ELECTRIC POWER RESEARCH INSTITUTE

Guidebook for Cost/Benefit Analysis of Smart Grid Demonstration Projects

Volume 1 Measuring Impacts

2011 TECHNICAL UPDATE

Guidebook for Cost/Benefit Analysis of Smart Grid Demonstration Projects

Volume 1 Measuring Impacts

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1021423
Technical Update, May 2011

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This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Guidebook for Cost/Benefit Analysis of Smart Grid Demonstration Projects: Volume 1 Measuring Impacts
EPRI, Palo Alto, CA: 2011.
1021423

Product Description

This report presents a step-by-step process for estimating the costs and benefits associated with smart grid demonstration projects. The entire guidebook is meant to function as a standalone user's manual for the analysis process, from the initial step of describing the project to the final step of communicating the results to all stakeholders. This volume of the guidebook presents detailed instructions for describing the project objectives, the research plan, and the technologies deployed; associating the technologies with enabled functions; and mapping these functions to impacts. The report builds on the Electric Power Research Institute (EPRI) report *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects* (1020342).

Results and Findings

As smart grid technology evolves from the research and development environment to production testing and deployment, reliable methods will be needed to assess the benefits of the new technology and weigh these benefits against the cost of deployment. Having a consistent, credible, and transparent approach will facilitate deployment of smart grid investments where they will yield the greatest value for customers, utilities, and society.

Challenges and Objectives

Integrating smart technology into the electricity distribution system is complex because there are so many new technologies that could be deployed in different applications and because multiple technologies can be part of a single project. Not enough is known about their performance to determine which technologies (or portfolio of technologies) will be optimal across the spectrum of possible applications. Thorough documentation of actual field performance will help resolve questions about how individual technologies and portfolios of technologies are likely to perform under different operating conditions and levels of investment.

The valuation process is also complex because many smart grid investments produce indirect impacts. Their benefits are derived from how they enable us ". . . to integrate, interface with and intelligently control innovations such as wind turbines, plug-in hybrid vehicles and solar arrays."[1] Thus, a large part of the value of smart grid investments is derived from other technologies whose use they enable. Assessing the value of smart grid investments must include these functions that it enables, as well as the value that it provides directly.

Applications, Value, and Use

Engineers, planners, project managers, and other professionals can perform cost/benefit analysis for smart grid demonstrations by following the steps listed in this guidebook. Any project stakeholder involved in the process of defining specific values related to smart grid technology implementation will find value in its methodology. The process will allow for accurate analysis of the costs and benefits of various smart grid designs and will ultimately aid the stakeholder in steering smart grid deployment in a way that will provide the greatest value to the intended beneficiaries.

EPRI Perspective

The goal of the guidebook is to present a comprehensive set of guidelines and specific instructions for estimating the benefits and costs of smart grid projects. It is unique in its level of technical specificity and in the range of technologies it is intended to cover. The guidebook is intended to complement previous publications that deal with the concepts of cost/benefit analysis as applied to the smart grid. Finally, it is intended to help utilities produce evaluations that meet reporting requirements for DOE-funded smart grid projects, as well as provide the types of information that regulatory commissions are likely to require in order to approve the investments for cost recovery through regulated rates.

Approach

The guidebook presents a step-by-step framework that provides a standardized approach for estimating the benefits and costs of smart grid demonstration projects. This volume contains detailed discussion of the first 17 steps, from initial project definition to establishing measurement and verification protocols. Further, it applies these steps to a specific smart grid technology to illustrate how the methodology can be applied.

Keywords

Cost/benefit analysis
Demonstration projects
Functionality
Smart grid
Smart grid benefits
Smart grid costs

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[1] Litos Strategic Communication, "The Smart Grid: An Introduction," prepared for the U.S. Department of Energy, Contract No. DE-AC26-041818, Subtask 560.01.04, undated, p. 15.

Executive Summary

Smart grid initiatives are taking place all over the world that are utilizing advanced technologies in order to optimize the performance of the power system for the benefit of consumers and society at large, as well as utilities. Understanding the costs and benefits of smart grid applications requires an in-depth assessment of the technical and commercial performance of technologies and the interoperable networks that support them. A report jointly funded by the Department of Energy and the Electric Power Research Institute (EPRI), *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects* (EPRI report 1020342), provides a framework for estimating benefits and costs associated with smart grid projects. This guidebook builds on the previously mentioned publication by functioning as a standalone user's manual that guides the user step by step in performing a cost/benefit analysis (CBA) from the initial description of the project to the final step of communicating results to various beneficiaries.

Performing a CBA for smart grid demonstration projects poses several challenges due to the scope, scale, and market span of these technologies and their implementation. In order to extract the greatest value from these demonstrations, detailed documentation of the project and the analysis methodology should be made to ensure consistency of results.

The guidebook presents a 24-step framework for performing a CBA and works through the process by providing an example application in Appendix A and a collection of templates in workbook format in Appendix B. Section 1 of the document describes the background and purpose of the guidebook and how it should be used.

To set the stage for the CBA process, Section 2 instructs the user to document the project purpose, including the problem or opportunity description, a high-level baseline description, and project goals and objectives. The section also outlines the information to be included in the project summary such as the geographic scope of the project, technologies involved, potential benefits, targeted customer groups, project partners, a high-level project timeline, and so on.

Sections 3 and 4 guide the user through defining the research problem or opportunity, identifying the technologies to be deployed, and describing the functions that will be enabled and tested throughout the demonstration.

Section 5 comprises the majority of the project documentation schematic. The section includes several critical steps, including establishing hypotheses focusing on potential project impacts, establishing the baseline, specifying the experimental design, and developing a detailed project timeline.

Section 6 guides the user through the development of measurement and verification protocols including development of data collection instructions and identification of data collection points, as well as data testing, screening, storage, and retrieval protocols.

Remaining steps for estimating the project benefits and costs based on monetizing project impact metrics and communicating analytical results to various stakeholders are not discussed in detail in this volume.

Ultimately, great value can be extracted from the demonstrations by aggregating the results to understand the system-wide and societal costs and benefits of smart grids around the world. Communicating results to all beneficiaries will also facilitate wide-scale understanding of smart grid technology.

To maximize learning opportunities from the smart grid demonstration projects, the CBA should:

- Enable transferability of results – Projects, individually as well as part of a larger portfolio, should produce results that can be extrapolated to other technical and market circumstances.
- Advance understanding –Projects should advance the understanding of where, how, and why smart grid technologies perform as they do.
- Facilitate optimal deployment – Smart grid technologies are deployed in a manner that maximizes benefits to consumers, utilities, and society.

For these goals to be achieved, the methodology must be credible and sufficiently detailed to allow independent verification by others.

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Section 1: Background

1.1 Purpose and Overview

The *Guidebook for Cost/Benefit Analysis of Smart Grid Demonstration Projects* presents a comprehensive, step-by-step framework for conducting a cost/benefit analysis and reporting the results. The guidebook specifies the steps from the preliminary stage of identifying the problem or opportunity that prompted the project, to the communication of the analytical results to stakeholders. In this volume, the first seventeen steps are discussed in some detail. This document builds on a previously published report, the *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*, (Methodology Report) which was co-funded by the Electric Power Research Institute (EPRI) and the U.S. Department of Energy (DOE).[2] That report provides broad context for this guidebook in that it:

- presents a general methodological approach for estimating benefits and costs of Smart Grid projects,
- describes a broad range of issues associated with measuring technology impacts as a precursor to assigning monetary values,
- summarizes recent studies assessing the benefits and costs of Smart Grid technologies, and
- provides references and data sources that can be used for estimating a variety of inputs and assumptions.

Though the guidebook builds on the previous work, it is intended in its entirety to be a standalone guide for designing experiments and demonstration projects that produce consistent and transparent results that can be understood and validated by a range of interested parties. Nevertheless, although the guidebook can be implemented without the need for side-by-side reference to the Methodology Report, the latter contains useful background which will be referenced as needed.

The guidebook is intended to facilitate consistent and insightful implementation of Smart Grid pilot programs and experiments. More specifically, EPRI's goal is that the EPRI-sponsored Smart Grid projects yield experimental results that will advance our understanding of where (in what locations), how (in what applications and functions), and why (system operating conditions, grid

[2] EPRI, Palo Alto, CA: 2010. 1020342.

characteristics, climate, etc.) Smart Grid technologies can be expected to perform. Having verifiable experimental results will facilitate extraction of research value from the demonstration projects, and promote deployment of the technologies in a manner that maximizes the benefits to customers, utilities and society. Achieving these goals requires establishing a format that engineers and scientists can use to articulate how a specific technology is expected to affect the electricity sector (and in some cases other sectors of the economy) and to demonstrate those impacts convincingly. A credible demonstration of impacts requires detailed documentation so that actions and results can be evaluated by the project teams, and validated by others.

This volume of the *Guidebook for Cost/Benefit Analysis of Smart Grid Demonstration Projects* follows the workflow presented in Figure 1-1 below.

