LBNL-XXXX

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Summary of Utility Studies: Smart Grid Investment Grant Consumer Behavior Study Analysis

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Environmental Energy Technologies Division

May 2013

The work described in this report was supported by the National Electricity Division of the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

Acknowledgments

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The authors would like to thank Joe Paladino (DOE OE) for his support. The authors would also like to thank the members of the LBNL Technical Advisory Group who contributed their wisdom and guidance: Peter Cappers, Annika Todd, Charles Goldman and Andy Satchwell (LBNL); Catherine Wolfram, Meredith Fowlie, and Lucas Davis (University of California at Berkeley); Michael Sullivan, Stephen George, Michael Perry, Josh Bode, and Matt Mercurio (Freeman, Sullivan & Company); Miriam Goldberg, Curt Puckett and Roger Wright (KEMA); Ahmad Faruqui, Sanem Sergici, and Ryan Hledik (Brattle Group); Mary Sutter and Tami Buhr (Opinion Dynamics); Rich Scheer (Scheer Ventures, LLC); Karen Herter (Herter Energy Research Solutions, Inc.); Roger Levy (Levy Associates); Theresa Flaim (Energy Resource Economics, LLC); Richard Feinberg (Purdue University); and Lisa Schwartz (Oregon Department of Energy).

This report was prepared by Lawrence Berkeley National Laboratory for the Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231..

This document was final as of XXXX.

If this document is referenced, it should be cited as:

Cappers, P., A. Todd, and C. Goldman. 2013. Summary of Utility Studies: Smart Grid Investment Grant Consumer Behavior Study Analysis. Lawrence Berkeley National Laboratory, LBNL-XXXX.

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Glossary of Acronyms, Abbreviations, and Terms

AMI	**Advanced Metering Infrastructure –** All components that allow two-way communication between meters and the electric utility's meter data management system to collect electricity usage and related information from customers and to deliver information to customers.
CA	**California**
CAC	**Central Air Conditioning**
CBS	**Consumer Behavior Study**
CBSP	**Consumer Behavior Study Plan**
CPP	**Critical Peak Pricing –** A time-based rate component that increases the price on electricity consumed for participating customers during the hours included in a declared critical event. This higher price is overlaid onto the existing retail rate. Critical events are called either on a day-ahead or in-day basis in response to forecasted or achieved, respectively, high wholesale market electricity prices, short-term system reliability problems, or both. The primary objective of this rate design is to promote reductions in the peak demand of electricity.
CPR	**Critical Peak Rebate –** A demand response program that pays participating customers for reducing electricity consumed in relation to a baseline during the hours included in a declared critical event. Critical events are called either on a day-ahead or in-day basis in response to forecasted or achieved, respectively, high wholesale market electricity prices, short-term system reliability

problems, or both. The primary objective of this program design is to promote reductions in the peak demand of electricity.

DECo	**Detroit Edison Company**
DLC	**Direct Load Control**
DOE	**Department of Energy**
FE	**FirstEnergy Ohio**
FOA	**Funding Opportunity Announcement**
GMP	**Green Mountain Power**
HEMS	**Home Energy Management System**
IBR	**Inclining Block Rate –** A rate program design that charges customers for electricity usage based on the how much they consume. Blocks of usage are defined and the price for each block of usage increases as the amount of consumed electricity increases. The primary objective of this rate design is to promote overall conservation of electricity.
IHD	**In-Home Display**
ISO	**Independent System Operator**
kWh	**Kilowatt-hour**
LBNL	**Lawrence Berkeley National Laboratory**
LE	**Lakeland Electric**
MMLD	**Marblehead Municipal Light Department**
MN	**Minnesota**

NDPT	**Nevada Dynamic Pricing Trial**
NVE	**NV Energy**
NVP	**Nevada Power**
OE	**DOE Office of Energy Delivery and Electricity Reliability**
OG&E	**Oklahoma Gas & Electric**
OK	**Oklahoma**
PCT	**Programmable Communicating Thermostat**
RCT	**Randomized Controlled Trial** - A research strategy in which customers who volunteer to be exposed to a treatment are randomly assigned to treatment and control conditions.
RED	**Randomized Encouragement Design** - A research design in which two groups of customers are selected from the same population at random and one is offered a treatment while the other is not. Not all customers offered the treatment are expected to take it but, for analysis purposes, all those who are offered the treatment are considered to be in the treatment group.
SGIG	**Smart Grid Investment Grant**
SMUD	**Sacramento Municipal Utility District**
SPP	**Sierra Pacific Power**
TAG	**Technical Advisory Group**
TOU	**Time-Of-Use** - A time-based rate program design that charges customers for electricity usage based on the block of time it is consumed. The price schedule is fixed and

	predefined, based on season, day of week, and time of day. The primary objective of this rate design is to promote overall shifting of electricity away from the peak period to other periods.
VEC	**Vermont Electric Cooperative**
VPP	**Variable Peak Pricing** – A time-based rate program design that charges customers for electricity usage based on the block of time it is consumed. The price schedule is variable and differs daily, based on bulk power system conditions during that period of the day. The primary objective of this rate design is to promote targeted shifting of electricity away from the peak period to other periods.
VT	**Vermont**

Foreword

As far back as the 1890s, the electric industry has been debating the issue of how to efficiently and optimally charge customers for consuming electricity (Hausman and Neufeld 1984). At that time, there were emerging but very contentious discussions among economists about the merits of pricing the new commodity differentially based on time. The challenge with such pricing schemes revolved around metering—cost-effective technology did not exist at that time to allow electricity consumption to be captured at the required level of detail. Thus, virtually all customers were charged for their electricity consumption at a rate that was time-invariant (i.e., flat).

By the 1970s, the debate had moved beyond issues of economic efficiency and instead turned towards more practical concerns about consumer behavior—could mass-market (i.e., residential and small commercial) customers manage their electricity consumption under time-based rate programs? The results of studies undertaken by the Federal Energy Administration, the predecessor to the U.S. Department of Energy (DOE), indicated such customers were, in fact, capable of managing their electricity consumption by moving it away from the expensive "peak" period to the less-expensive "off-peak" period (see Faruqui and Malko 1983 for a meta-analysis of these experiments). In spite of this evidence, the lack of low-cost interval or period-based metering technology continued to limit the industry's ability to expand the application of time-based rate programs at the residential level through the end of the 20th century.

Over the past ten years, however, the costs of interval meters, the communications networks to connect the meters with utilities and the back-office systems necessary to maintain and support them (i.e., advanced metering infrastructure or AMI) have dramatically decreased. The implementation of AMI and interval meters by utilities, which allows electricity consumption data to be captured, stored and reported at 5 to 60-minute intervals in most cases, provides an opportunity for utilities and policymakers to once again seriously consider the merits of the widespread deployment of time-based rate programs. However, many regulators and other key policymakers have determined that more definitive answers to key policy questions must be addressed before they will fully support a paradigm shift in the way retail electricity providers charge residential and small commercial customers for consuming electricity.

The American Recovery and Reinvestment Act of 2009 included $3.4B for the Smart Grid Investment Grant (SGIG) program with the goal of creating jobs and accelerating the transformation of the nation's electric system by promoting investments in smarter grid technologies, tools and techniques (DOE 2012a). Among other topics, the Funding Opportunity Announcement (DE-FOA-0000058) identified interest in AMI projects that examined the impacts and benefits of time-based rate programs and enabling control and information technologies through the use of randomized controlled experimental designs.

Based on responses to this FOA, DOE decided to co-fund ten utilities to undertake eleven experimentally-designed Consumer Behavior Studies (CBS) that proposed to examine a wide range of the topics of interest to the electric utility industry. Each chosen utility was to design, implement and evaluate their own study in order to address questions of interest both to itself and to its applicable regulatory authority, whose approval was generally necessary for the study to proceed. The DOE Office of Energy Delivery and Electricity Reliability (OE), however, did set guidelines, both in the FOA and subsequently during the contracting period, for what would constitute an acceptable study under the Grant.

To assist in ensuring these guidelines were adhered to, OE requested that LBNL act as project manager for these Consumer Behavior Studies to achieve consistency of experimental design and adherence to data collection and reporting protocols across the ten utilities. As part of its role, LBNL formed technical advisory groups (TAG) to separately assist each of the utilities by providing technical assistance in all aspects of the design, implementation and evaluation of their studies. LBNL was also given a unique opportunity to perform a comprehensive, cross-study analysis that uses the customer-level interval meter and demographic data made available by these utilities due to SGIG-imposed reporting requirements, in order to analyze critical policy issues associated with AMI-enabled rates and control/information technology. Over the next several years, LBNL will publish the results of these analyses in a series of research reports that attempt to address critical policy issues relating to on a variety of topics including customer acceptance, retention and load response to time-based rates and various forms of enabling control and information technologies. This report is the first in that series and provides a description of each study.

Executive Summary

The U.S. Department of Energy's (DOE's) Smart Grid Investment Grant (SGIG) program is working with a subset of the 99 SGIG projects to assess the response of mass market consumers (i.e., residential and small commercial customers) to time-varying electricity prices (referred to herein as time-based rate programs) in conjunction with the deployment of advanced metering infrastructure (AMI) and associated technologies. The effort provides an opportunity to advance the electric industry's understanding of consumer behavior. In addition, DOE is attempting to apply a consistent study design and analysis framework for the SGIG Consumer Behavior Studies (CBS). The aim is to collect information across the studies on variables and impacts that have been defined in a consistent manner. This will enable Lawrence Berkeley National Lab (LBNL), as DOE's principal investigator for these Consumer Behavior Studies, to leverage the data from the individual studies and conduct comparative analysis of the impacts of AMI, time-based rate programs and enabling technologies that facilitate customer control, automation and information/feedback on customer energy usage.

To implement such a framework, DOE is requiring the ten utilities undertaking such Consumer Behavior Studies to apply randomized controlled experimental methods in their studies. Evaluations of experiments that employ random selection and random sampling possess estimates of effects that are credible (i.e., they are internally valid) and increase the likelihood that the estimates are more precise and can be extrapolated to similar groups outside of the study sample (i.e., they are externally valid) as compared to studies that do not use employ such methods.

The ten utilities implementing these eleven studies are on different time tables. Two utilities have already completed their studies (i.e., Oklahoma Gas & Electric and Marblehead Municipal Light Department). One utility who is running an identical study in its two service territories has only recently recruited participants (i.e., NV Energy), while the remaining seven utilities have some field experience with their study.

The Consumer Behavior Studies focus on a broad array of issues that examine the impacts of exposing residential (and to a very limited extent, small commercial) customers to time-based rates and enabling technology between 2010 and 2015. The utilities conducting these experiments range from small municipal entities (e.g., Marblehead Municipal Light

Department with ~10,000 residential customers) to large investor-owned utilities (e.g., Detroit Edison with ~1.9 M residential customers and NV Energy with two major subsidiaries Nevada Power and Sierra Pacific Power). Each study shares some features in common with others, although each also includes unique elements that incorporate and reflect the research priorities and focus of that utility.

All utilities are using some form of an opt-in recruitment effort, although three are augmenting this with an opt-out approach to study differences in recruitment methods (see ES Table 1). These latter utilities (e.g., Lakeland Electric and Sacramento Municipal Utility District) are testing the same program design elements in both an opt-in and opt-out environment, which will allow each utility and LBNL to assess customer preferences for and response to the same rates and technology under these two different recruitment methods.[1]

	Opt-In	**Opt-Out**
Detroit Edison	●	
FirstEnergy Ohio	●	
Green Mountain Power	●	
Lakeland Electric	●	●
Marblehead Municipal	●	
Minnesota Power	●	●
NV Energy – Nevada Power	●	
NV Energy – Sierra Pacific Power	●	
Oklahoma Gas & Electric	●	
Sacramento Municipal	●	●
Vermont Electric Cooperative	●	
TOTAL	**11**	**3**

ES Table 1. Summary of utility studies by enrollment method

Recruitment is a major issue for utilities and state regulatory commissions as they grapple with how time-based rates should be introduced to electric customers: either through

[1] MN Power is only testing its information feedback treatments in both an opt-in and opt-out environment. The rate treatments are exclusively implemented as an opt-in program offer.

voluntary programs that customers must select and opt in, which is the traditional approach; or as the default rate design from which a customer must opt out if they wish not to be on it. Gaining a better understanding of customer acceptance and retention with opt-in and opt-out recruitment methods should provide policymakers, regulatory commissions and utilities with additional information with which to make more informed decisions on this topic.

The studies are also examining a variety of different time-based rate designs (see ES Table 2). Seven utility studies are looking at evaluating acceptance of and response to time-of-use (TOU) rates. All except one of these studies includes a critical peak pricing (CPP) overlay on this TOU rate to see how this augments peak period load reductions. Several utility studies are focusing on critical peak rebate (CPR) programs layered on top of the existing flat/block rate. In one study, the utility is testing the response to CPP and CPR as single treatments in the study, but also as treatments that customers are exposed to in sequential years (CPR in year 1 and CPP in year 2). Two utility studies are using a novel rate design (variable peak pricing or VPP) that looks like TOU rate but the peak price changes daily to reflect exigent system costs and reliability conditions. Collectively, these utilities are implementing rate designs and recruitment methods that are at the forefront of policy discussions about what default service should look like for residential customers.

	CPP	TOU	VPP	CPR
Detroit Edison	●	●		
FirstEnergy Ohio				●
Green Mountain Power	●			●
Lakeland Electric		●		
Marblehead Municipal	●			
Minnesota Power	●	●		
NV Energy – Nevada Power	●	●		
NV Energy – Sierra Pacific Power	●	●		
Oklahoma Gas & Electric	●	●	●	
Sacramento Municipal	●	●		
Vermont Electric Cooperative			●	
TOTAL	**8**	**7**	**2**	**2**

ES Table 2. Summary of utility studies by rate treatment

Many utilities are also including non-rate elements as treatments in their studies that are either offered in conjunction with a time-based rate or on a stand-alone basis. Five utility studies include an offer of some type of in-home display (IHD) and/or programmable communicating thermostat (PCT) treatment (see ES Table 3). One utility (represented by its two subsidiaries) is looking to assess the role of energy education on response and attrition, while another is explicitly focused on feedback from a web portal. The ability of enabling technology to augment customer acceptance and response to time-based rates is another key policy and program design issue for electric utilities and state regulatory commissions; these studies should be able to provide additional insights on this issue.

	IHD	PCT	Education	Web
Detroit Edison	●	●		
FirstEnergy Ohio	●	●		
Green Mountain Power	●			
Lakeland Electric				
Marblehead Municipal				
Minnesota Power				●
NV Energy – Nevada Power		●	●	
NV Energy – Sierra Pacific Power		●	●	
Oklahoma Gas & Electric	●	●		
Sacramento Municipal	●			
Vermont Electric Cooperative				
TOTAL	**5**	**5**	**2**	**1**

ES Table 3. Summary of utility studies by non-rate treatment

1. Introduction

The U.S. Department of Energy's (DOE's) Smart Grid Investment Grant (SGIG) program is working with a subset of SGIG award recipients to assess the response of mass market consumers (i.e., residential and small commercial customers) to time-varying electricity prices (referred to herein as time-based rate programs) in conjunction with the deployment of advanced metering infrastructure (AMI) with two-way communication networks that can record and provide at least hourly interval data and associated technologies. The effort provides an opportunity to advance the electric industry's understanding of consumer behavior. In addition, DOE is attempting to apply a consistent study design and analysis framework for the SGIG Consumer Behavior Studies (CBS). The aim is to collect information across the studies on variables and impacts that have been defined in a consistent manner. This will enable Lawrence Berkeley National Lab (LBNL), as DOE's principal investigator for these Consumer Behavior Studies, to leverage the data from the individual studies and conduct comparative analysis of the impacts of AMI, time-based rate programs and enabling technologies that facilitate customer control, automation and information/feedback on customer energy usage.

To implement such a framework, DOE is requiring the ten utilities undertaking such Consumer Behavior Studies to apply randomized controlled experimental methods in their studies. Evaluations of experiments that employ random selection and random sampling can provide credible estimates of effects. Additionally, data about the customers subjected to the treatments is being collected for the sake of understanding how accurately the estimated effects can be extrapolated to broader populations at the same utilities and populations at other utilities. In other words, the experimental designs of each study will lead to internally valid results and additional data collection will provide an understanding of those results' external validity.

