:
    - Monthly Billing Data;
    - Program Specific Characteristics;
    - Customer Demographics; and
    - Climate Data.

  – The time period of the data stretched from January 2007 – January 2010
    - More than 2.5 million observations from 80,000 members

# Third Party Evaluation

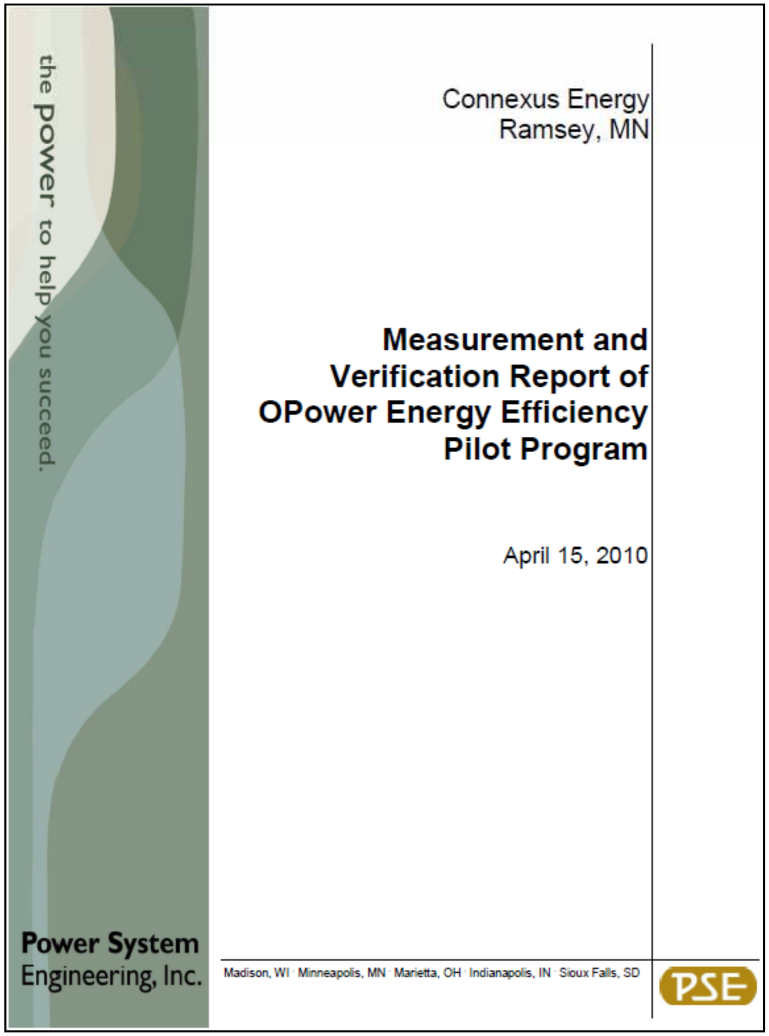
- In evaluating the energy savings of the program, three measurements were calculated:

1. True Impact Test
2. Ordinary Least Squares Econometric Model
3. Fixed Effects Model

| Estimated Per Customer Savings of OPower Program | | | |
|---|---|---|---|
| | Annual kWh Savings per Customer | | Percentage Reduction |
| | Daily | Annual | |
| True Impact Test | 0.485 | 177 | 1.62% |
| OLS Model | 0.524 | 191 | 1.76% |
| Fixed Effects Model | 0.549 | 200 | 1.84% |
| **Average** | **0.519** | **190** | **1.74%** |

# Third Party Evaluation - Conclusion

- PSE concluded that there are tangible energy savings resulting from the program.
  - *Results are robust with a high degree of confidence.*
- PSE can verify a savings between 1.84 and 2.14 percent for the first year.
  - *Annual savings can vary depending on the start and end date that are chosen.*


the power to help you succeed.

Connexus Energy
Ramsey, MN

**Measurement and Verification Report of OPower Energy Efficiency Pilot Program**

April 15, 2010

Power System Engineering, Inc.

Madison, WI · Minneapolis, MN · Marietta, OH · Indianapolis, IN · Sioux Falls, SD

PSE

# 2010 CIP Results

| Actual kWh Savings | Actual Rebate Spending | Cost/kWh Saved (first year) | Cost/kWh Saved (lifetime)* |
|---|---|---|---|
| 149,900,902 | $25,143,386 | $0.168 | $.021 |

**Assumes 8 year average lifetime of energy efficiency measures.*

*Achievements represent 135% of the 1.5% Energy Conservation Goal*



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# Ongoing Behavioral Activities

- Assisting several member cooperatives with different program designs
  - Opt-in internet based programs

- Trying to drive additional value through the touch points that behavioral program provide
  - Seeking to increase participation in other programs

- Ongoing work to drive the cost per kWh saved down to the portfolio average.



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# Next Steps in Program Delivery

- Continue to evaluate different delivery methods
  - Quarterly vs. Monthly vs. Bi-monthly
- Evaluate the appropriate cost allocation for these programs
  - Assignment of advertising dollars to other programs
- Work with the State of Minnesota on appropriately crediting behavioral programs.
  - Persistence & life of measure are ongoing challenges

# Thank you!

Jeff Haase

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# QUESTIONS

**To ask a question over the phone dial 866-431-5314 and enter passcode 754577.**

**Press *1 to ask a question**