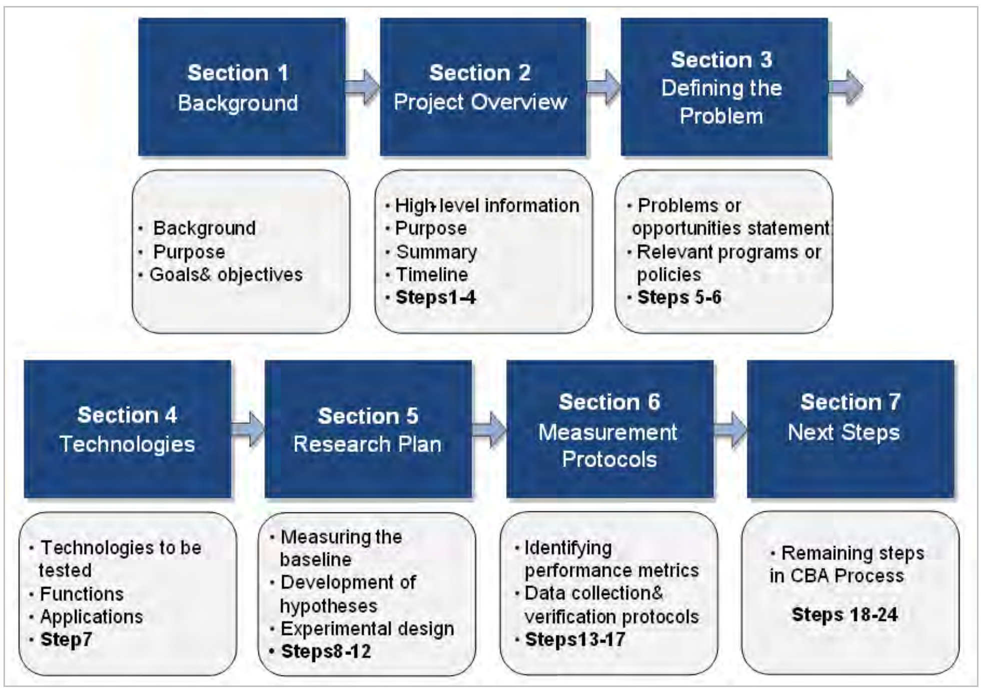

Figure 1-1
Guidebook for Cost/Benefit Analysis of Smart Grid Projects Workflow

Viewed broadly, the guidebook provides the tools necessary to develop a detailed research plan, identify project impacts, associate impacts with project benefits, and track project costs that are tightly aligned with the specific deployment and operation of Smart Grid technology. Following this process will promote consistency in how costs and benefits attributable to Smart Grid demonstration projects are measured and monetized. This consistency will facilitate comparisons across projects undertaken in different locations over time, thereby accelerating what is learned from the pilots and demonstration projections. Monetizing impacts, tracking costs and outlining the detailed steps to perform an analysis are not included in this volume of guidebook, which intended to assist in the early phases of project design and development. Development of greater detail regarding data requirements, formulas to assess various smart grid functions, and the instructions for upstream mapping, in terms of monetization and association of cost and benefits with various beneficiaries, will proceed in parallel with demonstration project development.

Appendix A is an example of the guidebook's workflow process applied to a generic Volt/VAR optimization project. Appendix B is structured in workbook format to allow users to document project information and data as they work through the cost/benefit analysis process outlined in this report. Key terms are defined in Appendix C of this document.

1.2 What Is a Smart Grid?

The National Energy Technology Laboratory (NETL) has developed a list of seven principal characteristics of a Smart Grid which have been widely adopted across the industry. They are described in detail in Section 4 of the DOE/EPRI Methodology Report and are summarized here for ease of reference.

The principal characteristics are that a Smart Grid[3]:

1. Enables informed participation by customers
2. Accommodates all generation and storage options
3. Enables new and improved products, services and markets
4. Provides power quality for the range of needs in the 21st century economy
5. Optimizes asset utilization and operating efficiency
6. Addresses disturbances through automated prevention, containment and restoration
7. Operates resiliently against all hazards

Distilled to basics, a Smart Grid involves exploiting new technologies and communications to advance widespread, efficient and cost-effective deployment of utility and customer-side technologies in the distribution system, and to enhance overall power system operations.[4] Smart Grid technologies include[5]:

- Integrated communications connecting components using open architecture to enable real-time information and control, through two-way communications
- Sensing and measurement technologies which can provide better visibility of what's going on in real-time without the need to dispatch crews to individual locations

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[3] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*, EPRI, Palo Alto, CA, 2010. 1020342, pp. 4-5 thru 4-11.

[4] EPRI Smart Grid Demonstration Initiative, Two-Year Update, July 2010, p. 2.

[5] Litos Strategic Communication, *The Smart Grid: An Introduction*, prepared for the U.S. Department of Energy, Washington, DC, Contract No. DE-AC26-04NT41817, Subtask 560.01.04, p. 29 (undated).

- Advanced components, to apply the latest research in superconductivity, storage, power electronics and diagnostics
- Advanced control methods, intelligent devices which can accept data and implement commands for better optimization and control of the system
- Improved interfaces and decision support

1.3 How is Cost/Benefit Analysis for Smart Grid Projects Different?

Several attributes of Smart Grid investments make conducting cost/benefit analysis more challenging than for many other types of investments.

Scope of technologies. The scope of the technologies involved can be quite broad and can range from the generation bus to the devices that customers use in their homes or businesses. They can facilitate the integration of new technologies into dispatch operations and into wholesale electricity markets. They can also facilitate the integration of distributed electricity generation installed at various locations on the system. In other words, they serve a lot of purposes, sometimes complementary, and other times as alternatives.

Scale of technologies. The scale of technologies can range from small, isolated parts of the grid to expansive projects that span several stages of the delivery system.

Span of markets and market participants. Smart Grid investments can cross customer classes, utility markets, market participants (including customers, utilities, and energy service companies), states, and regional market operators and reliability organizations such as Independent System Operators/Regional Transmission Operators (ISO/RTOs).

This combination of scope, scale and market span makes it challenging to identify market barriers and program beneficiaries, and complicates program evaluation. For example, if a distribution utility installs advanced metering infrastructure (AMI), the better data improves utility commercial operations. It may also improve performance of the distribution system, influence system-level supply costs, and have regional implications. Sorting these out and making the proper attribution is challenging.

1.4 How the Guidebook Should be Used

The guidebook was created to provide a practical approach to performing cost/benefit analysis for Smart Grid demonstration projects. It provides the narrative, illustrations and instructions needed for establishing a detailed research and corresponding data collection plan and identifies what has to be measured. The underlying philosophy is to present a standardized approach that can be consistently applied to projects with similar elements. Nevertheless, sufficient flexibility is built into the process to accommodate the integration of other methods, such that benefit estimates can be derived for projects that do not "fit the mold."[6]

The twenty-four steps constitute the structure of the CBA process, and are numbered independently of the sections of this volume. The steps fall within the numbered Guidebook sections as shown below. In the narrative, the Steps are identified closest to the text explaining the details of the process the Step is referring to.

1. **Guidebook Purpose**
2. **Description of Smart Grid Project**
   - **Step 1:** Document project information at a high-level
   - **Step 2:** Provide a general description of the project purpose including
   - **Step 3:** Provide a high-level project summary
   - **Step 4:** Provide a high-level project timeline
3. **Defining the Research Problem**
   - **Step 5:** Define the research problem or opportunity that prompted the project
   - **Step 6:** Describe any relevant programs or policies that are pertinent to the project
4. **Identifying Technologies to be Deployed**
   - **Step 7:** Describe the technologies to be deployed and their associated functions
5. **Developing the Research Plan**
   - **Step 8:** Estimate project impacts
   - **Step 9:** Describe the baseline(s) required to measure performance
   - **Step 10:** Describe the formal hypotheses to be tested in experiments
   - **Step 11:** Identify experiments, describe how each will be conducted.
   - **Step 12:** Develop a detailed project timeline
6. **Establishing Measurement & Verification Protocols**
   - **Step 13:** Define the physical measurements to be take in experiments
   - **Step 14:** Define the time intervals for measurements
   - **Step 15:** Describe external factors that will require normalization of the data sets
   - **Step 16:** Identify data collection points and describe data collection instructions
   - **Step 17:** Identify data testing, screening, storage and retrieval protocol

[6] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects.* EPRI, Palo Alto, CA: 2010 1020342, p. 4-8.

Additional Steps (not detailed in this volume):

1. **Estimating and Tracking Project Costs**
   - **Step 18:** Calculate physical impact measurements by beneficiary group
   - **Step 19:** Convert physical impact measurements to monetary values
   - **Step 20:** Identify Smart Grid functions with benefits for multiple beneficiaries
2. **Estimating and Tracking Project Costs**
   - **Step 21:** Estimate costs incurred by customers per year for baseline and project
   - **Step 22:** Estimate utility costs by function/classification for baseline and project
3. **Benefit/Cost Analysis Using Pilot Project Data**
   - **Step 23:** Summarize costs and benefits
4. **Communicating Results**
   - **Step 24:** Communicate results

Section 2: Project Overview

The first and defining step is to provide a high-level overview of the project, describing generally what the utility proposes to do, the goals of the project, project participants (including any co-funders), the role of the regulator (if applicable), targeted customer groups, etc. A detailed description of the project will be developed in sections 3, 4 and 5, which describe the research problem, technologies to be deployed, and a specific research plan.