In addition, DOE has encouraged consistency in the research topics included in each of the utility consumer behavior studies in order to increase the depth of knowledge that will be garnered from these studies. To this end, each project is required to include at least one time-based rate treatment in their study.

This report provides information on the scope and approach for each of the eleven SGIG Consumer Behavior Studies.[1] Specifically, the following categories of information are provided for each of the studies:

- Overview – Brief description of the utility and its study;
- Goals and Objectives – Detailed description of what the study seeks to evaluate;
- Treatments of Interest – Detailed description of the specific rate, enabling control and information technologies[2], and energy education elements that are included in the study;
- Experimental design – Detailed assessment of how customers are recruited into and/or assigned to receive the treatments of interest;[3]
- Enrollment incentives and retention activities – Detailed description of any methods used to boost recruitment into the study and maintain customers in the study through its duration;
- Sample Size Requirements and Enrollment Results –Summary of customer counts to compare how the initial sample size requirements (as defined in the approved Consumer Behavior Study Plan) may have differed from the actual enrollment results; and
- Key milestones – Summary of key events in the study and their actual/expected timeline.

In a few cases, utilities encountered problems during implementation that necessitated altering the study's initial design in order to maintain a high probability of achieving most of the study's goals.[4] Our intent is to describe the study that was actually implemented by the utilities, with minimal context for why it might have changed from its original design.

[1] One utility is running an identical study in its two service territories. Thus, we are counting this as two studies emanating from a single utility.

[2] DOE's Smartgrid.gov website uses the term "customer systems" to broadly refer to enabling control and information technology. However, to maintain greater consistency with industry, we will continue to use the latter term throughout this report.

[3] For more detailed technical information about the experimental designs employed by these consumer behavior studies, see Appendix A.

[4] Part of the technical assistance LBNL provided each of the ten utilities included conversations about how best to address any problems that were encountered during the utility's implementation of the study.

As such, we provide little to no commentary or explanation for why changes were made to the study's design as this is ancillary to the goals of this report.[5]

The information contained in this report is based on three key sources of information:

1. Technical Advisory Group (TAG): To assist the study teams in meeting DOE's requirements, LBNL formed technical advisory groups to provide technical assistance and support in a pragmatic and collaborative manner. Individual TAGs worked jointly with each of the SGIG utility's CBS teams. During the design phase of the study, the TAG's goal was to assist the utility's study team in aligning DOE's methodological framework and policy goals with the objectives of the utility and the practical realities of the organizational and regulatory environment in which each utility operated. During the enrollment and implementation phases of the study, the TAG received updates on how the study progressed and provided technical assistance to help utilities address any issues that arose. Finally, during the evaluation phase of the study, each TAG will provide an independent peer review of the utility's evaluation of its CBS to assist the utility in providing an evaluation report filed with DOE that is consistent with DOE guidelines.
2. Consumer Behavior Study Plan (CBSP): Each SGIG consumer behavior study team was required to submit a comprehensive but confidential and proprietary CBSP that was reviewed by the TAG and approved by DOE. In its CBSP, each utility documented the proposed study elements, including: objectives, research hypotheses, sample frame and development approach, enrollment method and experimental treatments. Each utility's CBSP also provides details surrounding the implementation effort, including: schedule for regulatory approval and recruitment efforts; how the study sample will be achieved and maintained throughout the project; and how the data collection processes will be managed.[6] Finally, each utility included a proposed analysis framework to address the set of study objectives in their CBSP.
3. CBS Utilities: Many of the implementation details in this report were provided through personal communications with the utilities themselves.

[5] Each of the ten utilities may undertake a process evaluation in an attempt to identify, among other things, the root causes for challenges that arose during the enrollment and implementation phases of the study. For our purposes, results of these process evaluations may not be readily available because the evaluation has not yet been completed or because such documents are not publicly available. Either way, a determination for why the changes were made in the study designs detract from the primary purpose of this report which is to convey the final design of each of the ten utilities' studies as implemented.

[6] Each utility must also file with DOE a data set that includes customer-level interval meter and demographic data for all study participants that does not contain any personally identifiable information which could link the data to any specific customer. For more information, see DOE (2012b).

4. The ten utilities implementing these eleven studies are all on different time tables. Two utilities have already completed their studies (i.e., Oklahoma Gas & Electric and Marblehead Municipal Light Department). One utility (i.e., NV Energy) has only recently completed recruitment of participants, while the remaining seven utilities have some field experience implementing their study. This report begins with a description of studies that are completely implemented and then progress to studies that are not as far along. Updated versions of this report may be available after key milestones are reached; the dates of key milestones are listed in this report.

2. Oklahoma Gas & Electric

2.1 Overview

Oklahoma Gas & Electric (OG&E) is a summer peaking investor-owned electric utility with ~756,000 customers in its ~30,000 square mile service territory that covers large parts of Oklahoma and western Arkansas. OG&E's SGIG project (Smart Study TOGETHER™) includes a CBS that evaluates customer acceptance and response to different enabling technologies combined with various time-based rates. The utility targeted AMI-enabled residential and small commercial customers in parts of Norman and Oklahoma City, Oklahoma to participate in the study.

2.2 CBS Features

2.2.1 Goals and Objectives

The study centers on evaluating the timing and magnitude of changes in residential and small commercial customers' peak demand and energy usage patterns due to exposure to time-varying rates and enabling technologies. The study tests several combinations of time-of-use (TOU) rate designs with a critical peak price (CPP) overlay and enabling technologies. OG&E is also interested in learning about customer acceptance of both the offered rates and enabling technologies.

2.2.2 Treatments of Interest

OG&E tested two rate designs: a two-period TOU rate with a variable peak pricing (VPP) component and a TOU with a CPP overlay. The VPP and TOU w/CPP overlay utilized a five-hour peak period (2 – 7 p.m.) during non-holiday weekdays in the summer season (June to September), where the VPP peak period price was set to one of four different pre-determined levels with day-ahead (by 5 p.m.) notice. Both rates included a CPP component applicable year-round for events when OG&E required an unexpected reduction in total system load. OG&E provided customers at least two hours notice of critical peak events and each event lasted no more than eight hours. Critical peak events were called under conditions of high expected temperature, high expected system load or to avoid system emergencies.

Control and information technology treatments included the deployment of IHDs and PCTs. In addition, all customers participating in Phase 1 of the study received web portal access, customer support and a variety of education materials. All customers in the service territory received access to the web portal during Phase 2 of the study.

Period	TOU w/CPP	VPP
Off-Peak	4.2	4.5
Low Peak	23.0	4.5
Standard Peak	23.0	11.3
High Peak	23.0	23.0
Critical Event	46.0	46.0

Table 1. OG&E rate levels (¢/kWh)

2.2.3 Experimental Design

The design for the study was a randomized controlled trial (RCT) with denial of treatment for the control group and pre-recruitment assignment (see Figure 1). AMI-enabled residential and small commercial customers in the Norman, OK area who met certain eligibility criteria were stratified and then randomly assigned to one of eight treatment groups or to the control group. These customers received an invitation to opt in to a study where participating customers could receive one of several treatments, with the understanding that this treatment was limited in supply, but were not notified of their assignment at that time. Customers who opted in to the study were then screened and surveyed to ensure that they qualified to receive their assigned treatment. If they were ineligible to receive their assigned treatment, they were reassigned to a treatment they were eligible to receive.[7] All participating customers were then notified of their assigned treatment. OG&E implemented this design in two phases with a different subset of target customers in each phase: Phase I in 2010, and Phase II in 2011.

[7] This re-assignment is not depicted in the figure and does not technically meet the standards of an RCT.

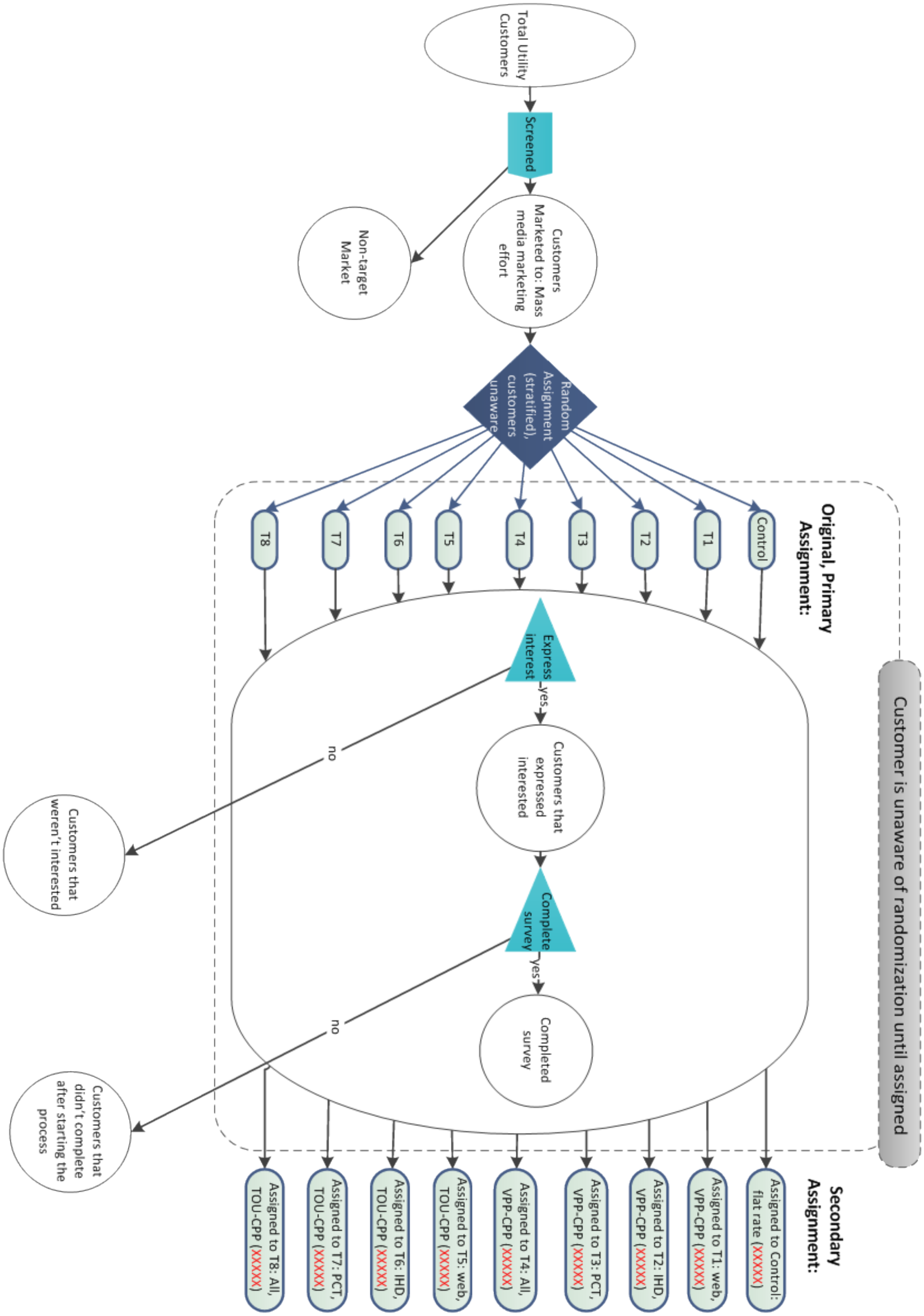

Figure 1. OG&E recruitment process

OG&E recruited customers into the study in two phases, separated by one year. The majority of participating customers received the correct control/information technology. However, in some cases participating customers had the wrong control/information technology installed on their premises. As such, the implementation of the study differed somewhat from the original experimental design.

2.2.4 Enrollment Incentives and Retention Activities

Participating customers received bill protection that ensured during the first twelve months of participation in any of the rate treatments the customer paid no more than what they would have paid under the existing flat rate. After this twelve month period was over, the bill protection was removed.

2.2.5 Sample Size Requirements (Residential only)

Phase I	Control	Web Only	IHD Only	PCT Only	Web & IHD & PCT
Phase I: VPP	480	480	480	480	480
Phase I: TOU w/CPP	480	480	480	480	480
Phase II: VPP	480	480	480	480	480
Phase II: TOU w/CPP	480	480	480	480	480

Table 2. OG&E sample size requirement

2.2.6 Key Milestones

Key Milestones	Target Dates
Study period begins	June 2010
Interim Evaluation Report submitted	January 2011
Study period ends	September 2011
Final Evaluation Report submitted	February 2012

Table 3. OG&E key milestones

3. Marblehead Municipal Light Department

3.1 Overview

Marblehead Municipal Light Department (MMLD) is a summer peaking municipal electric utility with ~10,000 customers (90% are residential) in its 4.5 square mile service territory that covers this coastal suburb north of Boston. MMLD's advanced metering infrastructure project that was co-funded by SGIG includes a consumer behavior study that evaluated customer acceptance of and response to a voluntary flat rate with CPP overlay and various forms of enabling control technologies. The utility targeted residential customers throughout the entire service territory to participate in the study.

3.2 CBS Features

3.2.1 Goals and Objectives

This study focuses primarily on evaluating the timing and magnitude of changes in customers' peak demand and energy usage patterns due to exposure to a flat rate with CPP overlay (Flat w/CPP). MMLD was also interested in assessing residential customer acceptance and retention associated with this type of rate design, as well as how that changed with the introduction of different enabling control technologies and experience with this rate design.

3.2.2 Treatments of Interest

Rate treatments included the application of a Flat w/CPP overlay that utilizes up to a six-hour period (12 – 6 p.m.) for critical events on non-holiday weekdays from June through August. Customers were notified of critical peak events, which were called in conjunction with ISO New England demand response events, by 5 p.m. the day before. Participants would receive notification of up to 12 critical peak events each year of the study.

All customers participating in the study received web portal access, customer support and a variety of education materials. All participants also had access to enabling technologies in the second year of the study to assist in controlling water heaters and air conditioners to better manage electricity bills and respond to critical peak events.

Period	Flat w/CPP
Base	9.0
Critical Event	105.0

Table 4. MMLD rate levels (¢/kWh)

3.2.3 Experimental design

The design for the study involved a randomized controlled trial with delayed treatment for the control group (see Figure 2). Residential customers in this small coastal suburb of Boston who met certain eligibility criteria received an invitation to opt in to a study where participating customers received the Flat w/CPP rate treatment, with the understanding that the application of this treatment could be delayed by one year. At this point, no mention of the enabling technology to be offered in year two of the study was provided. Customers who opted in were randomly assigned to either the rate treatment or their existing flat rate for summer 2011. Random assignment was done within stratification cells, defined based on customer data collected during a survey taken immediately after the opt-in decision. All participating customers received the rate treatment in the second year of the study (i.e., 2012).

In addition to the rate treatment, although no formal experimental design was applied, all participating customers who were eligible, based on survey responses, received an invitation in year 2 of the study to have a free water heater switch or PCT installed by a licensed contractor of their choice.

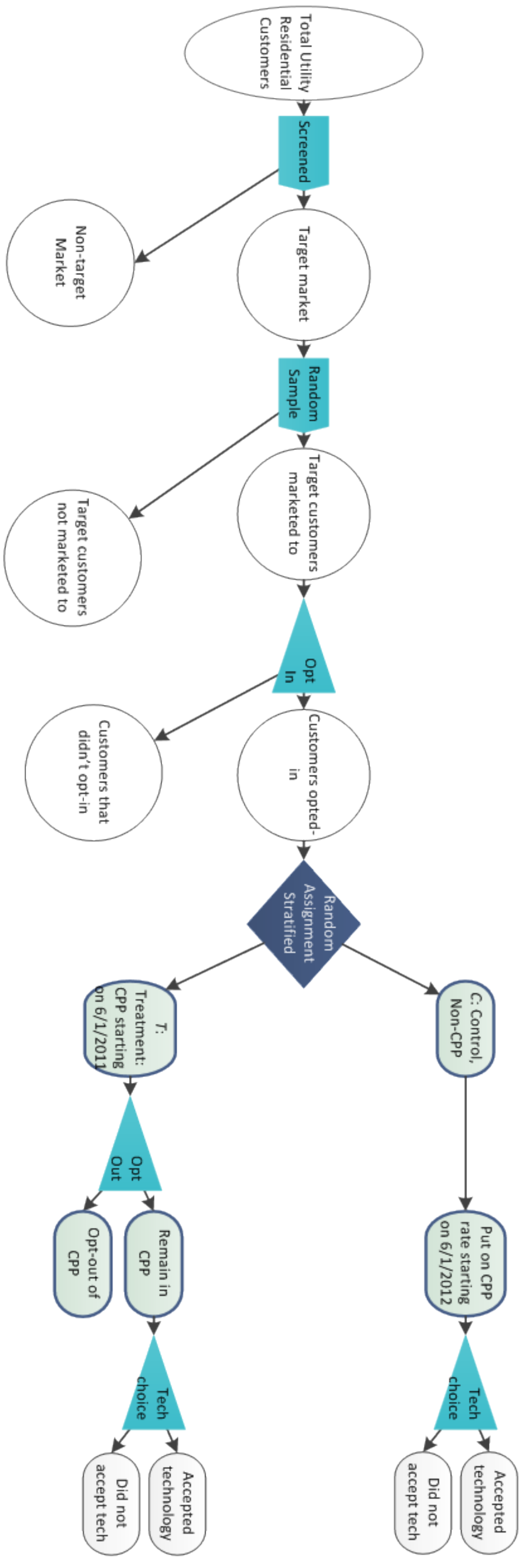

Figure 2. MMLD recruitment process

3.2.4 Enrollment Incentives and Retention Activities

Participating customers received bill protection that ensured that they would pay no more than what they would have paid under the existing flat rate during the first twelve months of participation in the rate treatment. Bill protection was removed after twelve months.

3.2.5 Sample Size Requirements

Experimental Cell	Customers
CPP Rate Treatment in Year 1 and Year 2	250
CPP Rate Treatment in Year 2 Only	250

Table 5. MMLD sample size requirements

3.2.6 Key Milestones

Key Milestones	Target Dates
Study begins	June 2011
Interim Evaluation Report submitted	July 2012
Study ends	May 2013
Final Evaluation Report submitted	July 2013

Table 6. MMLD key milestones

4. Sacramento Municipal Utility District

4.1 Overview

Sacramento Municipal Utility District (SMUD) is a summer peaking municipal electric utility with ~600,000 customers in its ~900 square mile service territory that covers the Sacramento, CA metropolitan area. SMUD's SGIG project (SmartSacramento) includes a consumer behavior study that evaluates customer acceptance and response to enabling technology combined with various time-based rates under different recruitment methods. The utility is targeting AMI-enabled residential customers across the entire service territory to participate in the study.

4.2 CBS Features

4.2.1 Goals and Objectives

This study focuses on evaluating the timing and magnitude of changes in residential customers' peak demand patterns due to exposure to varying combinations of enabling technology, different recruitment methods (i.e., opt-in vs. opt-out), and several time-based rates. SMUD is also interested in learning about customer acceptance of the different time-based rates under the alternative recruitment methods.

4.2.2 Treatments of Interest

Rate treatments include the implementation of three time-based rate programs in effect from June through September: a two-period TOU rate that includes a three-hour on-peak period (4 - 7 p.m.) each non-holiday weekday; a CPP overlaid on their flat underlying rate; and a TOU with CPP overlay (TOU w/CPP). Customers participating in any CPP rate treatments receive day-ahead notice of critical peak events, called when wholesale market prices are expected to be very high and/or when system emergency conditions are anticipated to arise. CPP participants will be exposed to 12 critical peak events during each year of the study.

Control/information technology treatments include the deployment of IHDs. SMUD is offering IHDs to all opt-out customers in any given treatment group and to more than half of the opt-in customers in the treatment group. All participating customers receive web portal access, customer support and a variety of education materials.

Period	Flat w/CPP	TOU	TOU w/CPP
Base (<700 kWh)	8.5		
Base (>700 kWh)	16.7		
Off-Peak (<700 kWh)		8.5	7.2
Off-Peak (>700 kWh)		16.6	14.1
Peak		27.0	27.0
Critical Event	75.0		75.0

Table 7. SMUD rate levels (¢/kWh)

4.2.3 Experimental design

Due to the variety of treatments, the study includes three different experimental designs: randomized controlled trial with delayed treatment for the control group, randomized encouragement design (RED) and within-subjects design (see Figure 3).

In all three cases, AMI-enabled residential customers in SMUD's service territory are initially screened for eligibility and then randomly assigned to one of the seven treatments or the RED control group.

For the two treatments that are included in the RCT "Recruit and Delay" study design, customers receive an invitation to opt in to the study where participating customers receive an offer for a specific treatment. Upon agreeing to join the study, customers are told if they are to begin receiving the rate in the first year of the study (i.e., June 2012) or in the summer after the study is complete (i.e., June 2014).

For two of the three treatments that are included in the RED, customers are told that they have been assigned to a specific identified treatment but have the ability to opt out of this offer. Those who do not opt out receive the indicated treatment for the duration of the study. Those who opt out are nonetheless included in the study's evaluation effort but do not receive the indicated treatment. For one of the three RED treatments, customers receive an invitation to opt in to the study where participating customers receive a specific treatment. Customers that opt in are then assigned to receive the treatment in year 1 of the study (i.e., 2012).

For the two treatments that are included in the within-subject design, customers are told they have been assigned to either the Flat w/CPP treatment or the TOU w/CPP treatment with technology.[8] In the former case, customers only have the ability to opt in to this specific treatment. In the latter case, customers only have the ability to opt out of this specific treatment.

[8] The within-subjects method was designed to use no explicit control group; instead it estimates the effects of the treatment for each participant individually, using observed electricity consumption behavior both before and after becoming a participant in the study as well as on critical peak event and non-event days. However, the control group selected for the RED design may be used as a control group.

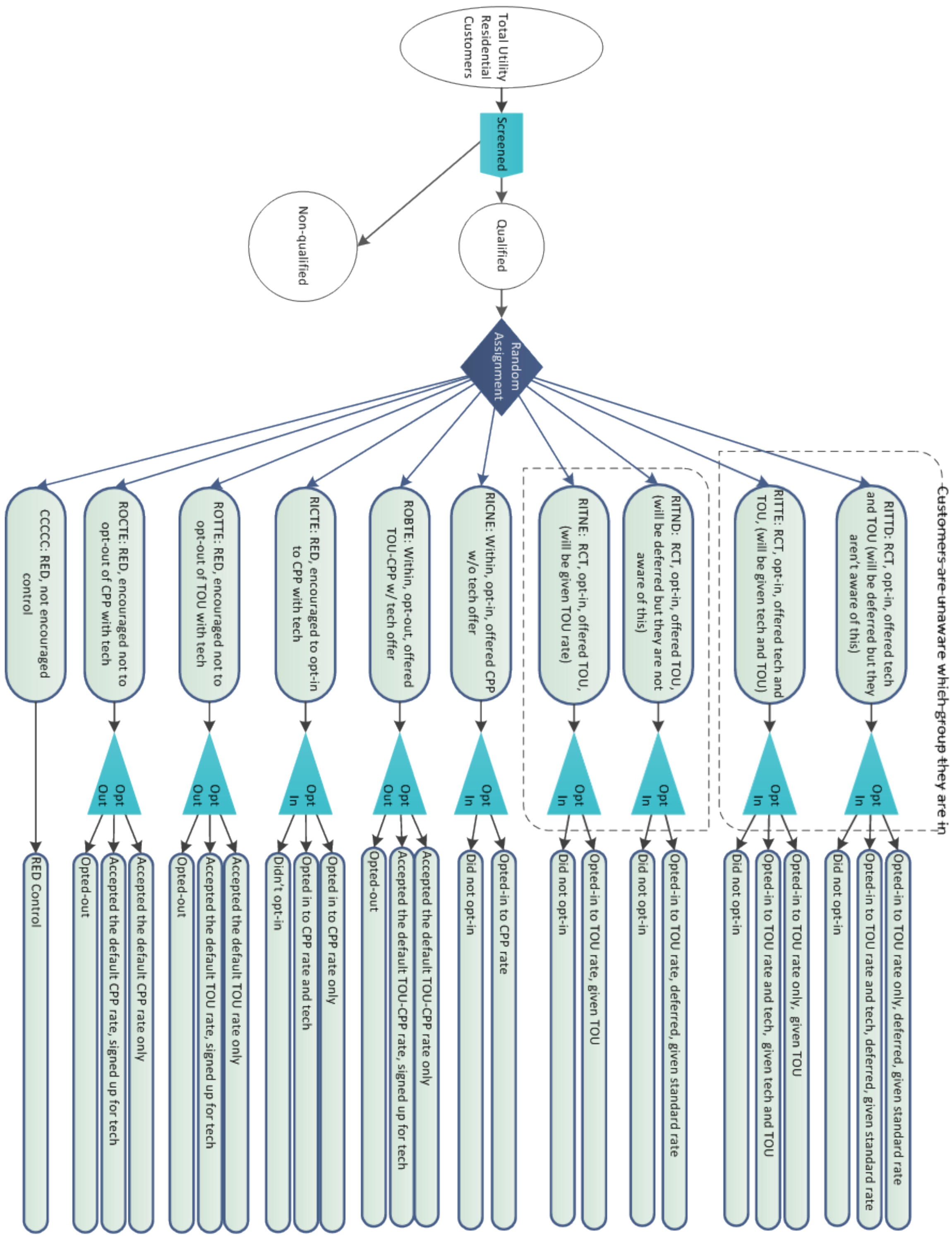

Figure 3. SMUD recruitment process

4.2.4 Enrollment Incentives and Retention Activities

None

4.2.5 Sample Size Requirements

Experimental Cell	Year 1 & 2	After Study Ends
TOU w/o IHD Opt-In RCT	1,178	1,178
TOU w/IHD Opt-In RCT	1,963	1,963
TOU w/IHD Opt-Out RED	1,240	n/a
TOU w/CPP w/IHD Opt-Out Within-Subjects	375	n/a
Flat w/CPP w/o IHD Opt-In Within-Subjects	188	n/a
Flat w/CPP w/IHD Opt-In RED	1,131	n/a
Flat w/CPP w/IHD Opt-Out RED	431	n/a
Control	37,682	n/a

Table 8. SMUD sample size requirements

4.2.6 Key Milestones

Key Milestones	Target Dates
Study begins	June 2012
Interim Evaluation Report submitted	April 2013
Study ends	September 2013
Final Evaluation Report submitted	January 2014

Table 9. SMUD key milestones

5. Detroit Edison Company

5.1 Overview

Detroit Edison Company (DECo) is a summer peaking investor-owned electric utility with ~2.1 million customers in its ~7,600 square mile service territory that covers southeast Michigan. DECo's SGIG project (SmartCurrents℠ Smart Home) includes a consumer behavior study that evaluates customer acceptance and response to a three-period TOU rate with a CPP overlay, enabling technologies and information feedback. The utility is targeting residential customers in the part of its service territory where AMI has been installed for least six months prior to the commencement of recruitment into the study. Customers in this part of DECo's service territory generally use more electricity and have higher incomes than the utility's average residential customer population.

5.2 CBS Features

5.2.1 Goals and Objectives

This study focuses on evaluating the timing and magnitude of changes in residential customers' peak demand and energy usage patterns due to exposure to a three period TOU rate with a CPP overlay, use of enabling control technologies and access to various information feedback technologies. DECo is also interested in learning about customer acceptance of the various types of enabling control and information feedback technologies.

5.2.2 Treatments of Interest

Rate treatments include the implementation of a three-period TOU rate with a CPP overlay (TOU w/CPP) during the peak period (weekdays and non-holidays 3 – 7 p.m.). The shoulder period encompasses the hours between 7 a.m. and 3 p.m., and between 7 and 11 p.m., weekdays and non-holidays. Critical peak events are announced with day-ahead notice to participating customers. Up to 20 critical peak events can be called each year.

Control/information technology treatments include the deployment of IHDs and programmable controllable thermostats. In addition, all customers participating in the study receive web portal access, customer support and a variety of education materials.

Period	TOU w/CPP
Off-Peak	4.0
Shoulder	7.0
Peak	12.0
Critical Event	100.0

Table 10. DECo rate levels (¢/kWh)

5.2.3 Experimental design

The study design is a randomized controlled trial with denial of treatment for the control group (see Figure 4). A simple random sample of AMI-metered residential customers in the service territory who meet certain eligibility criteria will receive an invitation to opt in to the study where participating customers could receive one of several treatments, with the understanding that this treatment is limited in supply. Customers who opt in are then screened and surveyed to ensure that they qualify to potentially receive a treatment.

Those who self-identify as having central air conditioning are randomly assigned either to a control group or to receive an offer to opt in to one of four studies, each of which takes service under a TOU w/CPP rate design and includes an offer of either no technology, an IHD only, a PCT only, or an integrated PCT with IHD.

Those who self-identify as not having central air conditioning are randomly assigned either to a control group or to receive an offer to opt in to one of two studies, each of which take service under a TOU w/CPP rate design and include an offer of either no technology or an IHD.

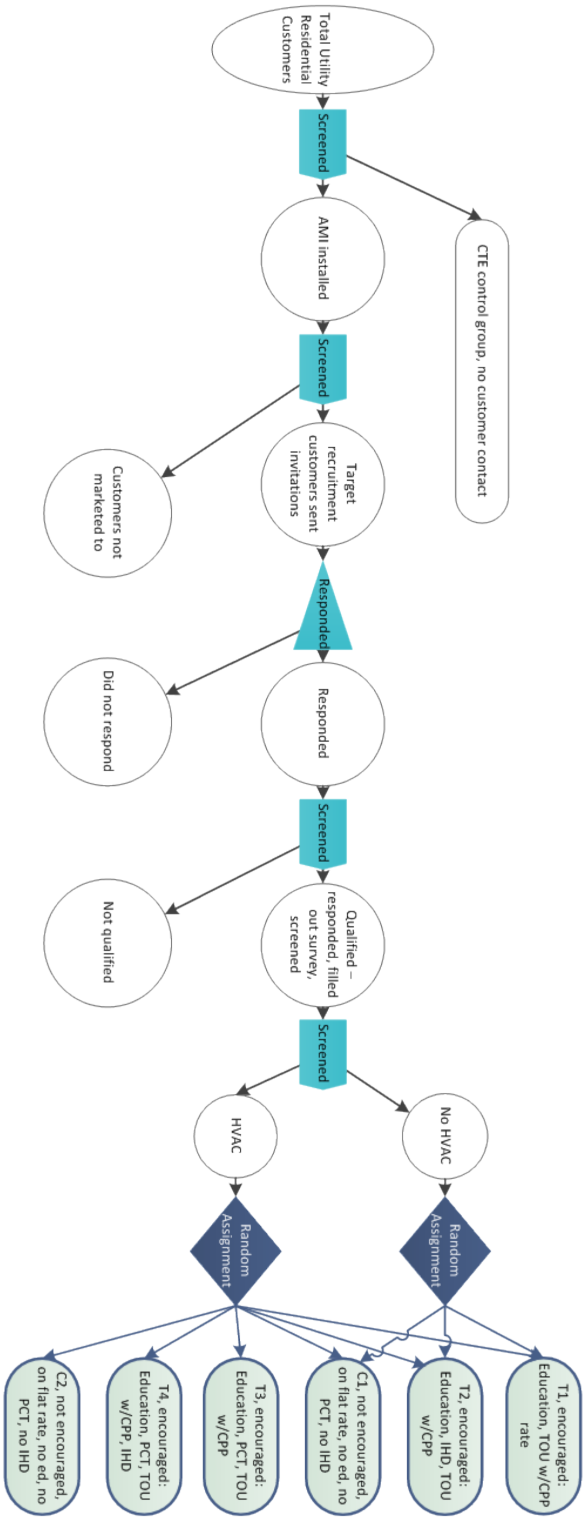

Figure 4. DECo recruitment process

5.2.4 Enrollment Incentives and Retention Activities

Customers are provided with shadow billing comparisons to familiarize them with the financial implications of time-based rates relative to their old flat rate.

5.2.5 Sample Size Requirements

Presence of Central Air Conditioning (CAC)	No IHD (& PCT)	IHD (& PCT)	Control
w/o CAC	375	375	375
w/CAC	375	375	375

Table 11. DECo Sample Size Requirements

5.2.6 Key Milestones

Key Milestones	Target Dates
Study begins	January 2012
Interim Evaluation Report submitted	December 2012
Study ends	December 2013
Final Evaluation Report submitted	February 2014

Table 12. DECo Key Milestones

6. Cleveland Electric Illuminating Company

6.1 Study Abstract

The Cleveland Electric Illuminating Company (CEIC), a FirstEnergy (FE) company, is a summer peaking investor-owned utility with ~750,000 customers in its ~1,680 square miles service territory that covers the northwest corner of Ohio (i.e., Cleveland and its environs). CEIC's SGIG project (Smart Grid Modernization Initiative) includes a consumer behavior study that evaluates customer acceptance of and response to different levels of enabling technologies combined with various time-based rate programs. The utility is targeting AMI-enabled residential customers in the suburbs east of Cleveland for the study.