2.1 General Information

Step 1: Specify project information at a high-level.

General information would typically include the following types of information:

Name of Project	Official Smart Grid Demonstration Project Title
Lead Organization	Company Name
Other Participants	Smart Grid Demonstration Collaborators
Project Manager/Contact Information	PM Name and Contact Information
Planned Duration of Project	Commencement and End of the Demonstration
Total Budget	Total Funding of the Demonstration
Federal Cost Share	Portion of the Demonstration funded by the Department of Energy

2.2 Project Purpose

Step 2: Provide a general description of the project purpose including: 1) the problem or opportunity statement, 2) baseline description, and 3) project goals and objectives.

2A) Problem or Opportunity Statement:

Provide a general description of the problem the utility is trying to solve or the opportunities for improvement that have been identified. For example:

- Reduce line losses or frequency and duration of customer outages.
- Facilitating integration of intermittent distributed generation or dynamic pricing to allow customers greater control of their energy costs.

2B) Baseline Description:

A short description of the baseline ("but for") case; characterizing performance if these technologies were not slated for adoption. Examples might include:

- Costly meter reading
- Status quo in reducing outages
- No improvement in losses
- High cost to accommodate distributed generation

2C) Project Goals and Objectives:

Describe project goals and objectives: How are the new technologies expected to improve the conditions described in sections 2A and 2B?

For Example:

- Project seeks to demonstrate lower capital and operating cost associated with integrating PV and battery energy storage as a dispatchable resource.
- Project seeks to demonstrate improved operational efficiency of distribution feeder voltage by decreasing line losses and reducing energy use through conservation voltage reduction strategies.
- Project seeks to quantify load changes induced by demand response

Constructing a thorough description of the project's goals and objectives, and relating how they will be accomplished (experimental design), should serve as a roadmap for conducting the project and measuring its accomplishments. Figure 2-1 below illustrates the steps between outlining project goals and objectives, and producing metrics to perform the cost/benefit analysis. The figure portrays that project objectives determine hypotheses that dictate the experiments and measurements that need to be taken to perform the CBA.

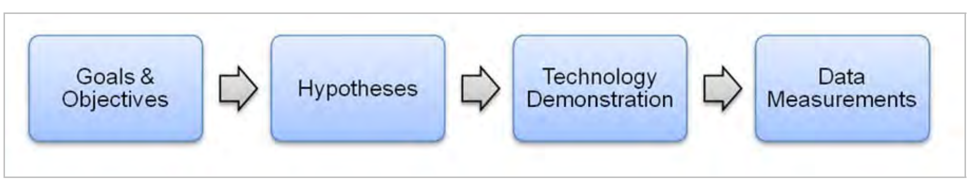

Figure 2-1
High-level Process Flow

2.3 Project Summary

Step 3: Provide a high-level project summary

3A) Description of the utility's service territory:

Service territory statistics such as the total number of customers, peak load information, number of substations etc.

3B) Describe the geographic scope of the project:

May include graphic illustration of the area served.

3C) Description of project elements (technologies, devices, systems, etc.):

A brief description of the project elements, i.e., the technologies, devices and systems which will collectively comprise a Smart Grid project.

3D) Description of functions the project will provide:

The functions that are enabled by the Smart Grid technology.

3E) Description of potential benefits expected:

Potential benefits that are expected to result.

3F) Targeted customer groups (if relevant):

Characteristics of the customer groups (residential, commercial, and other demographic information that may be applicable to the evaluation, etc).

3G) Project Budget: $

High-level summary of the project cost-share.

3H) Key Project Partners & Collaborators:

Companies & Organizations involved in the project.

- General description of roles and responsibilities (Roles and responsibilities could be organized based on three project areas including: 1) Financial 2) Operational and 3) Performance related tasks.
- Co-Funders.

3I) Market Structure:

Include if this is relevant to understanding the project, how benefits are created, who benefits, and necessary approvals

3J) Regulatory Authorities:

Regulatory authorities (how they impact the project, the extent to which regulatory approvals are required and their timing)

- Local, state, federal (standards, land use, permitting, zoning, etc.)
- Regulatory commission(s) (Public Utility Commissions, FERC, etc.)

2.4 High-level Project Timeline

The last step in section 2 suggests the user develop a high-level project timeline. The bullet list below includes tasks related to project management and other high-level tasks.

Step 4: Provide a high-level project timeline

Development of a high-level project timeline may include the information listed below:

- Project development (including internal & external approvals of budget & scope)
- Regulatory approvals (if required)
- Pre-planning and preparation (equipment purchases & installation, development of marketing, communication and customer recruitment materials, if relevant)
- Time required to measure baseline conditions
- Field implementation, data collection and monitoring
- Time required for data collection, processing, analysis and report writing

Task	Completion Date
1.	
2.	
3.	
…	
N	

To reiterate, Section 2 provides the high-level information necessary to introduce the Smart Grid demonstration project, provide the background justification for development of the project, and communicate the overall project goals and objectives. The subsequent sections will provide greater detail on the various stages of the process.

Section 3: Defining the Research Problem

3.1 Problems to be Solved or Opportunities to be Pursued

Step 5: Define the research problem or opportunity that motivated and authorized the project

Defining the research problem involves identifying the problem that the utility wants to solve or the opportunities for improvements that have been identified. Some of the problems or opportunities that might be addressed include:

- Reduce the cost of meter reading
- Reduce the costs of service connections and disconnections
- Reduce line losses
- Improve service reliability by reducing the frequency, scope and duration of outages
- Facilitate the integration of distributed energy resources including demand response, storage, distributed generation and renewable generation such as wind and photovoltaic's.
- Facilitate dynamic pricing which would allow consumers to save money by reducing consumption when prices are high and shifting load to periods when prices are low.

For each of these potential opportunities for improvement, detailed questions should be addressed. For example, what adverse impacts have been observed? What could be done to address the observed impacts using current technologies? What new technologies are being considered? What specific hypotheses are going to be tested?

3.2 Programs and Policies

Step 6: Describe any relevant programs or policies that are pertinent to the project

What types of regulatory policies or business practices constitute barriers to be overcome or opportunities for improvement? What rates, policies, programs or practices are required to achieve the result? Most barriers cited in this category include flat (non-time differentiated rates), distributed resource interconnection policy, and regulatory policies regarding cost recovery.

Opportunities for overcoming these types of barriers, therefore, might include:

- Time-differentiated, dynamic rates and other programs including, but not limited to:
  - Demand-response programs integrated into wide-scale markets, or operated by a utility, for economic and reliability purposes
  - Critical-peak pricing
  - Peak-time rebates
  - Real-time pricing, including day-ahead, and real-time posting
- Improved distributed resource interconnection policy
- Regulatory policies that remove financial disincentives to implementing otherwise beneficial programs, including, but not limited to:
  - Rate/revenue decoupling
  - Rate redesign to recover fixed costs through fixed rate components
  - Appropriate and timely regulatory review and approval of Smart Grid investments

Section 4: Identifying Technologies to be Deployed

After the research problem is identified, the next step is to describe the proposed solution. As discussed in Section 1.2, a Smart Grid project involves implementing technology to enhance overall power system operations, or to integrate distributed energy resources into the distribution system, or both. Technology here is used in the broadest sense to include devices and equipment, information, and commercial terms of service like pricing structures or other behavioral inducements. The goals of the project will identify the problems to be solved (or opportunities to be exploited), which, in turn, determine the types of functions desired. These, in turn, define the types of technologies, devices and/or systems that need to be proposed for this project. Table 4-1 describes the types of Smart Grid functions that can be deployed to enhance the integration of distributed energy resources (DERs) into the utility's distribution system and operations.

Table 4-1
Distributed Energy Resources and Definitions of Smart Grid Functions That Can Enhance their Integration into the Distribution System[6]

Enabled Distributed Energy Resource	Definition of Functions Needed to Integrate into the Distribution System
Distributed Generation (DG)	Smart Grid functions allow utilities to integrate and if desired, remotely operate DG systems to control output, defer upgrades to generation and T&D assets, and improve voltage regulation. DG includes intermittent technologies, such as photovoltaics, wind, etc. and dispatchable technologies such as combined heat and power systems, fossil fuel powered backup generators, bio-fuel powered backup generators (e.g., biodiesel, waste to energy, digester gas), or geothermal energy.
Stationary Electricity Storage	Remote utility control of electricity storage inflow/outflow reduces energy costs and enhances power generation and T&D capacity utilization.
Plug-in Electric Vehicles	Remote utility control of plug in hybrid electric vehicles (PHEV) and electric vehicles (EV) inflow/outflow reduces energy costs and enhances power generation and T&D capacity utilization.

The functions that different technologies can provide are listed in Table 4-2, grouped by primary application level, i.e., transmission, distribution, substation or customer premise. Table 4-2 also identifies the types of technologies that provide those functions.

[6] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects.* EPRI, Palo Alto, CA: 2010. 1020342, p. 4-8.