6.2 CBS Features

6.2.1 Goals and Objectives

This study focuses on evaluating the timing and magnitude of changes in customers' peak demand and energy usage patterns due to exposure to several different designs of a CPR and use of various enabling control technologies. CEIC is also interested in learning about customer acceptance of the various enabling control technologies.

6.2.2 Treatments of Interest

Rate treatments include the implementation of a CPR that provides a payment to customers for reducing electric load during declared critical peak events, while the price charged by CEIC for electricity consumed stays at the customers' existing flat rate (Flat w/CPR). CEIC's original plans included testing two levels of rebate (40 ¢/kWh and 80 ¢/kWh) and two critical peak periods (four hours and six hours) within the hours of 1 and 7 p.m. during weekday non-holidays in the summer season (June to August). Customers receive day-ahead notification of critical peak events and can receive such notification up to 15 times per year.

Control/information technology treatments include the deployment of IHDs; direct load control devices for air conditioners, water heaters and pool pumps; and a PCT. The thermostat has two treatment methods: (1) PCTs under customer control and; (2) utility-controlled PCTs. These devices, in conjunction with customer web portal access, facilitate information exchange and enable customers to better manage their electricity bills through improved understanding of electricity consumption patterns of appliances and equipment. All participating customers receive web portal access, customer support and a variety of education materials.

Due to recruitment efforts that fell short of planned experimental cell requirements, CEIC chose to drop 12 of the 16 rate and technology treatments in order to provide the best opportunity for sufficiently precise impact estimates. CEIC restricted the scope of the study to a Flat w/CPR with a $0.40/kWh rebate with either: a four hour event duration that could be paired with an IHD or customer-controlled PCT; or a four- or six-hour event duration that could be paired with a utility-controlled PCT.

Period	Flat w/CPR (1)	Flat w/CPR (2)
Base	n/a*	n/a*
Critical Event	40.0	80.0

* Retail competition exists in CEIC's service territory so Base energy charges depend upon the entity supplying electricity to the participating customer.

Table 13. CEIC rate levels (¢/kWh)

6.2.3 Experimental design

The design for the pilot involves a randomized encouragement design, where customers are randomly assigned to either be offered a treatment or not offered a treatment. Data from customers who are offered a specific treatment but eschew the offer are nonetheless included in the study's evaluation effort, as well as data from the customers who were randomly assigned not to be offered a treatment (see Figure 5).[9]

All residential customers in several adjacent suburbs in the service territory who respond to a survey are pre-qualified to potentially receive an offer of treatment.

[9] In a randomized encouragement design, customers are "encouraged" to take up the treatment but some may not do so. The evaluation of the treatment effect in such a design necessitates including both the customers who actually took up the treatment and those who did not. In aggregate, this "treatment" group can be compared against a randomly drawn control group from the general population, which would likewise be comprised of those who, if given the offer of treatment, would accept it as well as those who would reject the offer. This randomly drawn control group from the customer population is therefore, in expectation, an unbiased counterfactual to the behavior of the aggregate "treatment" group.

Those who self-identify as having central air conditioning are randomly assigned either to a control group or to receive an offer to opt in to a study where they receive a PCT and take service under a Flat w/CPR rate design. Those who opt in are then given the choice to receive either the utility-controlled or customer-controlled PCT but are randomly assigned to one of the available Flat w/CPR rate treatments.

Those who self-identify as not having central air conditioning are randomly assigned either to a control group or to receive an offer to opt in to a study where they take service under a Flat w/CPR rate design. Those who opt in are then randomly assigned to one of the available Flat w/CPR rate treatments.

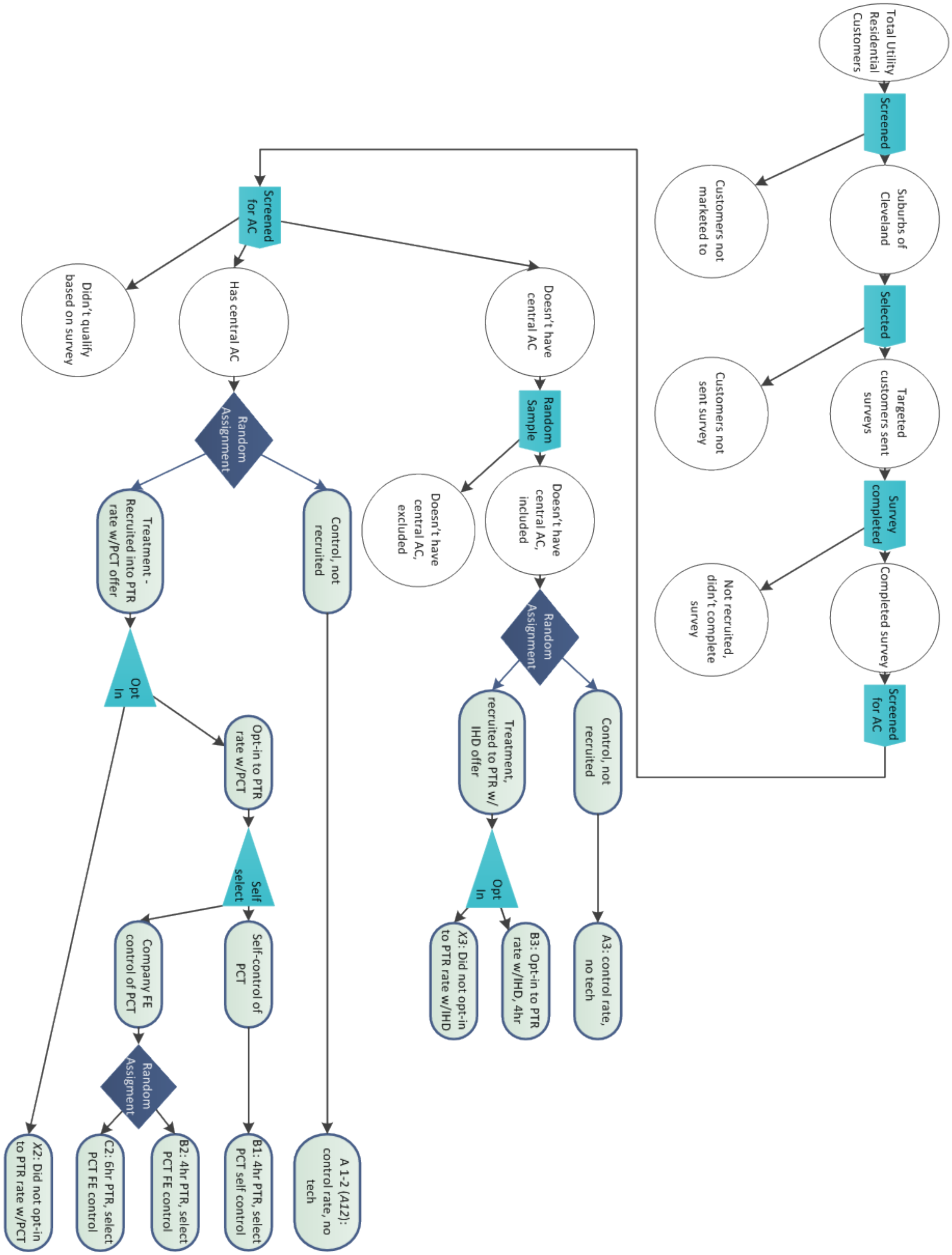

Figure 5. CEIC recruitment process

6.2.4 Enrollment Incentives and Retention Activities

None

6.2.5 Sample Size Requirements

Experimental Cell		Power Switch	Customer Controlled PCT	Utility Controlled PCT	IHD
CPR 40¢/kWh	4-hour event	260	173	173	260
	6-hour event	260	173	173	260
CPR 80¢/kWh	4-hour event	260	173	173	260
	6-hour event	260	173	173	260
Control		280	280		280

Table 14. CEIC sample size requirements

6.2.6 Key Milestones

Key Milestones	Target Dates
Study begins	June 2012
Interim Evaluation Report submitted	September 2012
Study ends	August 2014
Final Evaluation Report submitted	September 2014

Table 15. CEIC key milestones

7. Green Mountain Power

7.1 Study Abstract

Central Vermont Public Service, now Green Mountain Power (GMP), is a summer peaking investor-owned electric utility with ~250,000 customers in its service territory that covers most of Vermont. GMP is one of 20 utility participants in the Vermont SGIG project (named eEnergy Vermont) and one of two utilities performing consumer behavior studies. The GMP study evaluates customer acceptance and response to different time-based rates coupled with information feedback treatments under different transition strategies towards more time-based rates. The utility is targeting AMI-enabled residential customers in the Rutland area for participation in the study; a county with a slightly older and lower-income population than the rest of the state.

7.2 CBS Features

7.2.1 Goals and Objectives

This study focuses primarily on the timing and magnitude of changes in residential customers' peak demand due to exposure to either CPP or CPR. GMP is also interested in understanding customer preferences for different transition strategies towards more time-based rates.

7.2.2 Treatments of Interest

Rate treatments include the application of time-based rates and rebate designs. The utility is implementing a critical peak rebate that provides a payment to customers for reducing electric load during declared critical peak events, while the price charged by GMP for electricity consumed stays at the customers' existing flat rate (Flat w/CPR). In addition, GMP is implementing a CPP rate design that slightly lowers the customers' existing standard flat rate but augments it with a substantially higher price overlay during declared critical peak events (Flat w/CPP). Both the Flat w/CPR and Flat w/CPP rates are in effect year-round and critical peak events, which can be called on weekdays between the hours of

1 and 6 p.m., are declared based on wholesale market conditions, coincident with the ISO New England annual system peak, which has traditionally occurred in the summer.[10]

Control/information technology treatments include the deployment of IHDs. This technology acts as a means for viewing site-level electricity consumption information but also provides the customer with notification of a declared critical event. All participating customers receive direct notification (e.g., email, text, voice message) of peak events, web portal access to interval meter data, customer support and a variety of education materials.

Period	Flat w/CPP	Flat w/CPR
Base	14.184	14.557
Critical Event	60.000	60.000

* Retail competition exists in FE's service territory so Base energy charges depend upon the entity supplying electricity to a customer.

Table 16. GMP rate levels (¢/kWh)

7.2.3 Experimental design

The design for the pilot is a randomized controlled trial with denial of treatments for the control group and pre-recruitment assignment (see Figure 6). AMI-enabled customers in the Rutland, VT area who meet certain eligibility criteria are randomly assigned to either one of the two control groups (differing by customers' awareness about the study and critical peak events) or one of the six treatment groups. In addition, there is one unaware control group of customers who were never contacted; this group consists of customers that might have qualified for the study (based on their rate category) but were not selected for recruitment into one of the other treatment or control cells. These customers, except those assigned to the unaware control group, receive an invitation to opt in to the study where participating customers could receive one of several treatments, with the understanding that this treatment is limited in supply, but are not notified of their assignment at this time. Customers who opt in are then screened and surveyed to ensure that they qualify to potentially receive a treatment. Those who do are then notified of their assignment to one of the treatment or control cells. Customers assigned to the Flat w/CPP treatment cell must opt-in (agree) to this rate change. Customers assigned to the Flat

[10] In order to ensure enough events are called to accommodate robust load impact estimates, GMP may declare critical peak events on days not expected to be coincident with the ISO New England annual system peak

w/CPR treatment cell or one of the control cells are simply told of their assignment, and so may opt-out if they choose. The pilot transitions customers in two treatment groups from the Flat w/CPR in year one of the study (2012) to a Flat w/CPP rate design in year two (2013), while the remaining customers are exposed to their specific rate treatments for two full years (2012 and 2013).

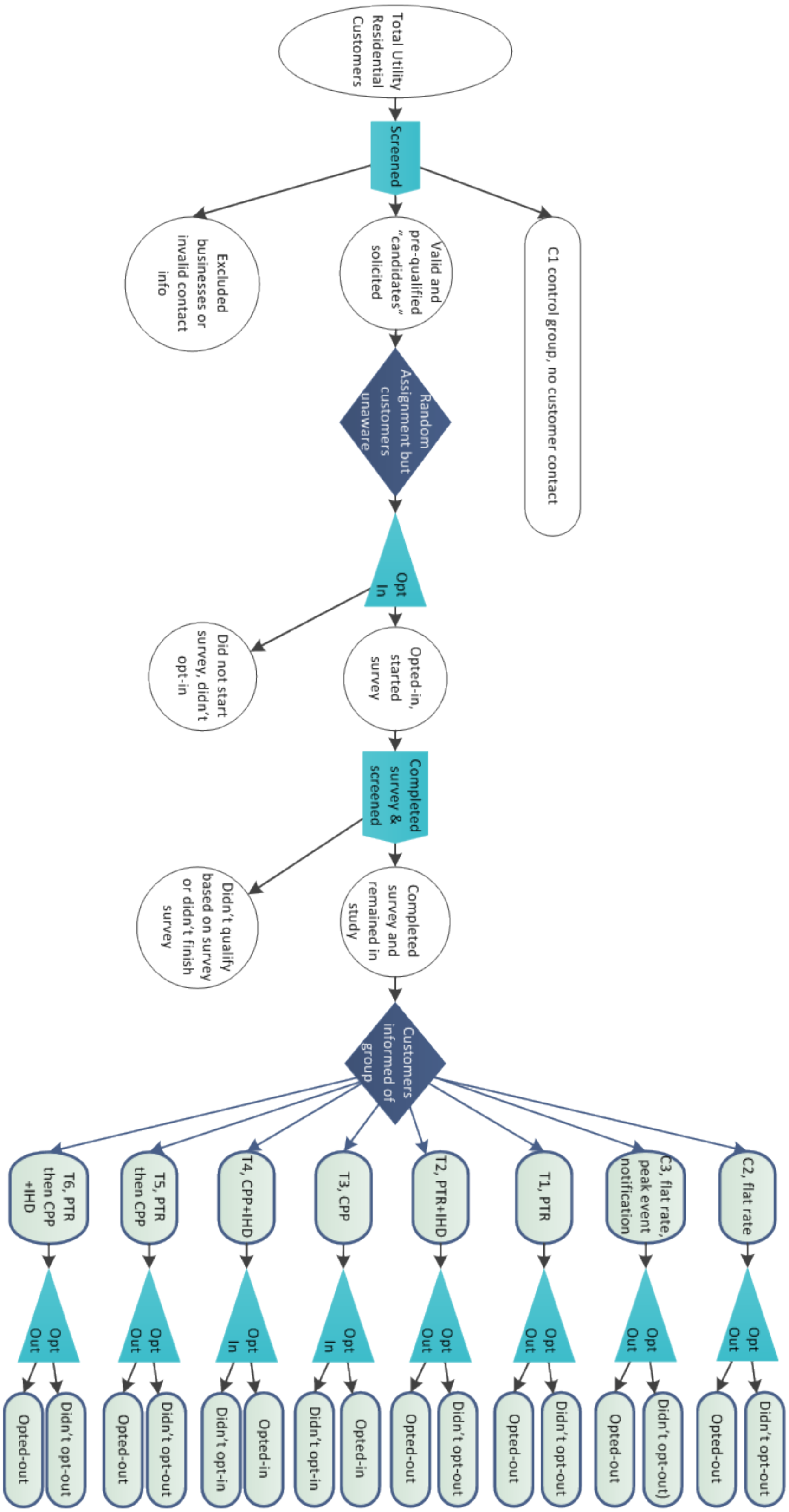

Figure 6. GMP recruitment process

7.2.4 Enrollment Incentives and Retention Activities

None

7.2.5 Sample Size Requirements

Experimental Cell		No IHD	IHD
CPR in 2012 & 2013		390	195
CPR in 2012 & CPP in 2013		390	195
CPP in 2012 & 2013		390	195
Control	Unaware of study	1,200	n/a
	Aware of study	390	n/a
	Aware of events	390	n/a

Table 17. GMP sample size requirements

7.2.6 Key Milestones

Key Milestones	Target Dates
Study begins	June 2012
Interim Evaluation Report submitted	June 2013
Study ends	May 2014
Final Evaluation Report submitted	November 2014

Table 18. GMP key milestones

8. Lakeland Electric

8.1 Overview

Lakeland Electric (LE) is a winter peaking municipal electric utility with ~120,000 customers in its ~260 square mile service territory that covers the city of Lakeland, Florida. The utility's SGIG project includes a consumer behavior study that evaluates customer acceptance of and response to a seasonal three-period TOU rate under different enrollment approaches. The utility is targeting AMI-enabled residential customers throughout the service territory for participation in the study.

8.2 CBS Features

8.2.1 Goals and Objectives

This study focuses primarily on evaluating the timing and magnitude of changes in residential customers' peak demand and energy usage patterns due to exposure to a seasonal three-period TOU rate. LE is also interested in assessing residential customer acceptance, retention and response associated with different enrollment approaches (opt in and opt-out) to the seasonal three-period TOU rate.

8.2.2 Treatments of Interest

Rate treatments include a seasonal three-period TOU rate, where the definition of the peak period (weekdays and non-holidays) differs between summer (2 – 8 p.m. April – October) and winter months (6 – 10 a.m. November – March) as does the definition of the shoulder period (Summer: 12 Noon – 2 p.m. April – October; Winter: 10 a.m. – 12 Noon & 7 – 10 p.m. November – March).

All customers participating in the study receive web portal access, customer support and a variety of education materials.

Period	TOU
Off-Peak	2.435
Shoulder	7.420
Peak	11.130

Table 19. LE rate levels (¢/kWh)

8.2.3 Experimental design

The design for the study is a randomized controlled trial with delayed treatment for the control group. Two different enrollment approaches are tested: opt-in and opt-out (see Figure 7).

LE first randomly allocates ~75% of the eligible AMI-enabled residential customers in the service territory to a pool of study participants. From this pool, LE then randomly allocates 90% for inclusion in the opt-in part of the study, leaving the remaining 10% to be eligible for the opt-out part of the study, subject to the provisions described below.

Opt-in: The pool of eligible AMI-enabled residential customers in the service territory allocated for this part of the study receive an invitation to opt in to the study where participating customers receive the rate treatment, with the understanding that the application of this treatment could be delayed by one year. Customers who opt in are then randomly assigned either to receive the rate treatment or to remain on their existing inclining block rate (IBR). Those who remain on the existing IBR act as a control group during 2012 for those immediately assigned to the treatment. All participating customers receive the rate treatment in the second year of the study (i.e., 2013).

Opt-out: The pool of eligible AMI-enabled residential customers in the service territory allocated for this part of the study receive notification that they have been chosen to participate in a study where participating customers receive the rate treatment. Customers who don't opt out are then randomly assigned either to receive the rate treatment or to remain on their existing inclining block rate. Those who remain on their existing IBR act as a control group during 2012 for those immediately assigned to the treatment. All participating customers receive the rate treatment in the second year of the study (i.e., 2013).

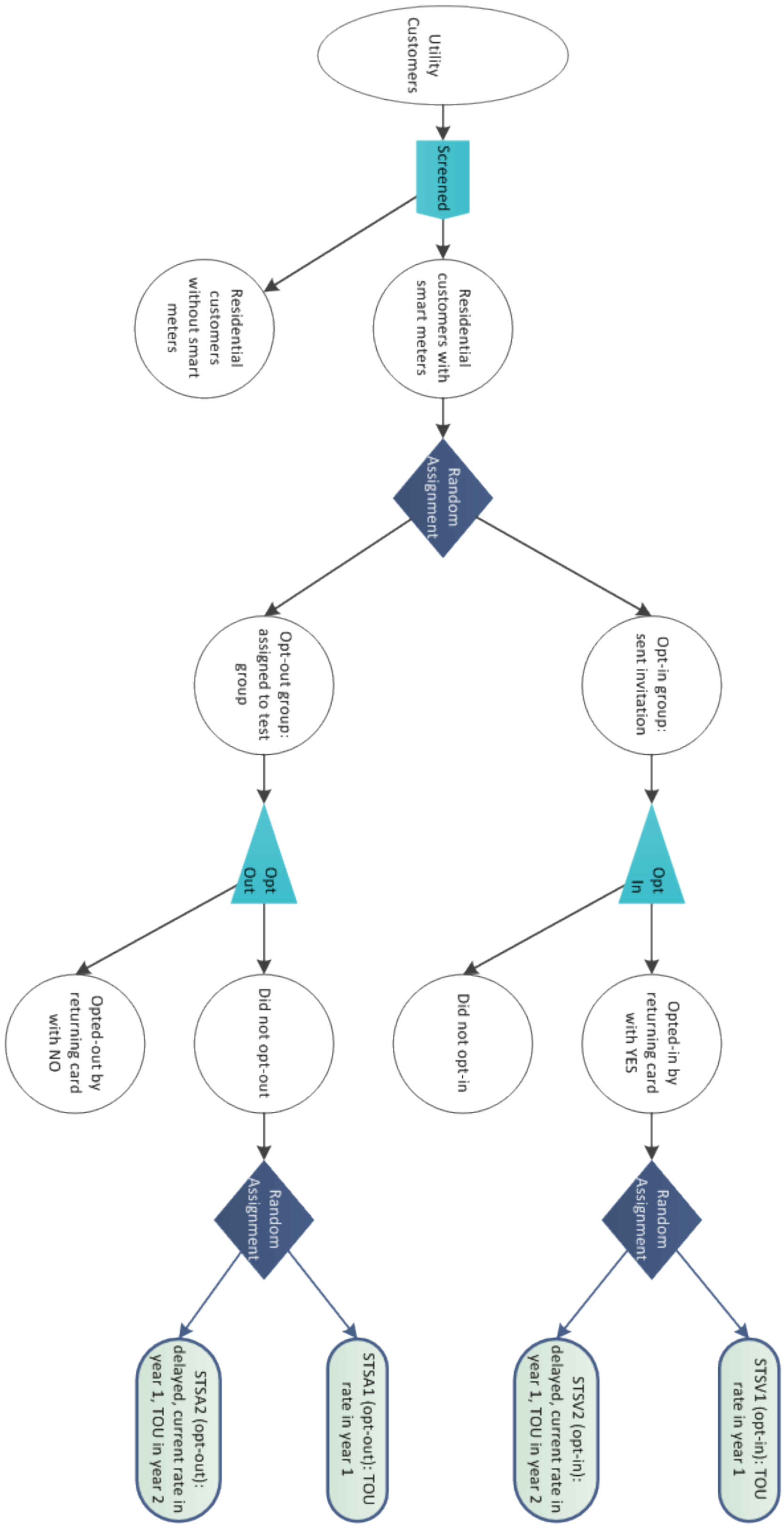

Figure 7. LE recruitment process

8.2.4 Enrollment Incentives and Retention Activities

Participating customers receive bill protection that ensures that they pay no more than what they would have paid under the existing flat rate during the first six months of participation in the rate treatment. After this six month period is over, the bill protection is removed.

Participating customers will also receive enhanced bills that include shadow billing comparisons to familiarize them with the financial implications of time-based rates relative to their existing inclining block rate.

8.2.5 Sample Size Requirements

Experimental Cell	Opt-In	Opt-Out
TOU Rate Treatment in Year 1 and 2	600	600
TOU Rate Treatment in Year 2 Only	600	600

Table 20. LE sample size requirements

8.2.6 Key Milestones

Key Milestones	Target Dates
Study begins	April 2012
Interim Evaluation Report submitted	July 2013
Study ends	March 2014
Final Evaluation Report submitted	September 2014

Table 21. LE key milestones

9. Minnesota Power

9.1 Overview

Minnesota Power (MN Power) is a winter peaking investor-owned electric utility with ~145,000 customers in its ~26,000 square mile service territory that covers central and northeastern Minnesota. The utility's SGIG project includes a two phase consumer behavior study. The first (Phase One) evaluates customer acceptance to various forms and timing of information feedback about electricity consumption, while the second (Phase Two) evaluates customer response to a TOU rate with a CPP overlay. The utility is targeting residential customers in the Duluth/Hermantown area for both phases of the study; an area with a slightly older and higher-income population than the rest of the state.

9.2 CBS Features

9.2.1 Goals and Objectives

MN Power is implementing two phases of their consumer behavior study which address different goals and objectives.

In Phase One, the study centers primarily on customer preferences for various electricity usage feedback approaches that are higher in latency (e.g., daily vs. monthly) and resolution (e.g., hourly vs. monthly) compared to what customers currently receive. MN Power is also interested in evaluating the timing and magnitude of changes in customers' energy usage patterns due to the various feedback approaches.

In Phase Two, the study centers primarily on evaluating the timing and magnitude of changes in customers' peak demand due to exposure to a TOU rate with a CPP overlay (TOU w/CPP). MN Power is also interested in learning about customers' willingness to accept and remain on a TOU rate with CPP overlay.

9.2.2 Treatments of interest

MN Power is implementing a two period TOU rate that augments its existing flat rate and includes a 13 hour on-peak period (i.e., 8 a.m. – 10 p.m.) each weekday. In addition, MN Power is testing the effects of substituting, during various blocks of the on-peak period, a higher price on critical peak event days (TOU w/CPP). Customers receive day-ahead notice of critical peak events, called when a major energy event is taking place in the Midwest Independent System Operator markets or on MN Power's system. Participants will be exposed to no more than 160 hours of critical peak events each year of the study.

Control/information technology treatments include the deployment of an enhanced web-portal with access to meter data at a variety of levels of resolution and latency: 1) monthly aggregated data provided on a monthly basis (this will be the control cell); 2) daily aggregated data provided on a daily basis; or 3) hourly aggregated data provided on a daily basis (requires installation of an AMI smart meter). In addition, a treatment was planned to include IHDs (which require the installation of an AMI smart meter) with hourly aggregated meter data on an hourly basis. Due to recruitment efforts that fell short of planned experimental cell requirements, MN Power chose to drop the IHD treatment. All customers participating in the study receive customer support and a variety of education materials.

Period	TOU w/CPP†
Off-Peak	-2.990
Peak	1.415
Critical Event	77.000

† Rate levels represent adders to existing volumetric retail rates, which are largely based on an inclining block design.

Table 22. MN Power rate levels (¢/kWh)

9.2.3 Experimental design

Phase One of the study is a randomized controlled trial with denial of treatment for the control group (see Figure 8). All residential customers in the Duluth/Hermantown area who meet certain eligibility criteria receive an invitation to opt in to a study where participating customers can gain access to a web portal and receive one of three information feedback treatments. Customers who opt in are surveyed, stratified and then randomly assigned to receive one of the three web portal information feedback treatments.

Due to recruitment efforts that fell short of planned experimental cell requirements, MN Power augmented the existing study sample. All AMI-enabled residential customers who passed up the original offer to join the Phase One study were stratified and randomly assigned to receive one of the three information feedback treatments. These customers are notified of this opportunity, effectively allowing them to opt out of the treatment by choosing to not access the information now made available to them via the web portal.

Phase Two of the study is a within subjects design. All customers with installed AMI meters as well as residential customers in the Duluth/Hermantown area who meet certain eligibility criteria to have an AMI meter installed receive an invitation to opt in to a study where participating customers receive the rate treatment for one year. A limited number of AMI meters are available to be installed for those who opt in to this phase of the study but don’t currently have one.

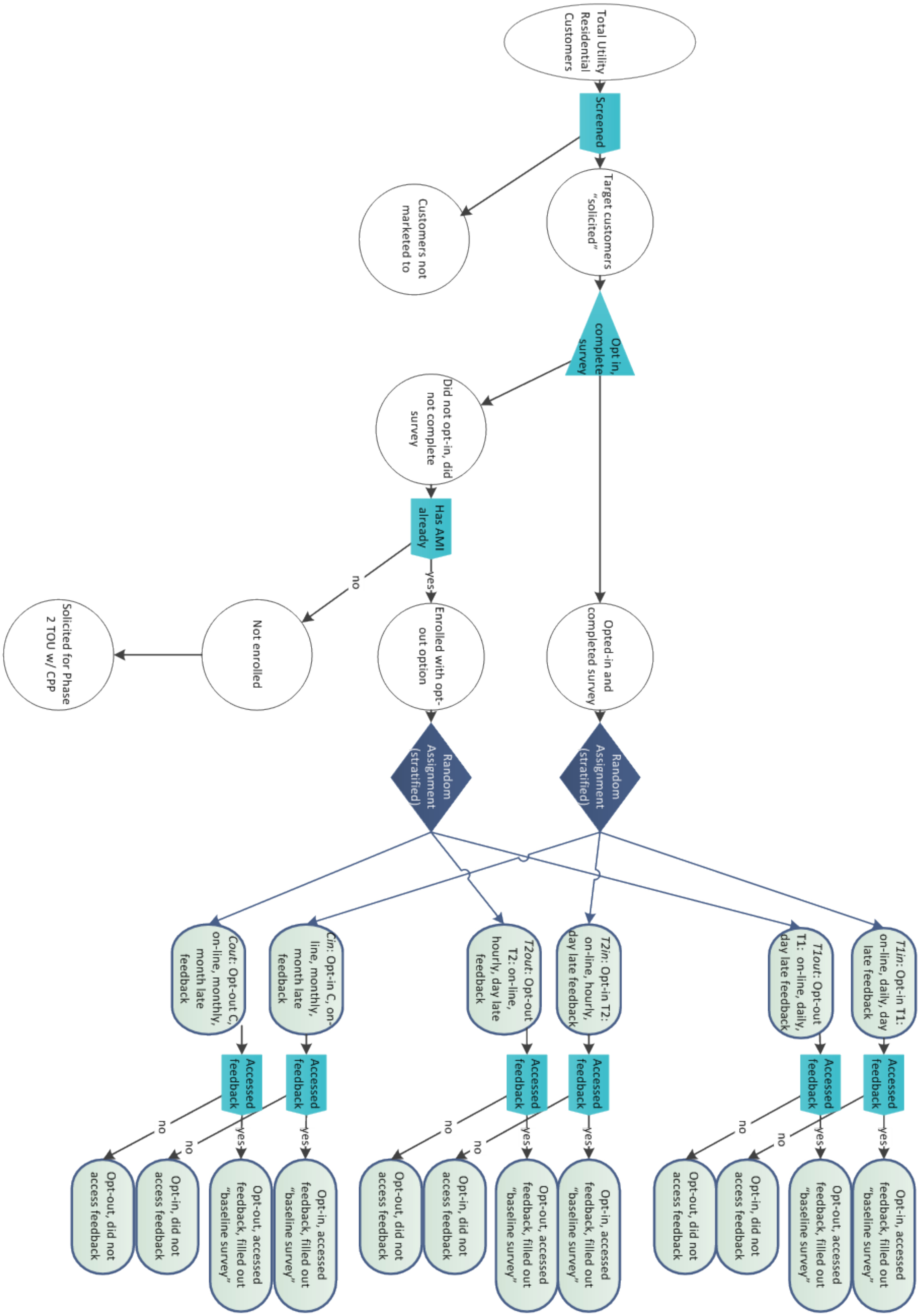

Figure 8. MN Power recruitment process

9.2.4 Enrollment Incentives and Retention Activities

None

9.2.5 Sample Size Requirements

Phase One

Experimental Cell	Opt-In	Opt-Out
Monthly feedback data provided monthly (Control)	1,000	768
Daily feedback data provided daily	675	768
Hourly feedback data provided daily	675	768
IHD (Control)	1,000	n/a
IHD (Treatment)	675	n/a

Table 23. MN Power Phase One sample size requirements

Phase Two[11]

Experimental Cell	Opt-In
TOU with CPP overlay	n/a

No specific sample size requirements were developed due to the type of experimental design used.

Table 24. MN Power Phase Two sample size requirements

9.2.6 Key Milestones

Key Milestones	Target Dates
Phase One study period begins	March 2012
Interim Evaluation Report submitted	March 2013
Phase Two study period begins	May 2013
Phase One and Two study period ends	March 2014
Minnesota Power provides Final Evaluation Report	June 2014

Table 25. MN Power key milestones

[11] MN Power has not set any recruitment goals for Phase Two of the study at this time, but can accommodate up to 4,770 customers, based on AMI smart meters available for the study.