Table 4-2
Definition of Smart Grid Functions and Types of Technologies[7]

Function	Definition and Types of Technologies
Transmission Level	
Flow Control	Flow control requires techniques that are applied at transmission and distribution levels to influence the path that power (real & reactive) travels. This uses such tools as flexible AC transmission systems (FACTS), phase angle regulating transformers (PARs), series capacitors, and very low impedance superconductors.
Wide Area Monitoring and Visualization	Wide area monitoring and visualization requires time synchronized sensors, communications, and information processing that allow the condition of the bulk power system to be observed and understood in real-time so that action can be taken.
Distribution Level	
Adaptive Protection	Adaptive protection uses adjustable protective relay settings (e.g., current, voltage, feeders, and equipment) in real time based on signals from local sensors or a central control system. This is particularly useful for feeder transfers and two-way power flow issues associated with high DER penetration.
Automated Feeder Switching	Automated feeder switching is realized through automatic isolation and reconfiguration of faulted segments of distribution feeders via sensors, controls, switches, and communications systems. These devices can operate autonomously in response to local events or in response to signals from a central control system.
Automated Islanding and Reconnection	Automated islanding and reconnection is achieved by automated separation and subsequent reconnection (autonomous synchronization) of an independently operated portion of the T&D system (i.e., microgrid) from the interconnected electric grid. A microgrid is an integrated energy system consisting of interconnected loads and distributed energy resources which, as an integrated system, can operate in parallel with the grid or as an island.

[7] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects.* EPRI, Palo Alto, CA: 2010 1020342 (p. 4-6 – 4-7.)

Table 4-2 (continued)
Definition of Smart Grid Functions and Types of Technologies[8]

Function	Definition and Types of Technologies
Automated Voltage and VAR Control	Automated voltage and VAR control requires coordinated operation of reactive power resources such as capacitor banks, voltage regulators, transformer load-tap changers, and distributed generation (DG) with sensors, controls, and communications systems. These devices could operate autonomously in response to local events or in response to signals from a central control system.
Enhanced Fault Protection	Enhanced fault protection requires higher precision and greater discrimination of fault location and type with coordinated measurement among multiple devices. For distribution applications, these systems will detect and isolate faults without full-power re-closing, reducing the frequency of through-fault currents. Using high resolution sensors and fault signatures, these systems can better detect high impedance faults. For transmission applications, these systems will employ high speed communications between multiple elements (e.g., stations) to protect entire regions, rather than just single elements. They will also use the latest digital techniques to advance beyond conventional impedance relaying of transmission lines.
Real-time Load Transfer	Real-time load transfer is achieved through real-time feeder reconfiguration and optimization to relieve load on equipment, improve asset utilization, improve distribution system efficiency, and enhance system performance.
Substation Level	
Diagnosis & Notification of Equipment Condition	Diagnosis and notification of equipment condition is defined as on-line monitoring and analysis of equipment, its performance and operating environment to detect abnormal conditions (e.g., high number of equipment operations, temperature, or vibration). Automatically notifies asset managers and operations to respond to conditions that increase the probability of equipment failure.

[8] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects.* EPRI, Palo Alto, CA: 2010 1020342 (p. 4-6 – 4-7.)

Table 4-2 (continued)
Definition of Smart Grid Functions and Types of Technologies[9]

Function	Definition and Types of Technologies
Dynamic Capability Rating	Dynamic capability rating can be achieved through real-time determination of an element's (e.g., line, transformer etc.) ability to carry load based on electrical and environmental conditions.
Fault Current Limiting	Fault current limiting can be achieved through sensors, communications, information processing, and actuators that allow the utility to use a higher degree of network coordination to reconfigure the system to prevent fault currents from exceeding damaging levels.
Customer Level	
Customer Electricity Use Optimization	Customer electricity use optimization is possible if customers are provided with information to make educated decisions about their electricity use. Customers should be able to optimize toward multiple goals such as cost, reliability, convenience, and environmental impact.
Real-time Load Measurement and Management	This function provides real-time measurement of customer consumption and management of load through Advanced Metering Infrastructure (AMI) systems (smart meters, two-way communications) and embedded appliance controllers that help customers make informed energy use decisions via real-time price signals, time-of-use (TOU) rates, and service options.

Users of this Guidebook should identify for each project the Smart Grid functions it is intended to provide and the technologies, devices and systems that will provide those functions. Other relevant data should also be documented, including intended applications, key performance data and expected lifetimes.

Step 7: Describe the technologies to be deployed and the associated functions that will be enabled for the project including how they work and interact with one another.

This step is to specify what the project's elements include, from both a technology perspective and in regard to what science will be undertaken during the project. This informs constructing hypotheses (Section 5.3) that succinctly and objectively link the objectives (Section 2.2) to cause and effect relationships that define the science to be undertaken, and which in turn establish what needs to be measured and when (Section 6).

[9] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects.* EPRI, Palo Alto, CA: 2010 1020342 (p. 4-6 – 4-7.)

Section 5: Developing a Research Plan

By this point in the process, the research problem and the Smart Grid functions have been identified, along with the technologies, devices and systems that are proposed as part of the project. This section outlines the detailed design of the research plan which will allow the hypotheses to be tested and the project impacts to be measured rigorously. Subsequently the impacts can be monetized so that the benefits to customers, utilities and society can be estimated.

The overall process is illustrated conceptually in Figure 5-1. Smart Grid assets enable Smart Grid functions which produce impacts which need to be measured first in physical terms, and then monetized.

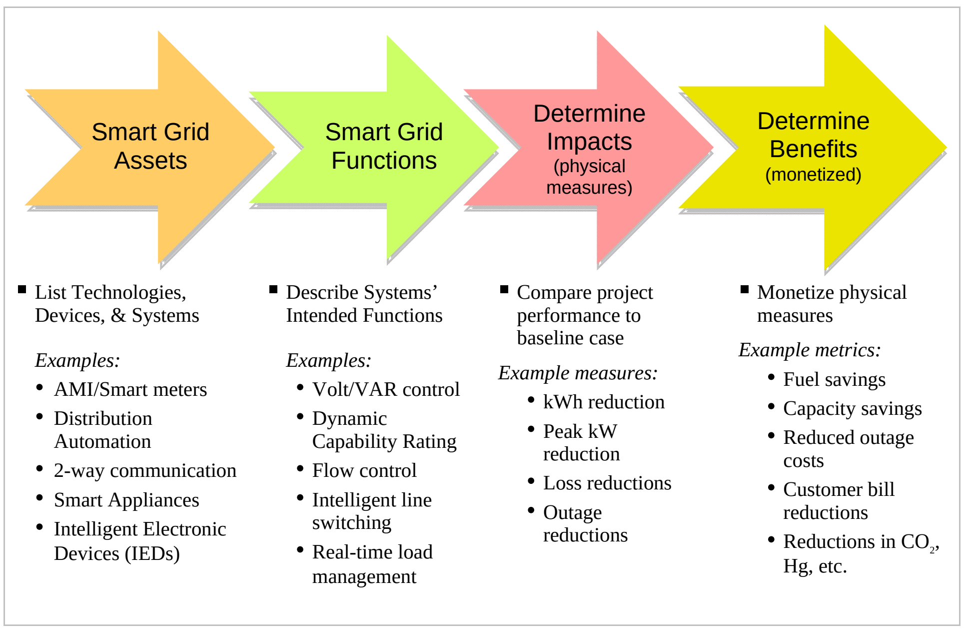

Figure 5-1
Conceptual Overview of the Smart Grid Evaluation Process

5.1 Identifying Potential Project Impacts

Step 8: Estimate project impacts.

What are the potential impacts of each Smart Grid Technology or Asset? Table 5-1 maps Smart Grid assets to the functions they can provide. Table 5-2 shows the linkages between the Smart Grid functions and the impacts they could provide. Both tables are based on the EPRI/DOE Methodology Report.[10] These tables can be used as a checklist to estimate project impacts and corresponding benefits, and to facilitate their capture in the experimental design.

The user may want to take this further and describe, at a high-level, the expected costs and benefits of the Smart Grid demonstration project. Statements expressing expected costs and benefits may be complex, encompassing multiple assertions about performance and cost that should be tested independently, if possible. For example, suppose the project involves distribution automation equipment deployed on a feeder where the expected costs and benefits may be as follows:

- Customers will, on average, experience shorter outages than they otherwise would have.
- Expenses for clearing faults will be lower
- By actively balancing loading among circuits, losses will be lower, and cost of transformers and breakers will be reduced over the long-term.
- Consumers will be subject to capital costs and maintenance expenses for DA equipment.

Thinking through this step should prepare the user for section 5.2 – Establishing the Baseline, as well as section 5.3 – Specifying the Experimental Design.

[10] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects.* EPRI, Palo Alto, CA: 2010 1020342 (Table 4-4 and Table 4-8.)