10. Vermont Electric Cooperative

10.1 Study Abstract

Vermont Electric Cooperative (VEC) is a winter peaking electric cooperative with ~34,000 customers in its ~2,100 square mile service territory that covers northern Vermont. This utility is part of the eEnergy Vermont SGIG project which includes two consumer behavior studies. This one evaluates customer acceptance of and response to a three-period, TOU rate with variable peak pricing component, enhanced customer service-based information feedback and various enabling technologies. The utility is targeting all residential customers throughout the service territory for participation in the study.

10.2 CBS Features

10.2.1 Goals and Objectives

This study focuses on evaluating the timing and magnitude of changes in customers' peak demand and energy usage patterns due to exposure to a three-period TOU rate with variable peak prices, enhanced customer service-based information feedback and various types of enabling control and information technologies. VEC is also interested in learning about customer acceptance of the rate under customer service-based information vs. technology-based information.

10.2.2 Treatments of Interest

Rate treatments include the application of a three-period TOU rate with a variable peak pricing (VPP) component, where the peak period price changes hourly to reflect the ISO New England (ISO-NE) day-ahead market Vermont load zone locational marginal price of electricity for that hour. The definition of each period differs seasonally. During the summer months (April – September), the peak period covers weekdays and non-holidays 11 – 5 p.m.; the shoulder period covers weekdays and non-holidays 5 – 10 p.m.; and off-peak period covers all other hours. During the winter months (October – March), the peak period covers weekdays and non-holidays 4 – 8 p.m.; the shoulder period covers weekdays and non-holidays 11 a.m. – 4 p.m. and 8 – 10 p.m.; and off-peak period covers all other hours.

Control/information technology treatments include the deployment of IHDs, proactive customer service and home energy management systems.

VEC is augmenting the web portal access that all participating customers receive with IHDs or proactive customer service methods as various feedback channels to provide customers with consumption information and notification of peak events. VEC considered a full HEMS, including PCTs and/or other wireless devices that enable control of various plug-loads. Due to cost considerations, VEC decided to drop the HEMS control technology treatment from the study before recruitment began.

Period	VPP
Off-Peak	12.844
Shoulder	15.730
Peak†	19.168

† Rate level represents an adder to the hourly ISO-NE Vermont load zone day-ahead locational marginal price, where the total applicable retail peak period electricity rate will be set at a minimum of 26.343 ¢/kWh .

Table 26. VEC rate levels (¢/kWh)

10.2.3 Experimental design

The design for the pilot is a randomized controlled trial with denial of treatment for the control group (see Figure 9). A simple random sample of AMI-enabled residential customers in the service territory who meet certain eligibility criteria receive an invitation to opt in to the study where participating customers could receive one of several treatments, with the understanding that these treatments are limited in supply. Customers who opt in are then screened and surveyed to ensure that they qualify to potentially receive a treatment. Those who do are then randomly assigned to one of the three treatments or the control group. The pilot transitions all treatment customers from their existing flat rate to the VPP rate in May of 2013; all control customers will remain on their existing flat rate throughout the duration of the study.

Due to attrition problems experienced in the first few months of the study that led to questions about the comparability of the customers in the control group to the remaining pool of treatment customers, VEC decided to alter the experimental design. In order to provide the best opportunity to estimate sufficiently precise load impacts due to the VPP rate, VEC will be instituting a second study. All AMI-enabled residential customers in the service territory who meet certain eligibility criteria (i.e., excluding all of those customers who were exposed to treatment in the original study, but including the customers who were assigned to the control group) will receive an invitation to opt in to a new study where participating customers will be randomly assigned to either receive the VPP rate treatment starting in May of 2013 or remain on their flat rate (i.e., randomized controlled trial with denial of treatment for the control group).

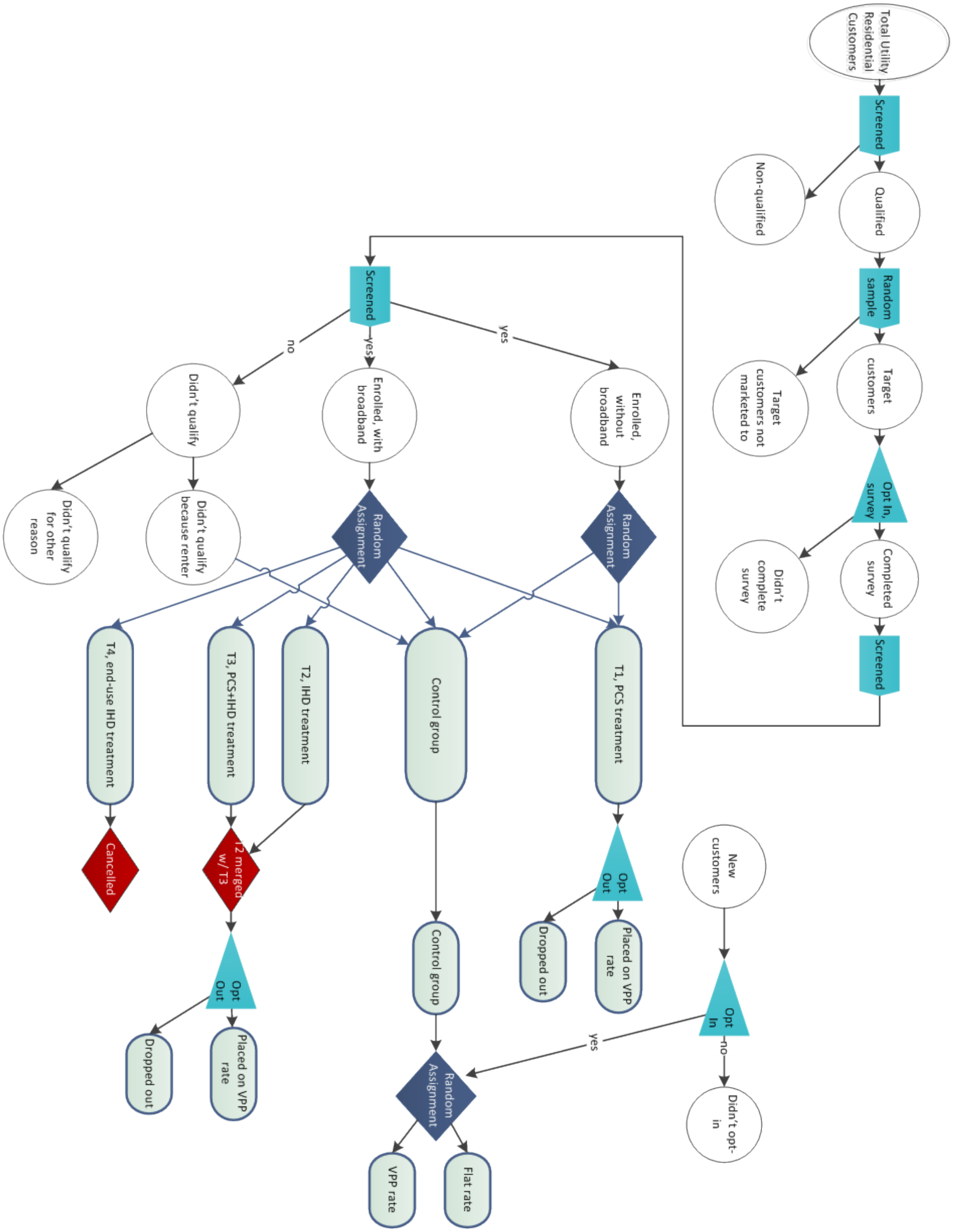

Figure 9. VEC recruitment process

10.2.4 Enrollment Incentives and Retention Activities

As an incentive to participate in the first study, those who completed the qualification survey, which dictated eligibility for the study, received an entry into a drawing for a free iPad. Neither incentives nor retention activities are undertaken in the second study.

10.2.5 Sample Size Requirements

Experimental Cell	No IHD	IHD	HEMS
No Proactive Customer Service	n/a	377	222
Proactive Customer Service	698	359	n/a
Control	2,500	n/a	n/a

Table 27. VEC sample size requirements (study one)

Experimental Cell	Opt-In
VPP	950
Control	950

Table 28. VEC sample size requirements (study two)

10.2.6 Key Milestones

Key Milestones	Target Dates
Study begins	February 2012
Interim Evaluation Report submitted	March 2013
Study ends	May 2014
Final Evaluation Report submitted	August 2014

Table 29. VEC key milestones

11. NV Energy: Nevada Power and Sierra Pacific Power

11.1 Study Abstract

NV Energy (NVE) is a summer peaking investor-owned electric utility with ~2.4 million customers in its ~46,000 square mile service territory. NVE's SGIG project (NVEnergize) includes the Nevada Dynamic Pricing Trial (NDPT) which is a consumer behavior study that evaluates customer acceptance and response to different combinations of enabling technologies, seasonal multi-period TOU rate with CPP overlay and energy education efforts.[12] NVE is targeting AMI-enabled residential customers in both its northern Nevada (i.e., Sierra Pacific Power or SPP) and southern Nevada (Nevada Power or NVP) service territories to participate in the study.

11.2 CBS Features

11.2.1 Goals and Objectives

This study focuses on evaluating the timing and magnitude of changes in residential customers' peak demand and energy usage patterns due to exposure to a seasonal multi-period TOU rate with CPP overlay. NVE is also interested in assessing residential customer acceptance, retention and response associated with enabling technology and energy education efforts.

11.2.2 Treatments of Interest

Rate treatments include the application of a multi-period TOU rate that utilizes a five-hour on-peak period (2 – 7 p.m. at NVP; 1 – 6 p.m. at SPP) with rates that differ depending on the time of year (Shoulder summer- June and September, Core summer - July and August, and Winter - October – May at NVP; Core summer - July – September and Winter - October – June at SPP). The shoulder period, which is only applicable in SPP, covers weekdays and non-holidays 10 a.m. – 1 p.m. and 6 p.m. – 9 p.m. NV Energy is augmenting the TOU rate with a substantially higher critical peak price overlay (TOU w/CPP) during a 4-hour weekday critical peak period in the summer (June – September 3 – 7 p.m. at NVP; July –

[12] Although the NDPT encompasses more treatments than are described here, LBNL chose to focus only on the three treatments that are the primary focus of DOE and the TAG.

September 2 – 6 p.m. at SPP). The CPP overlay is applied with day-ahead notice to participating customers when forecasted temperatures, system load or wholesale market prices are expected to be very high and/or when system emergency conditions are anticipated to arise. Study participants can be exposed to no more than 18 events each year of the study (18 events at NPV; 16 events at SPP).

Control/information technology treatments include the deployment of PCTs. In addition, all customers participating in the study receive web portal access.

Education treatments augment the customer web portal access with a curriculum designed to educate customers about energy, energy usage, energy costs and rates and energy management. Study participants in NV Energy's enhanced education treatments are being provided with information, examples, training and feedback through a combination of written and online materials and experiences.

Period	**TOU w/CPP (NVP)**	**TOU w/CPP (SPP)**
Shoulder Summer Off-Peak	7.333	
Shoulder Summer Peak	12.670	
Shoulder Summer Critical Event	43.962	
Core Summer Off-Peak	7.333	6.898
Core Summer Shoulder	n/a	21.309
Core Summer Peak	38.081	34.435
Core Summer Critical Event	75.920	58.093
Winter Off-Peak	7.333	6.898
Winter Peak	7.333	10.219

Table 30. NV Energy rate levels (¢/kWh)

11.2.3 Experimental design

The study uses a randomized encouragement design (see Figure 10 and Figure 11). A stratified random sample of AMI-enabled customers in the service territory who meet certain eligibility criteria are assigned to one of two pools of customers: one acts as the control group (i.e., remain on the existing flat rate without receiving an invitation for the time-based rate, technology or enhanced education) while the other receives an invitation to opt in to the study where participating customers receive a single specific offer of treatment that is a combination of the rate, control/information technology and/or education material. Offers to participate in the study for the specific identified treatment are made at random to customers from the pool until the samples are filled or the pool is exhausted. Data from customers who are offered the specific identified treatment but eschew the offer are nonetheless included in the study's evaluation effort, as well as data from customers in the control group who are not offered the treatments.[13] All customers who opt in to the study by accepting their treatment offer are then screened to ensure they qualify to potentially receive a treatment.

[13] In a randomized encouragement design, customers are "encouraged" to take up the treatment but some may not do so. The evaluation of the treatment effect in such a design necessitates including both the customers who actually took up the treatment and those who did not. In aggregate, this "treatment" group can be compared against a randomly drawn control group from the general population, which would likewise be comprised of those who, if given the offer of treatment, would accept it as well as those who would reject the offer. This randomly drawn control group from the customer population is therefore, in expectation, an unbiased counterfactual to the behavior of the treatment group.

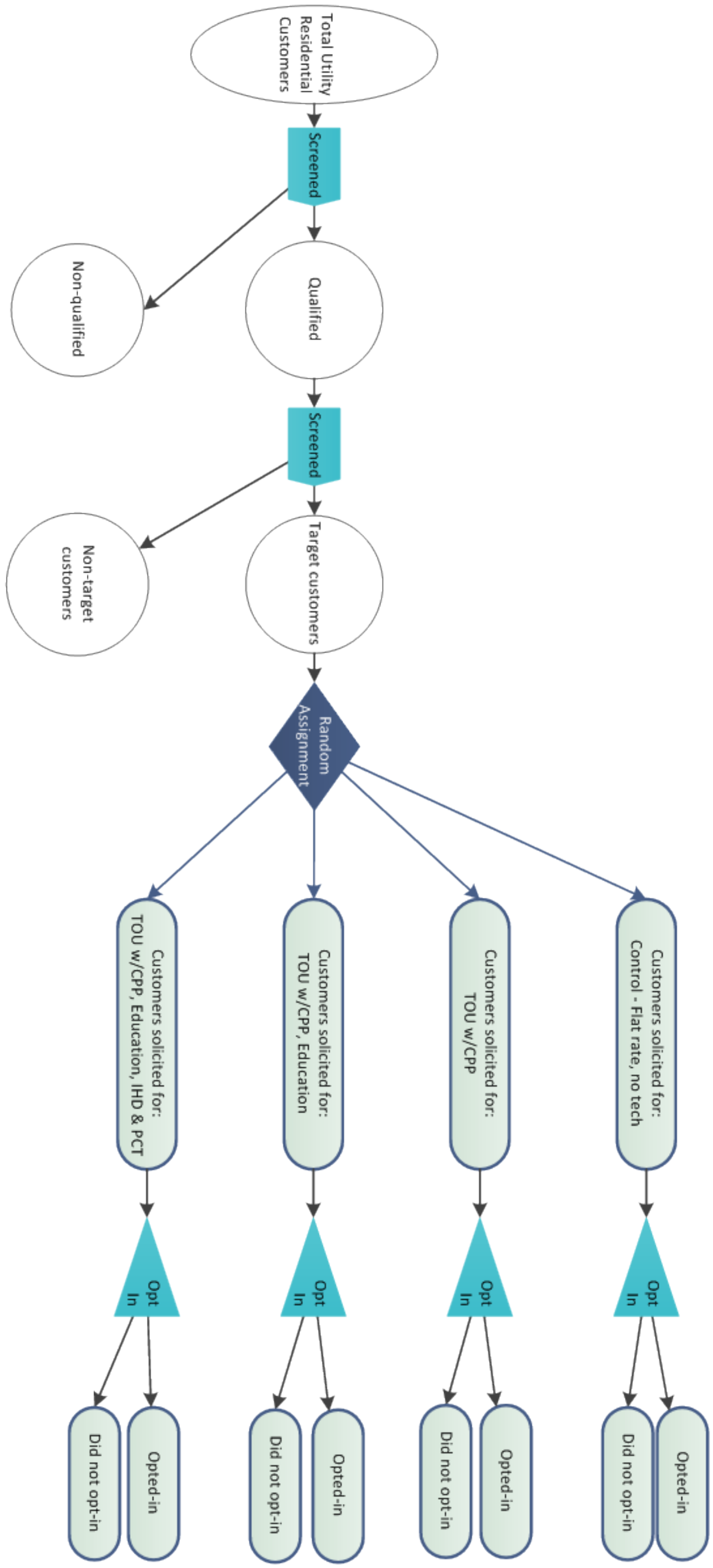

Figure 10. NVE recruitment process (SPP)