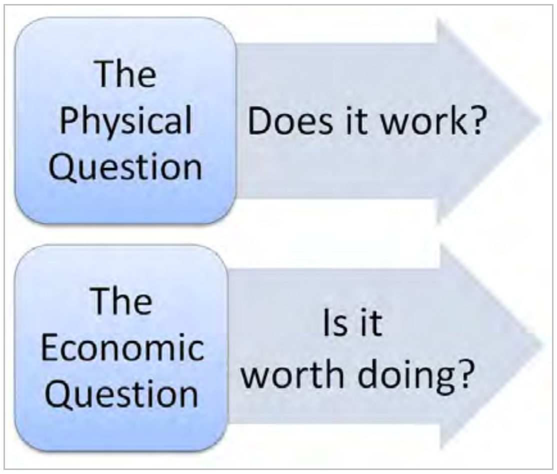

Figure 5-2
Distinction between physical performance and economic analysis

It is important to note that the purpose of the Smart Grid demonstration projects is twofold: 1) to demonstrate the technologies' benefits in specific applications 2) determine the economic viability of the demonstrated applications. The physical question should be separated from the economic question since we can test and observe physical performance through experimentation. However, economic performance is often not directly observable, but rather is estimable through analysis of the physical performance. Figure 5-2 illustrates this distinction.

Table 5-1
Linkage of Smart Grid Assets to Functions

Smart Grid Assets	**Functions**												
	Transmission Level		**Distribution Level**						**Substation Level**			**Customer Level**	
	Flow Control	Wide Area Monitoring and Viasualization	Adaptive Protection	Automated Feeder Switching	Automated Islanding and Reconnection	Automated Volt/VAR Control	Enhanced Fault Protection	Real-time Load Transfer	Diagnosis & Notification of Equipement Condition	Dynamic Capability Rating	Fault-Current Limiting	Customer Electricity Use Optimization	Real-time load Measurement and Management
Advanced Interrupting Switch							■						
AMI/Smart Meters						■						■	■
Controllable/regulating Inverter					■	■							
Customer EMS/Display Portal												■	
Distribution Automation			■	■	■	■		■					
Distribution Management System			■	■	■	■		■		■			■
Enhanced Fault Detection Technology							■						
Equipment Health Sensor									■	■			
FACTS Device	■												
Fault Current Limiter											■		
Loading Monitor								■	■	■			
Microgrid Controller					■								
Phase Angle Regulating Transformer	■												
Phasor Measurement Technology		■											
Smart Appliances and Equipment (Customer)												■	
Software – Advanced Analysis/Visualization		■								■			
Two-way Communications (high bandwidth)		■	■	■	■	■		■					■
Vehicle to Grid 2-way power converter													
VLI (HTS) cables	■												

Table 5-2
Mapping of Functions to Benefits

Benefits			Flow Control	Wide Area Monitoring & Visualization	Adaptive Protection	Automated Feeder Switching	Automated Islanding and Reconnection	Automated Volt/VAR Control	Enhanced Fault Protection	Real-time Load Transfer	Diagnosis & Notification of Equipment Condition	Dynamic Capability Rating	Fault Current Limiting	Customer Electricity Use & Optimization	Real-time Load Measurement and Management	Distributed Generation	Stationary Electricity Storage	Plug-in Electric Vehicles
		Functions	Transmission Level		Distribution Level						Substation Level			Customer Level		Energy Resources		
Economic	Improved Asset Utilization	Optimized Generator Operation		■													■	■
		Deferred Generation Capacity Investments												■		■	■	■
		Reduced Ancillary Service Cost		■				■							■	■	■	■
		Reduced Congestion Cost	■	■								■				■	■	■
	T&D Capital Savings	Deferred Transmission Capacity Investments	■	■								■	■	■		■	■	■
		Deferred Distribution Capacity Investments								■		■		■	■	■	■	■
		Reduced Equipment Failures							■		■	■	■					
	T&D O&M Savings	Reduced Distribution Equipment Maintenance Cost									■							
		Reduced Distribution Operations Cost				■		■										
		Reduced Meter Reading Cost													■			
	Theft Reduction	Reduced Electricity Theft													■			
	Energy Efficiency	Reduced Electricity Losses						■		■				■	■		■	
	Electricity Cost Savings	Reduced Electricity Cost												■			■	
Reliability	Power Interruptions	Reduced Sustained Outages			■	■	■		■		■				■	■	■	■
		Reduced Major Outages		■			■								■			
		Reduced Restoration Cost			■	■			■		■							
	Power Quality	Reduced Momentary Outages							■	■							■	
		Reduced Sags and Swells							■								■	
Environ-mental	Air Emissions	Reduced CO_2 Emissions	■			■		■						■	■	■	■	■
		Reduced SOx, NOx and PM-10 Emissions	■			■		■						■	■	■	■	■
Security	Energy Security	Reduced Oil Usage (not monetized)				■					■				■			■
		Reduced Wide scale Blackouts		■					■			■						

5.2 Establishing the Baseline

Step 9: Describe the baseline(s) that are required to measure performance of the technologies and/or applications.

The first step in developing a research plan is to articulate the pre-condition that has prompted the Smart Grid research. Depending upon the project goals, for example, the pre-condition might be based on a history of reliability problems on certain circuits. In others, it might be based on a projection of what would happen if, for example, distributed generation were to be installed at a customer's premise without the kinds of communications and controls that Smart Grid technologies can provide. In any case, establishing a baseline case (the "but for" counterfactual) is a critical step in estimating the project's impacts. Particular emphasis should be placed on measuring not just the baseline itself, but other conditions that could be important in understanding what affects the baseline and what doesn't.

Establishing a baseline requires various approaches depending on the situation. A controlled experiment, in which a "treatment" group is compared with a randomly assigned "control" group, should account for the counterfactual by its design and no baseline is required. However, for many smart grid projects, this approach is not workable, requiring construction of a counterfactual or use of regression methods to isolate the experimental effect. For example:

- Distribution automation responds to faults that occur on the distribution system, working to automatically restore service to customers if it can isolate the faulted section and restore service to unfaulted segments. Because faults and interruptions are unique, infrequent, and variable over time, it is not reasonable to statistically compare treated circuits with untreated circuits over relatively short periods of time. Rather, the reduction in duration of customer interruptions can be determined by forensic inspection of the equipment operation in response to a fault, constructing a counterfactual in which there were no distribution automation installed.
- The load-reducing effect of Conservation Voltage Reduction cannot be measured directly on a feeder as the system is either on or off. The effect also can't be accurately measured instantaneously – by switching the system on or off and observing the instantaneous change – as this instantaneous change is not representative of the average effect. (This is because thermostatically controlled devices such as refrigerators and air conditioners will run longer cycles to make up for lower power consumption.) A common method of measuring the effect is to run the system for 24 hours, followed by a 24-hour period where the system is off. However, adjacent days are not directly comparable, as each day's loads are unique, affected by weather and a number of other random or unmeasurable factors. Analysts compensate by adjusting either or both load observations for measured differences in temperature, and use regression techniques to isolate the load change related to reduction in voltage. While the regression techniques obscure the existence of the counterfactual, essentially the method is comparing the series of days-on with the weather-adjusted series of days-off, using the latter as a counterfactual.

5.2.1 How Many Baselines are Needed?

A baseline will be needed for each major project goal to be measured, and in some cases, for each experiment.

Example: AMI Project with Multiple Objectives

Suppose the project involves advanced metering infrastructure (AMI) and the utility's goals are to: (1) test the effectiveness of dynamic rates to encourage load reduction during critical peak periods; (2) test the impact of providing customers with real-time information about their loads and prices; and (3) determine the savings associated with remote meter reading and remote service connections and disconnections.

Each of these objectives would require its own baseline for measuring impacts:

1. For testing the effectiveness of dynamic rates, the baseline would be the customers' hourly load profile on the base rate – the rate that the customer otherwise would pay. For most customer classes today, this is likely to be a flat (non-time varying rate). Measuring the baseline might involve collecting hourly data for a period of time before the dynamic rate begins – for customers on dynamic pricing and for a control group of customers.
2. For testing the impact of providing real-time information about loads and prices to customers, baselines might include both (1) and a comparison of hourly load profiles of customers who pay the dynamic rate, but are not provided the additional information.
3. For cost savings associated with meter reading and service connections and disconnections, the appropriate baseline would be characterizing how the utility would otherwise handle these customer services but for the Smart Grid project. For example, would they send out meter readers using hand-held devices? Would they plan a gradual phase-in of some other form of automated meter reading?[11]

In characterizing the baseline, it is also important to distinguish between current practices and what the utility might do in the future, absent the Smart Grid investment. For example, the utility's distribution system in the "but for" case could also involve investing in new Smart Grid assets, but on a longer time table, i.e., when existing infrastructure reaches the end of its useful life and needs to be replaced.

In collecting information about the baseline, the analyst should have an in depth discussion with the appropriate utility project managers to get a better understanding of how things are done today, how things are likely to evolve in the future (the projected "but for" case), and how things would evolve in the proposed Smart Grid case.

5.3 Specifying the Experimental Design

Step 10: Describe the formal hypotheses to be tested for each experiment

The experimental design should produce results that will advance our understanding of where (in what locations), how (in what applications and functions), and why (system operating conditions, grid characteristics, climate, etc.) Smart Grid technologies perform as they do. It is important that the results be credible, verifiable and rigorous in their derivation.

An exhaustive decomposition of the cost and benefit statements yields a list of independent hypotheses subject to testing through experimentation. Each experiment should be focused on a single hypothesis, which can be confirmed or

[11] See EPRI report 1020855 Guidelines *for Designing Effective Energy Information Feedback Pilots: Research Protocols* for further information on for protocols for measuring feedback impacts

denied through analysis of measurements made during the experiment. Hypotheses should therefore be stated in terms of measurable, physical quantities, and should not be dependent upon assumptions such as manpower cost, or the variable cost of energy. Figure 5-3 below illustrates the ideal structure for the hypotheses statements.

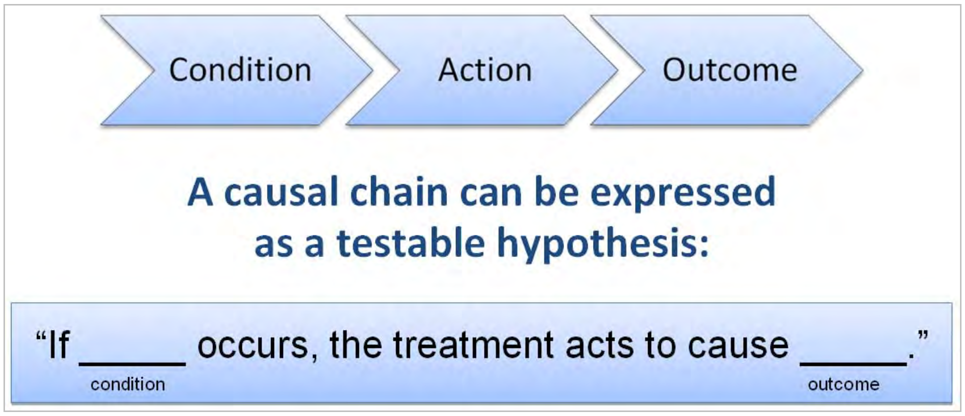

Figure 5-3
Demonstrating performance through testable hypotheses

The following are examples of focused hypotheses testable through experimentation:

- [Testable action] on the distribution feeders will result in X% improvement in utilization of the [specific asset].
- If a permanent fault occurs on a feeder, the system will re-energize all viable sections of the feeder within X seconds, thereby reducing customer outages by a percentage (%).

Where experimentation is inappropriate, observation of naturally occurring events and/or simulation of events may be required. For example, Distribution Automation equipment is designed to react to persistent faults on the distribution system that result in interruption of service to customers. Experimentation causing faults on live feeders would be inappropriate, so in this case continuous observation or simulation would be required.

In specifying the experimental design, there are a number of questions to be considered:

5.3.1 How will performance be measured?

Performance measures will be determined by the specific goal and might include:

- An improvement in the reliability of service (i.e., a reduction in the frequency, duration and geographic scope of outages)
- Reduction in line losses (the amount of kWh produced at one point in the system (such as the generator bus) compared to the kWh delivered at a point of delivery (such as a substation)

- For Volt/VAR performance:
  - Current
  - Real & reactive power
- Reductions in kWh or kW due to improved technologies or system operations
- Changes in kW or kWh consumed during specific time periods due to customer response to dynamic rates

The key is to focus the hypotheses on quantitative physical measures, and to avoid including variable assumptions, such as manpower-cost rates, that are independent of the experiment.

5.3.2 How Will the Experimental Design be Structured to Produce Accurate Impact Measures?

Step 11: Identify each experiment and describe how the experiment will be conducted.

The ideal approach would be to have a control group of projects that represent how the system would perform without the Smart Grid project, and pilot projects that apply the Smart Grid technologies so that the impacts could be measured in a statistically rigorous way while controlling for all corollary factors (weather, humidity, system conditions, outages, control actions, etc.). Unfortunately this ideal approach is rarely feasible, so less-ideal approaches must be undertaken, with attention in the design to measuring and tracking any necessary variables so that performance can be analyzed rigorously. Some of the alternatives might include:

- <u>Same Circuit with pre- and post-performance measurement</u>? i.e., track the operation of a given substation over a period of time before the SG equipment is installed, and then measure performance after it is installed? If so, what corollary data will be tracked and monitored to adjust for the effects of the different operating conditions in the pre- and post-performance periods? This acts to control for dynamic effects.
- <u>Same time period, different circuits, one with Smart Grid devices and one without</u>? Will performance be measured on two similar circuits over the same time period having similar environmental and loading conditions? If so, what corollary data will be tracked and monitored to adjust for the effects of the different operating conditions on the two different circuits?
- <u>One circuit, operating with and without Smart Grid devices on alternating days</u>? If so, what steps will be taken to ensure that the rigorous on/off operating schedule is actually followed, and what corollary data will be tracked and monitored to adjust for the effects of the different operating conditions on the alternating days?

Each of these approaches requires statistically rigorous analysis to produce valid, robust results, especially if the effect is small relative to the quantities being measured. Also, a sufficient amount of data must be collected for the result to be statistically valid, since the normal variations in the measured quantities may be greater than the effect.[12]

5.4 Developing a Project Timeline

Step 12 builds on the high-level table developed in step 4. The following step provides space to develop a detailed project timeline including deadlines for developing project documentation and for scheduling deployments.

Step 12: Develop a detailed project timeline through project design, implementation, analysis, and reporting.

The detailed project timeline should include the following project phases:

- Project Design – Developing proposal, internal approvals (budget and scope), obtaining regulatory approvals; pre-planning for equipment purchases and installation, development of marketing, communication and customer recruitment tools (if relevant), etc.
- Post-deployment scheduling – Provide schedule for when Post-deployment and baseline data will be gathered, analyzed, and reported (consistent with when technology deployed)
- Baseline measurement (if "pre" and "post" measurements are being used).
- Technology demonstration – during which the performance of the SG measures will be measured, data collection, etc.
- Post-processing, analysis and reporting.

Experiments should be organized and documented in such a way that the Smart Grid technology functionality tests produce measurable impacts. In order to produce valid and verifiable results it will be essential to coordinate when each test will be performed and to measure each time the effect associated with that treatment, not a combined effect resulting from another treatment concurrently applied. It is important to note this in the development of experiments, but also when documenting the detailed project timeline and measurement-and-verification protocols to be consistent in project documentation and to avoid overlap during project deployment.

[12] See EPRI report 1020855 Guidelines *for Designing Effective Energy Information Feedback Pilots: Research Protocols* for further information on the design of experiments.

Section 6: Establishing Measurement and Verification Protocols

For each Smart Grid function, it is necessary to specify a data collection plan. This data collection plan must specify costs and measurements that will be used to evaluate both the baseline performance and that of the Smart Grid equipment. At the system level, there are key physical points (meters, intelligent devices, communication infrastructure) where data can be collected. These data collection points, along with the specific instructions (time, interval, frequency, conditions), should be listed as part of project documentation.

Figure 6-1 below illustrates the difference between measures and metrics. This is important when a metric is not a single useful measurement or is a function of several measurements. For example, the mean reduction in energy to serve load associated with Conservation Voltage Reduction is a metric that cannot be directly measured. As discussed in Section 5, experiments produce observable, measurable quantities. The experimental hypotheses should be structured without cost factors or other data that are independent of the experiment. These other factors are properly brought into the analysis step that estimates changes in cost components or reliability indices (such as SAIFI and SAIDI). Identifying and collecting data in this sequential fashion forces attention to the baseline as a counterfactual (what would have been but for the experimental treatment) associated with a specific measurement. These measurements are input to algorithms which produce metrics.