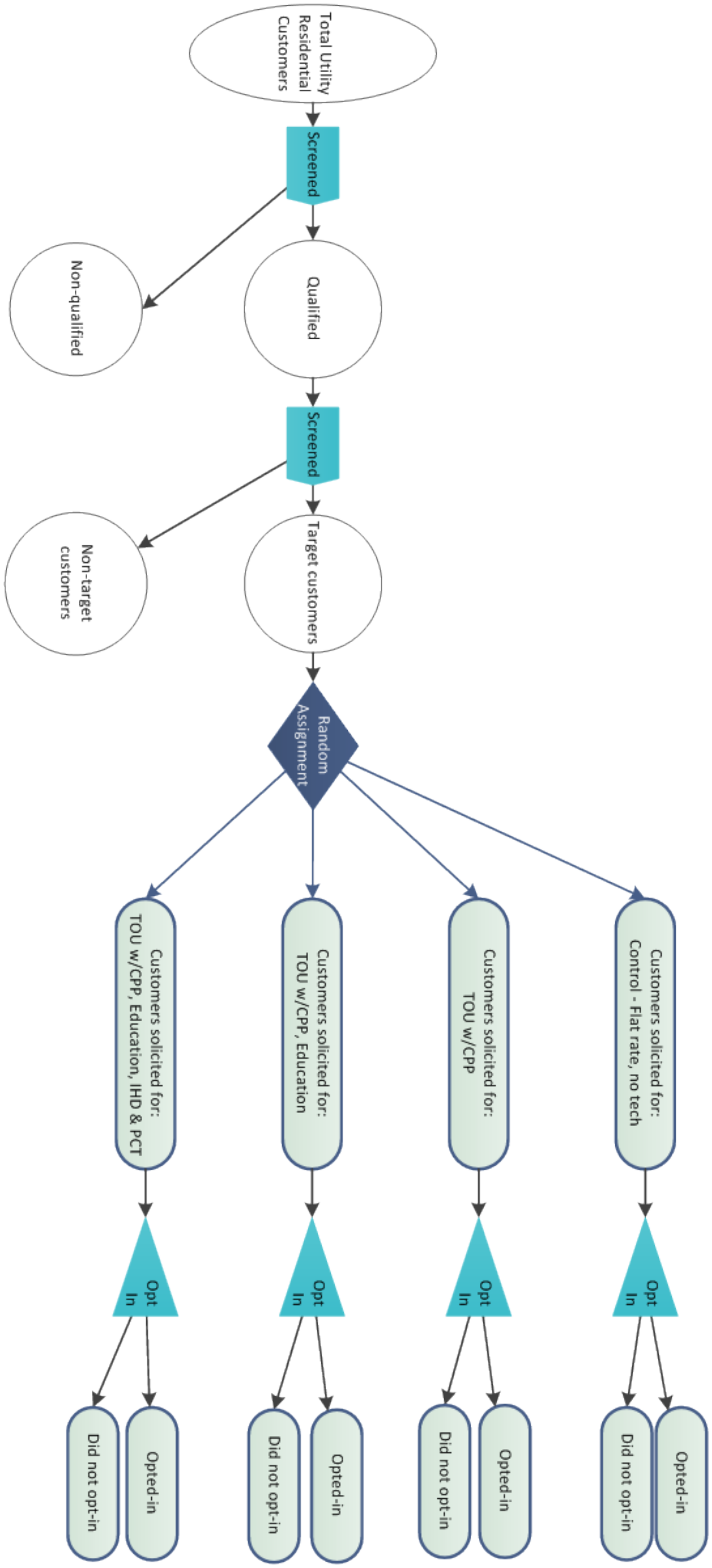

Figure 11. NVE recruitment process (NVP)

11.2.4 Enrollment Incentives and Retention Activities

Participating customers receive bill protection that ensures that they pay no more than what they have would have paid under the existing flat rate during the first twelve months of participation in any rate treatment. After this twelve month period is over, the bill protection is removed.

11.2.5 Sample Size Requirements

Experimental Cell	NVP	SPP
TOU w/CPP	496	248
TOU w/CPP & Enhanced Education	496	248
TOU w/CPP & Enhanced Education & Enabling Technology	496	248
Control	4,960	2,480

Table 31. NVE sample size requirements

11.2.6 Key Milestones

Key Milestones	Target Dates
Study begins	March 2013
Interim Evaluation Report submitted	September 2014
Study ends	February 2015
Final Evaluation Report submitted	September 2015

Table 32. NVE key milestones

12. Discussion and Conclusions

The DOE SGIG program is co-funding ten utilities to implement eleven consumer behavior studies that focus on a broad array of issues that examine the impacts of exposing residential (and to a very limited extent, small commercial) customers to time-based rates and enabling technology between 2010 and 2015. The utilities running these experiments range from small municipal entities (e.g., Marblehead Municipal Light Department with ~10,000 residential customers) to large investor-owned utilities (e.g., Detroit Edison with ~1.9 M residential customers). There is much that these studies share in common but they also have their unique differences as well, reflecting specific elements each utility wanted to focus their research efforts upon.

All utility studies are using some form of an opt-in recruitment effort, although three are augmenting this with an opt-out approach to study differences in recruitment methods (see Table 33). These latter utilities (e.g., Lakeland Electric, Minnesota Power and Sacramento Municipal Utility District) are testing the same program design elements in both an opt-in and opt-out environment, which will allow each utility and LBNL to assess customer preferences for and response to the same rates and technology under these two different recruitment methods.[14] This is a major issue for utilities and state regulatory commissions as they grapple with how time-based rates should be introduced to electric customers; through voluntary programs that customers must select and opt in, which is the traditional approach, or as the default or standard rate design (i.e., opt-out). Gaining a better understanding of customer acceptance and retention with opt-in and opt-out recruitment methods should provide policymakers, regulatory commissions and utilities with additional information with which to make more informed decisions on this topic.

[14] MN Power is only testing its information feedback treatments in both an opt-in and opt-out environment. The rate treatments are exclusively implemented as an opt-in enrollment opportunity.

	Opt-In	Opt-Out
Detroit Edison	●	
FirstEnergy Ohio	●	
Green Mountain Power	●	
Lakeland Electric	●	●
Marblehead Municipal	●	
Minnesota Power	●	●
NV Energy – Nevada Power	●	
NV Energy – Sierra Pacific Power	●	
Oklahoma Gas & Electric	●	
Sacramento Municipal	●	●
Vermont Electric Cooperative	●	
TOTAL	**11**	**3**

Table 33. Summary of utility studies by enrollment method

Seven utility studies are looking at evaluating acceptance of and response to TOU rates (see Table 34) . All except one of these studies includes a CPP overlay on this TOU rate to see how this augments peak period load reductions. Several utility studies are focusing on CPR programs layered on top of the existing flat/block rate. In one study, the utility is testing the response to CPP and CPR as single treatments in the study, but also as treatments that customers are exposed to in sequential years (CPR in year 1 and CPP in year 2). Two utility studies are using a novel rate design (variable peak pricing or VPP) that looks like TOU rate but the peak price changes daily to reflect exigent system costs and reliability conditions. Collectively, these utilities are implementing rate designs and recruitment methods that are at the forefront of policy discussions about what default service should look like for residential customers.

	CPP	TOU	VPP	CPR
Detroit Edison	●	●		
FirstEnergy Ohio				●
Green Mountain Power	●			●
Lakeland Electric		●		
Marblehead Municipal	●			
Minnesota Power	●	●		
NV Energy – Nevada Power	●	●		
NV Energy – Sierra Pacific Power	●	●		
Oklahoma Gas & Electric	●	●	●	
Sacramento Municipal	●	●		
Vermont Electric Cooperative			●	
TOTAL	**8**	**7**	**2**	**2**

Table 34. Summary of utility studies by rate treatment

Many utilities are also including non-rate elements as treatments in their studies that are either offered in conjunction with a time-based rate or on a stand-alone basis. Five utility studies include an offer of some type of IHD and/or PCT treatment (see Table 35). One utility (represented by its two subsidiaries) is looking to assess the role of energy education on response and attrition, while another is explicitly focused on feedback from a web portal. The ability of enabling technology to augment customer acceptance and response to time-based rates is another key policy and program design issue for electric utilities and state regulatory commissions; these studies should be able to provide additional insights on this issue.

	IHD	PCT	Education	Web
Detroit Edison	●	●		
FirstEnergy Ohio	●	●		
Green Mountain Power	●			
Lakeland Electric				
Marblehead Municipal				
Minnesota Power				●
NV Energy – Nevada Power		●	●	
NV Energy – Sierra Pacific Power		●	●	
Oklahoma Gas & Electric	●	●		
Sacramento Municipal	●			
Vermont Electric Cooperative				
TOTAL	**5**	**5**	**2**	**1**

Table 35. Summary of utility studies by non-rate treatment

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Appendix A: Experimental Design

Edited excerpt from "U.S. Department of Energy Smart Grid Investment Grant Technical Advisory Group Guidance Document #7: Design and Implementation of Program Evaluations that Utilize Randomized Experimental Approaches, November 8, 2010" (DOE 2010) [15]

A.1 Incorporating Randomization into Program Evaluation Design and Implementation

In addition to testing the impact of time-based rates and enabling technologies on electricity consumption patterns, eight studies are also explicitly testing how successful different types of program offers are at recruiting customers. For example, in one study with a time-based rate program, customers were r

In order to obtain internally valid estimates of how an intervention (e.g., dynamic pricing, real time information provision) affects household-level outcomes of interest (such as hourly or daily energy consumption), one needs an unbiased estimate of the household-level behaviors that would have been observed in the absence of the intervention. One approach involves comparing household energy expenditures and related outcomes before and after the intervention. However, this comparison will capture not only the effects of the intervention, but also the effects of other variables that change over time. For example, a before-and-after comparison could under-estimate the effects of a dynamic pricing program if weather were systematically more extreme, or if energy prices were lower and households consumed more, in the year following the intervention.

Multiple regression models can be used to try to control for differences in underlying time trends. There are several reasons why this could be particularly challenging in this context. The best case scenario is that the researcher has access to household-level demographics such as the age and number of household members, employment information, living patterns (e.g., people at home during the day, occupant schedules), as well as detailed information about equipment and appliance ownership (e.g., size, type, number, energy efficiency, and age of different appliances, heating and cooling equipment). However, these household characteristics change over time, and it is unusual to do the kind of in-depth,

[15] For an overview of implementing and evaluating program impacts, see Duflo et al. (2007)

repeated surveying that would be required to control in the regression for changes over time in these characteristics. Moreover, estimation results may be sensitive to the choice of functional form when modeling the relationship between energy consumption and observed time-varying factors.

Changes in energy consumption at participating households can be compared with changes in energy consumption at a set of observationally similar households before and after the program is introduced. Absent randomization, this kind of non-experimental difference-in-difference (DID) comparison yields a credible estimate only if the time-varying factors are unlikely to vary substantially (e.g., if the treatment effect is large enough and if the comparison of interest is to be made over a short interval of time).

Where panel micro-data are available, researchers typically improve the fit of their regressions dramatically by including household fixed effects. It is important to emphasize that household fixed effects can control only for time invariant factors. For example, many of the features of the home itself (e.g. type of home, number of floors, outside wall construction material, ceiling height, number of windows, etc.) are largely time invariant and fixed. Concerns arise with DID when there are time varying factors that differ between the treatment and the control group. Households who choose to participate in dynamic pricing programs are likely to have differences in some factors that vary with time along both observable and unobservable dimensions, and non-experimental DID is therefore unlikely to be credible.

Observable differences in time varying factors across treatment and control groups can be difficult to interpret. For example, when households in the treatment group are observed purchasing energy efficient appliances more frequently than households in the control group, is this the causal impact of the treatment or selection (i.e. that these households who chose to participate in the dynamic pricing program are different)? Perhaps more importantly, the validity of the DID estimates will be undermined if unobserved changes in household energy use over the study period are correlated with the decision to select into the program. A striking finding in electricity regressions is that even after controlling for a rich set of observable characteristics, there are large differences in electricity consumption between households.[16] Even small differences in underlying unobservable trends can confound the effects we are interested in detecting over time. This is more problematic if

[16] For example, see Allcott (2011).

we are interested in measuring how responses evolve over several months or years. As the time horizon of interest gets longer, it becomes more difficult to know what changes were driven by treatment and what changes were driven by differences in the myriad of other unobservable factors that change over time and impact electricity consumption.

A.2 Randomized Control Trials

Randomized control trials (RCTs) are widely viewed as the "gold standard" of program evaluation and offer a promising alternative to these more standard observational methods. The basic idea is to sample randomly from the population of interest, and then randomly assign selected participants to treatment and control groups. The intervention of interest is administered to the treatment group. The control group, by contrast, receives no intervention and represents what would have happened to the treatment group subjects in the absence of the treatment. [17] The difference-in-differences in observed outcomes across treatment and control groups, before and after the intervention, provides an unbiased estimate of the causal impact of the intervention.

These experimental approaches can be used to leverage both before and after comparisons and comparisons between the experimental treatment and control groups. Direct comparisons of differences in outcomes across treatment and control groups are possible because the effects of selection bias and other confounding factors are eliminated by design. If the study participants have been randomly selected from the population of interest, external validity is also achieved. This means that we can more confidently extrapolate the study findings to the larger population from which the sample was drawn.

Mandatory assignment of households to treatment (or program participation) status across households is not always practical or appropriate for all research questions or contexts. Even if mandatory assignment is possible in principle, it will often be the case that households assigned or offered a treatment (e.g. dynamic pricing tariff) will not comply with or accept their assignment, possibly due to state regulatory policies and practices (e.g., a PUC may decide that customers must make an affirmative choice to opt-in to a dynamic

[17] In an ideal setting, the control group would be unaware of their participation in the study; however, most practical applications of a dynamic pricing consumer behavior study may require control group participants to be informed as such. Under these circumstances, there are concerns about the "Hawthorne" effect, where individuals in an experiment or study will act differently simply because they are being observed. These concerns should be identified and/or dealt with appropriately in the study design.

pricing tariff). Given this situation, we highlight a research design that can accommodate these implementation situations: a randomized encouragement design (RED).

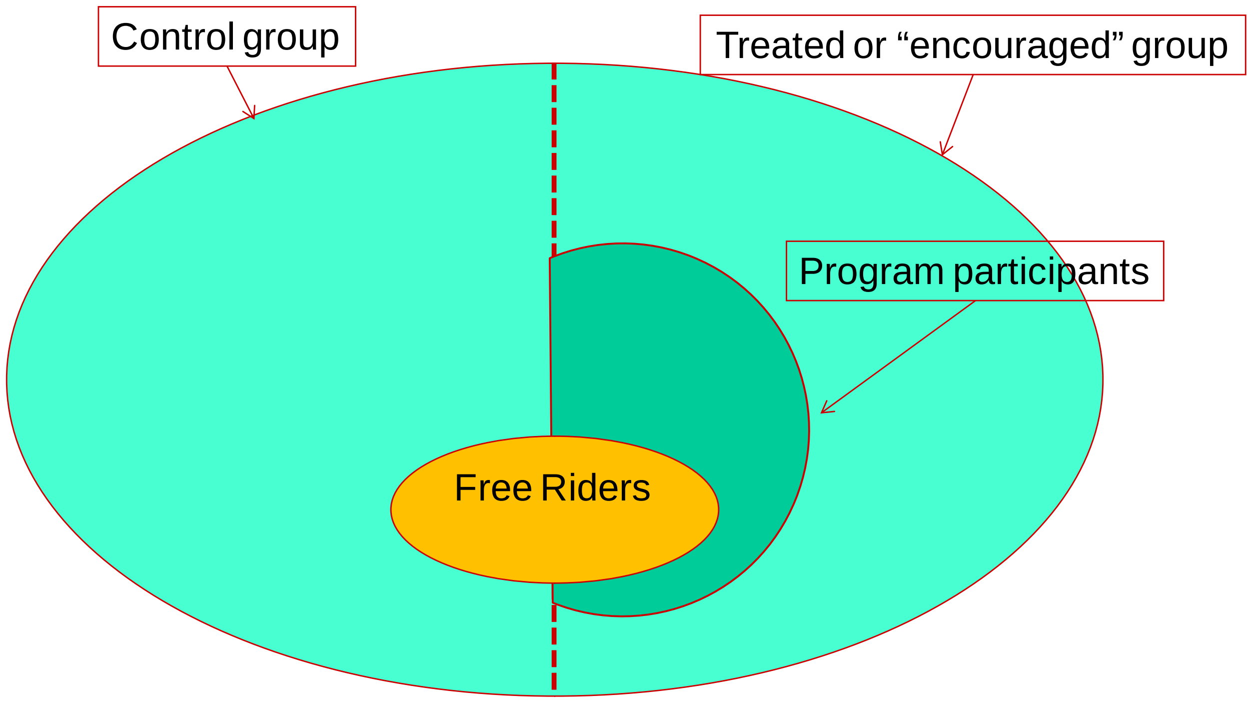
A.3 The Randomized Encouragement Design

The basic idea behind an RED is quite straightforward. The approach involves selecting a subset of eligible households, dividing them into treatment and control groups and then actively encouraging (hence the name of the design) households in the treated group to apply for the program. Note that this encouragement can come in many forms. It may manifest, simply, as extending the offer to a household to opt-in to the program or tariff that we are interested in studying. As a result of this encouragement, a larger proportion of the households in the treated group will participate in the program. The analysis proceeds by comparing outcomes across the households who received the encouragement and the households assigned to the control group.

A.3.1 A graphical introduction

Appendix Figure A-1 diagrams the RED concept. Assume that the large oval represents the sample of eligible households to be studied (e.g., utility customers with advanced metering infrastructure). The first step is to divide the population randomly into a treatment and control group—the two groups will look very similar in every dimension. Importantly, the hard-to-measure characteristics that can be important when interpreting the effects of a program will be distributed similarly across both groups. For instance, both groups will contain similar shares of consumers with strong interests in reducing their utility bills by adjusting their consumption in response to dynamic prices.

The treated group is then encouraged to participate in the program. Some of them will respond to the encouragement, and others will not. In the Figure, the subset of the population that responds is represented with the dark green semi-circle.



Appendix Figure A-1. Illustration of a randomized encouragement design

With any program evaluation, one crucial issue is to separate true behavioral changes that occur in response to the dynamic pricing program from changes that would have happened anyways. For example, in a program designed to study the effects of critical peak pricing, one could imagine some households signing up for the program because they know they will be on vacation in the hottest summer month, so their consumption will be low in the peak periods (and it would have been low absent the program). In the bubble graph, these households are reflected by the yellow circle. Importantly, there are would-be free-riders (i.e., consumers with the same naturally low peak usage) represented in the control group. So, with an analysis that compares the response of the whole treatment group to the whole control group, customers who would be free-riders if offered the program are expected to be equally represented in both populations. (Note that this also helps explains why it would be misleading to compare the subset of the treatment group who accept an offer to the entire control group drawn randomly from the population. One problem with such a comparison is that (would-be) free-riders would be more heavily represented in the treatment group than in the control group.)

A.3.2 Theoretical foundations of the RED

To illustrate the theory and associated assumptions underlying a randomized encouragement design (RED), we will use notation that is now standard in the econometric and statistical literature. A binary variable D_i indicates whether household i has been exposed to the intervention (or participated in the program) of interest ($D_i = 1$) or not ($D_i = 0$). Let Y_i denote the outcome observed at household i ; for i = 1…N. We postulate two potential outcomes: Y_i (1) denotes the outcome that would be realized at household i if it participates in (is exposed to) the dynamic pricing program of interest; Y_i (0) denotes the outcome if household i does not participate/is not exposed. For example, D_i might indicate whether a household i participates in a critical peak pricing program, and Y_i measures household electricity consumption during critical peak events.

Ideally, we would observe both Y (1) and Y (0) for each household. This would allow us to measure causal effect of the intervention for each household (i.e. Y_i (1) - Y_i (0)). Household-level measures of impacts could be used to construct not only aggregate impacts of the program, but also estimates of how program impacts vary with observable covariates (e.g., climate, dwelling characteristics, socioeconomic factors). The fundamental problem, of course, is that only one potential outcome can be observed for each household. Thus, to identify the causal effects of the program intervention, an estimate of the so-called "counterfactual" outcome must be constructed. More concretely, if household i participates in a CPP program in time period t, we need to estimate what the consumption patterns of household i in time t would have been had the household remained in the control state.

In a RED, researchers indirectly manipulate program participation using an encouragement "instrument" so as to generate the exogenous variation in program participation that is so essential for causal inference. This exogenous variation can then be used to identify the effect of the program on those households whose participation was contingent upon the encouragement.

The RED can be explained in the larger context of instrumental variables (IV) methods. Let z_i represent a valid "instrument" for program participation: a variable that is correlated with D_i but uncorrelated with any other determinants of the potential outcomes Y_i (0) and Y_i (1): Let Y_i ($D; z$) denote the potential outcome at household i if the household has participation status $D_i = D$ and instrument value z_i: Assuming a binary instrument that takes on a value of either 0 or 1, we denote D_{0i} to be the participation status of household *i* if $z_i = 0$ and D_{1i} to be the participation status of household *i* if $z_i = 1$.

Identification is predicated on three important assumptions:

A1: Potential outcomes Y_i (D; z) are independent of z_i:

(1) $[\{Y_i(D,z); \forall\, D,z\}, D_{1i}, D_{0i}] \perp z_i;$

where $z_i = 1$ if household *i* is assigned to the actively informed group; $z_i = 0$ otherwise. If assignment to encouraged and control groups is truly random, this assumption should hold by design.

A2: Potential outcomes $Y_i(D; z)$ are not directly affected by z_i:

(2) $Y_i(D,0) = Y_i(D,1)$ for $D = 0,1$

If the act of extending the option to participate in a program gets people thinking—and acting—differently, this could introduce bias into the estimates. For example, if households are educated about how stressed the bulk power system is during hot summer days as a means to encourage them to participate in a dynamic pricing pilot, then customers who eschew the offer could conceivably be provided with information that might induce them to turn down their air conditioning during such periods, thereby violating this assumption. Unless there is some expectation that this voluntary behavioral response will be pervasive even though there is very little economic incentive for doing so, such concerns should be substantially discounted.

A3: Monotonicity (i.e. the instrument z_i has a weakly positive effect on program participation for all i):

(3) $D_{1i} \geq D_{0i}\ \forall\ i$

Monotonicity implies that the encouragement will never decrease the probability that a household will be exposed to the intervention (although there may be cases where the information or encouragement provided has no effect on program participation). In most, if not all, of the research designs being considered, monotonicity is satisfied by design because control group participants do not have the option to participate in the programs being evaluated. Therefore, the program participation rate in the control group would be zero.

For any given program intervention, consumer behavior study participants can be categorized into one of three non-overlapping groups based on how they react to the encouragement:

(1) Never-takers are households that will never participate in the program regardless of z_i: Among never-takers, $D_{1i} = D_{0i} = 0$.
(2) Compliers are households that participate in the program if $z_i = 1$, but otherwise will not participate as they are not formally offered the opportunity ($z_i = 0$). Among the compliers, $D_{1i} = 1$; $D_{0i} = 0$.
(3) Always takers are households that will always participate in the program, regardless of z_i.[18] Among always-takers, $D_{1i} = D_{0i} = 1$.

A.3.3 Estimating local average treatment effects

Conditional on assumptions A1:A3, random assignment of information provision allows us to obtain an unbiased estimate of the so-called "local average treatment effect" (LATE). The LATE measures the average impact of program participation among compliers:

$$(4)\quad LATE = \frac{E(Y_i|z_i=1)-E(Y_i|z_i=0)}{E(D_i|z_i=1)-E(D_i|z_i=0)} = E\{Y_i(1) - Y_i(0)|D_{1i} > D_{0i}\}$$

Mechanically, our estimate of the local average treatment effect is essentially a weighted average. We construct it by computing the difference in the average energy consumption across the treatment and control groups and dividing this difference by the difference in participation rates across groups. This comparison is meaningful because the proportion of never takers and compliers and always takers will be the same in the treatment and control group in expectation (due to random assignment). Therefore, the contribution of the refusers to the control and treatment group averages, respectively, cancels out in the comparison. All that you are left with is the average treatment effect among the compliers.

This estimand and its statistical properties differ significantly from the average treatment effects estimated using observational methods. First, whereas the conditional independence assumption that rationalizes causal inference in an observational setting is untestable in principle, the independence assumption used to identify (4) is satisfied by design. A second advantage pertains to the construction of confidence intervals. In contrast

[18] If these “always takers” learn of the program (e.g., from a neighbor who is in the study), they will seek out the opportunity to participate. For simplicity, anyone not offered the treatment should not be allowed to receive the treatment during the study as it may undermine the initial randomization.

to observational methods, researchers can remain agnostic about distributions of outcomes and the nature of the underlying sampling process when quantifying uncertainty associated with average treatment effects.

A.4 Statistical Power

In the design stages of any randomized program evaluation, the importance of statistical power calculations cannot be overstated. Whereas randomization can credibly remove bias, these methods do not necessarily remove noise! An underpowered study potentially leads to inconclusive inferences and consequently misspends valuable time and financial resources allocated to the study. An overpowered study may waste valuable resources. Thus, performing sample size and power computations are a critical first step in the design phase.

The power and sample size calculations depend on the planned data analysis strategy. In the context of consumer behavior studies of customer acceptance and/or response to dynamic pricing, the "power" of a study is the ability to correctly detect a difference in group means of a given magnitude. A research design has adequate power if we can be reasonably sure that the observed differences in mean outcomes across treatment and control groups was "caused" by the intervention of interest. More formally, the power of a research design is a measure of the probability of detecting a causal effect of a given magnitude.

Statistical power is influenced by a number of factors and research design choices. This document summarizes the very basics of the power calculations that should be done to inform the design of any randomized field experiment. To be clear, each research design will likely have unique features that will affect how the final power calculation should be conducted. For the purpose of this technical memo, we consider the simple case where we are measuring the effect of a binary intervention (e.g., a critical peak pricing program) on an outcome of interest (household peak period demand). For expositional clarity, we assume we observe each household only once post-treatment. These basic power calculations can be modified to accommodate studies in which household-level outcomes are observed repeatedly pre- and post-intervention. In general, statistical power will increase with the number of observations collected per household.

In the next section, we present simple formulas for calculating power and related statistics. We explain how to do the calculations by hand. Because these calculations are based on the familiar and relatively simple t test, the formulas should be easy to use and understand.

A.4.1 Benchmark power calculation

The basic principles of power calculation can be illustrated using a textbook RCT design in which n subjects are randomly selected from the population of interest.[19] Some proportion *p* of this randomly selected group of *n* subjects is assigned to the treatment group and is exposed to the intervention of interest. The remaining (1-*p*) *n* subjects in the study are assigned to a control group and are not exposed to the intervention. We assume that all subjects adhere to (or comply perfectly with) their assignment.

In this simple case, the Ordinary Least Squares (OLS) coefficient in a regression of observed outcomes on the treatment indicator provides an unbiased estimate of the LATE:

(5) $Y_i = \alpha + \beta D_i + \varepsilon_i$

The variance of the OLS coefficient β is given by

(6) $var(\hat{\beta}) = \frac{\sigma^2}{\sum(D_i - \bar{D})^2}$

where σ^2 is the error variance. Intuitively, the larger the variation in the unobservables affecting the dependent variable the more difficult it is to estimate β. The denominator measures the variability in the treatment indicator. The more variance there is in this indicator variable, the easier it is to pick up the relationship between the treatment and the outcome. Note that:

(7) $\sum(D_i - \bar{D})^2 = p(1-p)^2 + (1-p)(-p)^2$

(8) $= p(1-p)$

A simple expression for the variance of our local average treatment effect estimate is:

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[19] This textbook example will not cover what would happen in research designs where pre-treatment data is often times readily available. In such cases, the use of this pre-treatment data allows for a reduction in the mean-squared error, which will *ceteris paribus* reduce the necessary sample size, but will also increase the number of total observations thereby reducing the proportion of treated observations, which will *ceteris paribus* increase the necessary sample size. The reduction in the MSE will likely be greater than the effect associated with the reduction in the proportion of treated observations on the required total sample size, but such should be evaluated on a case-by-case basis.

(9) $var(\hat{\beta}) = \frac{1}{p(1-p)}\frac{\sigma^2}{n}$

Ordinarily, one rejects the null hypothesis (i.e., zero effect) when the observed difference between means is large enough such that t exceeds the value set a priori to represent the Type I error rate.

Having selected the desired power (minimum probability of detection) κ, size (level at which statistical significance is to be tested) α, proportion p assigned to treatment, and total size of the study group n, the minimum detectable effect can be computed as:

(10) $$MDE = (t_{1-\kappa} + t_{\alpha})\sqrt{var(\hat{\beta})}$$

Rearranging, we can solve for the required sample size given κ, α, MDE, P, and σ^2.

(11) $$N = \frac{(t_{1-\kappa}+t_{\alpha})^2}{p(1-p)}\frac{\sigma^2}{MDE^2}$$

So, in this stylized RCT context, the power calculation depends on the following factors:

- The number of households in the study (N).
- Type I error rate (α). This is the probability of rejecting the null hypothesis when it is true, that is, of incorrectly rejecting the null hypothesis. We recommend a Type 1 error rate α = 0.05.
- The desired level of statistical power (κ). This is the probability that a difference of a given magnitude will be correctly detected. Thus, the power of the test is one minus the probability of not rejecting the null hypothesis when it is false, that is of incorrectly not rejecting the null hypothesis. Power in excess of 0.80 is generally accepted as adequate, but it will depend on the context and the cost of false positives versus false negatives.
- The proportion of the sample receiving the treatment (*p*). Power is maximized by setting p = 0.5, under a certain set of assumptions.
- Minimum detectable (or relevant) effect (MDE). This should be defined as the smallest effect that would justify the program being adopted (versus the expected effect). For example, for a system with a peak demand of 10,000 MW to avoid a new 200 MW peaking generation facility within 2 years, a critical peak pricing program must reduce aggregate peak demand by at least 2%.
- The variance of the outcome. The estimate of variance used in power calculations typically refers to measurement error associated with repeat sampling. This could be the MSE from the regression summarized above.

The power calculations for more complicated research designs are more complicated. The following section discusses one special case in detail.

A.4.2 Power calculation for a RED design

In a RED design, only a fraction of the households in the encouraged group accept (and are exposed to) the intervention. This complicates the power calculation somewhat. Recall that we cannot use all of the variation in the program participation variable D_i to identify the effect of the treatment. We can rest assured that the variation in treatment status of the compliers in the study is independent of the potential outcomes, so this is the variation we will use to identify the treatment effect. Let c denote the share of households that will participate in the program when encouraged.

The OLS coefficient in a regression of outcomes on the treatment (i.e. encouragement) indicator is used to construct the LATE estimate:

(12) $$Y_i = \alpha + \pi Z_i + \epsilon_i$$

Recall that $LATE = \frac{E(Y_i|z_i=1)-E(Y_i|z_i=0)}{E(D_i|z_i=1)-E(D_i|z_i=0)}$, where E($Y_i \mid z_i$=1) refers to the treated/encouraged group. The point estimate of π is thus divided by the difference in the share of treatment and control group households that participate in the program (c) to obtain an unbiased estimate of the average local average treatment (causal) effect of the program among the households that participate. The variance of this estimator is:

(13) $$var(LATE) = var\left(\frac{\pi}{c}\right)$$

(14) $$= \frac{1}{c^2}\frac{1}{P(1-P)}\frac{\sigma^2}{N}$$

Having selected the desired power, size, P and N, the minimum detectable effect can be computed as:

(15) $$MDE = (t_{1-\kappa} + t_\alpha)\sqrt{var\left(\frac{\hat{\pi}}{c}\right)}$$

(16) $$= (t_{1-\kappa} + t_\alpha)\sqrt{\frac{1}{c^2}\frac{1}{p(1-p)}\frac{\sigma^2}{N}}$$

Rearranging, we can solve for the required sample size given κ, α, MDE, P, c, and σ^2.

$$N = \frac{(t_{1-\kappa} + t_{\alpha})^2}{p(1-p)} \frac{\sigma^2}{MDE^2} \frac{1}{c^2} \qquad (17)$$

Note that, as compared to an RCT in which all households comply with their treatment assignment, the number of households required to obtain a given level of statistical power in a RED increases by a factor of $1/c^2$. Thus, for example, if the acceptance rate is 50% among those offered a program, the random encouragement design would require a sample size 4 times as large as the random assignment design, all else being equal. If the acceptance rate is only 10%, a sample size 100 times as large would be needed. If the acceptance rate is only 5%, a sample size of 400 times as large would be needed. This is why the Random Encouragement Design, though unbiased and conceptually straightforward, has practical limitations.