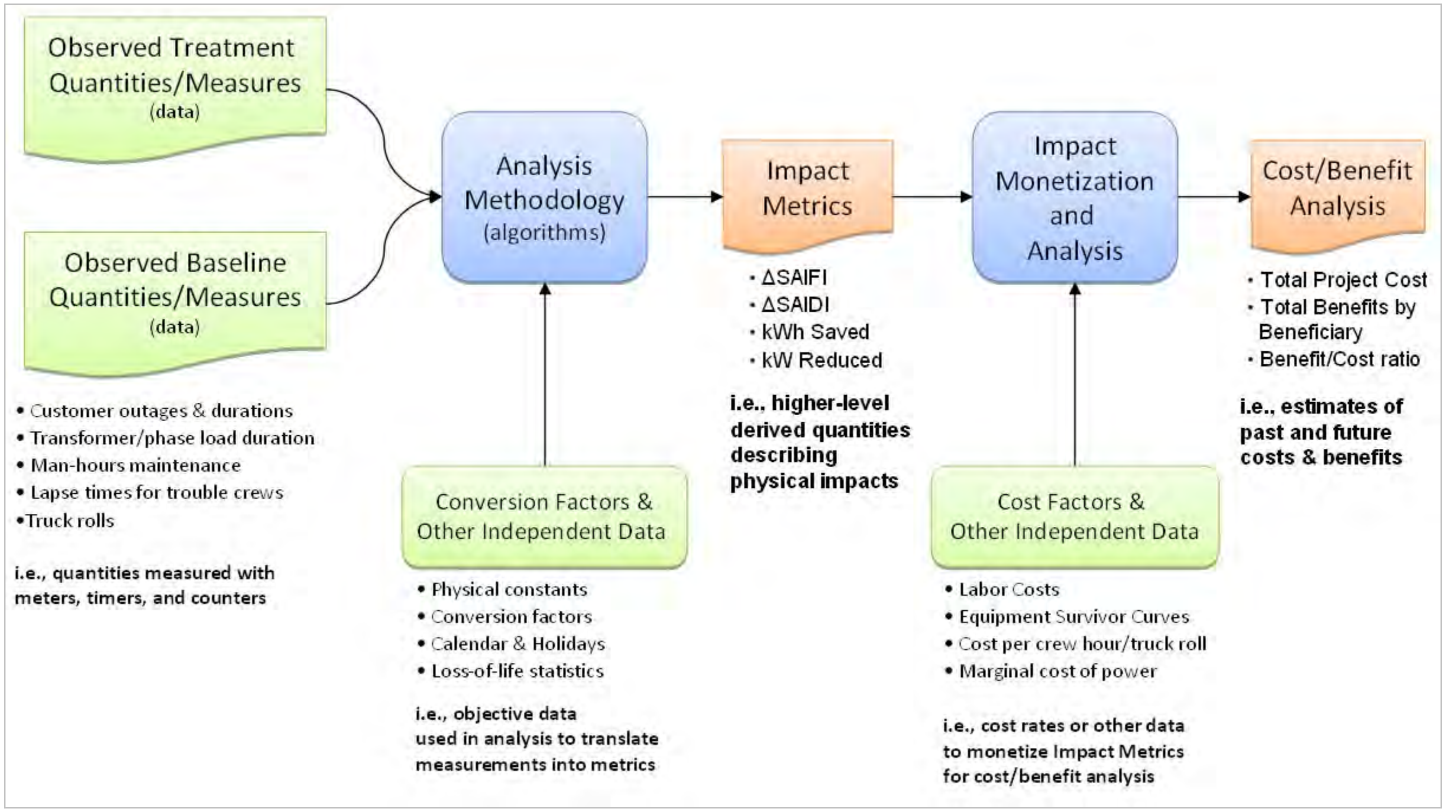

Figure 6-1
Measurements, Algorithms and Metrics

6.1 Identify Data Collection and Verification Protocols

A detailed plan for data collection, verification, and retrieval should be an integral part of the project design to assure that the relevant information for understanding both how the Smart Grid project performed and why. The performance metrics for both the baseline and the treatment groups should be identified including the physical measurement units and time intervals for measurement. To reiterate a point made in Section 5, it is imperative to coordinate when each test will be performed to avoid interactive effects that can skew the data.

6.1.1 Identify Physical Measurements and Time Intervals for Measurement

Step 13: Define the physical measurements

As part of a comprehensive and accurate cost benefit analysis plan, the physical measurements and time interval measurements for data should be documented at the appropriate level of detail for both the identified baselines and different experiments involved in the Smart Grid project. The first step is to determine the physical measurements and intervals to record measurements for each identified experiment.

Potential physical measures

- kW
- kWh
- interruptions (count and duration)
- losses
- asset loading
- switching and operations

Step 14: Define the time intervals for measurement

One important time dimension is the length of time for the experiment to be running. Is one month enough, or are one or two years required to produce meaningful results?

An additional and separate issue is what are the appropriate time intervals for data to be collected? Hourly? 15-minutes? Every five minutes?

Time intervals over which measurements may be recorded as follows:

- Minute-to-minute
- Every 15 minutes
- Hourly

- Weekly
- Monthly
- Annual
- Event-based
- Peak load conditions
- Other

6.1.2 Identify Corollary Data to be Collected and Time Intervals for Measurement

Step 15: Describe the external factors that will be accounted for to normalize the data sets

In addition to the performance measurements, what other conditions or effects must be measured in order to understand how and why performance might vary? Data for external factors such as climate, weather conditions, and abnormal system conditions should also be accounted for and interval measurements for these factors identified. For relevant environmental factors that can affect performance, measure at appropriate time intervals.

Corollary Data might include:

- Temperature
- Humidity
- Rainfall
- Insolation

Other system conditions that may be relevant to understanding performance include:

- Any abnormal disturbances (such as major storm, outages, line faults, planned outages), etc.
- All control movements (which can occur 20/30 times/day) and a note of the relevant performance measure immediately before and after each control action is taken.

Time Intervals

- Same as previous section

6.1.3 Data Collection Protocols

Once measurement units and time intervals for measurement have been identified the next step is to outline the data collection instructions. These protocols include the points for data collection, the location and instructions for data storage, and instructions for data retrieval at the time of analysis.

Documenting the software or other infrastructure used for housing the data and the reasoning for them may also be documented by project teams if necessary.

6.1.3.1 Key points for Data Measurement

Step 16: Identify data collection points and describe data collection instructions

The next step is to specify where in the system measurements will be taken. These data collection points and instructions should be specifically documented. General technology categories include:

- Substations
- Intelligent devices
- Communication infrastructure
- Customer meter, customer appliances, etc.

6.1.3.2 Data Testing, Screening, Storage and Retrieval

Step 17: Identify data testing, screening, storage and retrieval protocol

What steps will be taken to screen data for quality, missing observations, etc? After screening, where and how will the data be stored? Procedures such as simulation plans, lab testing, field testing and constraints should be analyzed in greater detail at this stage of analysis.

The data collection and access approach should include a method for aggregating and filtering data (e.g., searching for missing data, etc.) A method for performing a scan of data should be outlined to confirm that errors have been corrected if necessary and that all data required for the analysis has been accounted for.

Data should be stored within a database architecture that allows for access as needed to create system reports. A more sophisticated database scheme can also be devised to filter and forward performance data as it is gathered, thereby automating the data collection and reporting process.

Section 7: Next Steps

The *Guidebook for Cost/Benefit Analysis of Smart Grid Demonstration Projects* is envisioned as a guide presenting a comprehensive, step-by-step framework for conducting a cost/benefit analysis and reporting the results. The guidebook specifies the steps from the preliminary stage of identifying the problem or opportunity that prompted the project, to the communication of the analytical results to stakeholders. In total, the process from the onset of a project to completion of a cost/benefit analysis should take place over a period of several years. This volume describes in detail the first seventeen steps of the process, which deal with the initial project design phases that set plans for collection of data for use in subsequent cost benefit analysis. The release of this volume is to assist with projects in those early stages, while further development of cost/benefit analysis methods and processes continues in parallel.

Appendix A: Example Application: Volt/Var Optimization

The example application incorporated into this appendix provides a comprehensive illustration of how to follow the steps outlined in this document to prepare the detailed project documentation necessary to perform a cost/benefit analysis. The following example application works through steps 1-17 with a volt/var optimization example. Specifically, the example will illustrate the types of information required to prepare a robust research plan utilizing conservation voltage reduction (CVR) functionality.

2. Project Overview

The demonstration will implement and evaluate the Smart Grid technologies used to apply conservation voltage reduction (CVR) at the substation level. The demonstration seeks to reduce customer energy usage and reduce feeder losses, providing benefits to multiple stakeholders.

2.1 General Information

Step 1: Document project information at a high-level

Name of Project	Voltage/Var Optimization Smart Grid Demonstration Project
Lead Organization	XYZ Gas & Electric Company
Other Participants	XYZ Laboratory, EPRI, Department of Energy
Project Manager/Contact Information	John P. Manager / (xxx) xxx-xxxx / jpmanager@smartgrid.com
Planned Duration of Project	2 years
Total Budget	$5,000,000
Federal Cost Share	$2,500,000

2.2 Project Purpose

Step 2: Provide a general description of the problem to be solved, baseline, and project goals and objectives

2A) Problem or Opportunity Statement:

Supplying electricity at the proper voltage is not only desirable for high quality of service, but is regulated by the ANSI C84.1 standard which states that voltage at the residential meter must be within the range between 114.1–126.0 V. The current system of voltage control allows vars to be supplied from the substation or above, leads to voltage levels near the substation near the top of the ANSI range, while voltages at the ends of the feeder segments drop to the lower end of the range. Actively maintaining a reduced range of voltage from its highest point (usually, but not always, at the substation) to the low-voltage point (usually at the end of the feeder or one of its laterals), allows the average voltage on the feeder to be reduced, imperceptibly lowering customer loads and reducing losses along the feeder.

2B) Description of baseline ("but for") case(s):

Baseline 1: Customers energy usage level (kWh) continue to be consumed at existing levels

Baseline 2: Electricity losses continue at existing levels

2C) Project Goals and Objectives:

The main project goal is energy conservation through voltage reduction, and improving operational efficiency of the distribution system by reducing distribution line losses. Reducing the var loads that the distribution system presents to the transmission system will also reduce losses at the transmission and generation levels.

2.3 Project Summary

Step 3: Provide a high-level project summary

3A) Description of utility's service territory

XYZ Gas & Electric Company serves 1 million customers in the mid west region of the United States of which 800,000 are residential customers and 200,000 commercial customers. The XYZ Gas & Electric Company maintains 320 distribution substations, 1400 miles of distribution feeders, 15,000 miles of overhead distribution lines and 3500 miles of transmission lines.

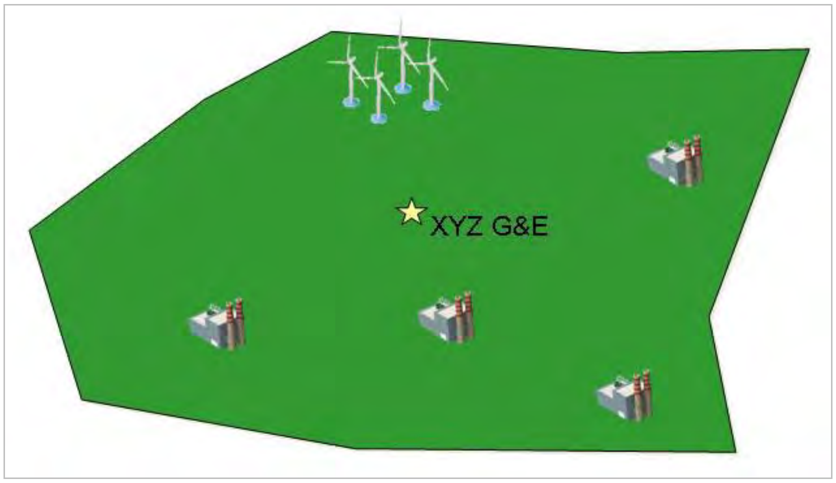

Figure A-1
Service Territory Graphic

3B) Describe the geographic scope of the project

The Voltage/Var Optimization Smart Grid Demonstration project will include "A" Substation, Circuit 1 and Circuit 2.

3C) Description of project elements (technologies, devices, systems, etc.):

- "A" Substation
- Transformer Load tap changer controls
- Line Capacitor bank controls
- Metering at substation level
- Metering at customer level
- Line voltage regulator controls
- 2-way communications
- SCADA system
- Distribution Management System (DMS)
- Line voltage sensors

3D) Description of functions the project will provide:

Advanced Voltage/Var Control

- Mechanisms:
  - Optimize voltage and var supply levels to decrease customer loads and distribution losses
  - Reduce emissions from carbon-based fuel
  - Reduce manual labor hours associated with capacitor switching and/or regulator operation

3E) Description of potential benefits expected:

- Reduce ancillary service costs
- Reduce T&D operations cost
- Reduce CO_2 / SOx / NOx / PM-10
- Reduce electricity losses
- Deferred distribution capacity investments
- Reduce maintenance cost

3F) Targeted customer groups (if relevant):

N/A

3G) Project Budget: $

- Equipment
- Installation expenses
- O&M

3H) Key Project Partners & Collaborators:

- Companies and Organizations
- Co-funders
- General description of roles and responsibilities

Table A-1
Key Project Partners and Collaborators

Role	Responsibility	Contact Name	Contact Information
EPRI Project Manager	•		
EPRI Lead Analyst	•		
EPRI Analyst	•		
Client Project Manager	•		
Client Technical Lead (per experiment)	•		
Baseline Test – Lead Contact	•		

3I) Market Structure (if relevant):

3J) Regulatory Authorities:

- Local, State & Federal (standards, land use, permits, zoning, etc.):
- Regulatory Commissions (Public Utility Commissions, FERC, etc.):

2.4 Project Timeline

Step 4: Develop a high-level project timeline

Table A-2
High-level Project Timeline

Task	Deadline
Project Development	
Project Summary Development	
Identify roles & responsibilities	
Outline project goals and objectives	
Develop project budget	
Identify project partners and collaborators	
Internal Approvals (Budget & Scope)	
External Approvals (Budget & Scope)	
Regulatory Approvals	
Local, State, Federal Approvals	
Regulatory Commission Approval	
Pre-Planning & Preparation	
Equipment Purchases	
Equipment Installation	
Marketing Material Development	
Communication & Customer Recruitment Material Development	
Baseline Measurements	
Identify duration for baseline measurement	
Field Implementation	
Technology installation (by project phase or sub-project)	
Data Collection	
Data collection (start - end)	
Data processing (start - end)	
Data analysis (start - end)	
Reporting	
Internal reporting (start - end) per requirement	
DOE reporting (if applicable)	
Other reporting requirements	

3. Defining the Research Problem

3.1 Problems to be Solved or Opportunities to be Pursued

Step 5: Define the research problem or opportunity that prompted the project

The system can currently be described as having limited voltage/var control ability. The traditional approach to voltage allows voltage to drop from substation to load, as long as it remains within the allowable range. As load varies throughout the year, combinations of voltage regulators and manually switched capacitors are used to maintain at least minimum acceptable voltage at the low points. While this approach may have minimized the amount of manual intervention and hardware needed to maintain voltage within range, it generally used the full range of allowable voltages, and allowed var loads to be served to some extent from the substation or the transmission system.

Questions to be addressed for each problem or opportunity for improvement may include:

- What adverse impacts have been observed?

  Electrical load devices generally are designed to operate normally at any voltage within the standard range of 114.1-126.0 V, but most of them consume more energy at the high end of the range and less at the low end. Consequently, devices located in the high-voltage areas of a feeder consume more energy than required for their operation. Since consumers are generally indifferent to device performance within the voltage range, the extra energy consumption can be considered end-use losses. Also, losses are higher on distribution transformers at higher voltage levels, and flow of vars from source to load contributes to distribution line losses.

- What could be done to address observed impacts using current technologies?

  Current technologies could be used to provide greater var support closer to loads, but closer matching of manually switched vars to var loads requires more interactivity than the traditional system has required.

- What new technologies are being considered?

  Volt/Var control uses automatically controlled capacitors to supply variable amounts of vars along the feeder, and controls regulators such that the voltage drop along the feeder is monitored and controlled. This flattening of the voltage profile allows operators to lower the voltage at the high point of the circuits. Reducing voltage levels, in turn, reduces energy consumption of many common electrical load devices, generally in ways that are imperceptible to the customers using them. Losses on the distribution system are also reduced because of lower voltage on transformers and lower var flows.

3.2 Programs and Policies

Step 6: Describe any relevant programs or policies that are pertinent to the project

- What types of regulatory policies or business practices constitute barriers to overcome or opportunities for improvement?
- What rates, policies, programs or practices are required to achieve the result?

4. Identifying Technologies to be deployed

Step 7: Describe the technologies to be deployed and the associated functions that will be enabled for the project including how they work and interact with one another.

The project will install an advanced Volt/var control (VVC) system that consists of load tap changers, capacitor banks, and other associated equipment. VVC uses algorithms, communication systems and intelligent devices to manage a voltage profile in a range between 126 V and 114V. Lower voltage can be supplied at the substation because voltage levels are supported downstream by capacitors and regulators, resulting in lower average voltage levels across the circuit. Operating a feeder at lower average voltage reduces energy consumption by a variety of consumer load devices, and reduces line and transformer losses.

Table A-3
Smart Grid Technologies

(See Table 4-1 and Table 4-2 for examples)

Technologies Deployed	Interactions among devices, systems, and operators
Remote Terminal Unit	An intelligent device, located at the substation, that interfaces SCADA and field devices, such as LTC controller, the feeder circuit breaker, and protective relays.
Transformer load tap changer controller	Responds to commands from the controller setting tap position, reporting position and various measurements to the Controller.
Line capacitor bank controls	Receives and responds to commands from the controller and reports data and alarms to VVO controller
SCADA system	Allows operators to issue control commands to various devices, retrieves data from devices and systems, including the VVO Controller, Line Capacitor Controllers, the RTU, and Voltage Sensors.
Distribution Management System (DMS)	Provides interface between human distribution operators, the SCADA system, and various systems providing state information and modeling capability of the distribution system.

Table A-3 (continued)
Smart Grid Technologies

Technologies Deployed	Interactions among devices, systems, and operators
Line voltage sensors	Measures voltage where installed, making data available through SCADA
Volt/Var Optimization (VVO) controller	A device that interacts with RTUs and field devices such as line capacitor controllers

Enabled Functions:

- Automatic volt/var control
- Conservation voltage reduction

Key Performance Data:

- Automatic volt/var control
  - Reduction in circuit voltage drop
  - Increase in circuit power factor at substation
- Conservation voltage reduction
  - Reduction in voltage at the substation
  - Reduction in average voltage on the circuit
  - Reduction in consumer loads
- Expected Lifetime:
  - With routine maintenance, the system is expected to operate for 15 years.

5. Developing a Research Plan

5.1 Identifying Potential Project Impacts

Step 8: Estimate project impacts [From Table 5-2]

For Volt-Var control:

- Deferred generation capacity investments
- Reduced Ancillary Services cost
- Reduced distribution operations cost
- Reduced electricity losses (including end-use losses)
- Reduced CO_2 emissions
- Reduced SOx, NOx, and PM-10 emissions

5.2 Establishing the Baseline

Step 9: Describe the baseline(s) that are required to measure performance of the technologies and/or applications.

Number of Baselines needed: (One for each major project goal or experiment)

Baseline 1: Baseline demand and energy consumption measurements (kW, kWh) for CVR determination on each feeder will be extracted using day on/day off operation using regression analysis to adjust for daily weather differences.

5.3 Specifying the Experimental Design

Step 10: Describe the hypotheses to be tested for each experiment.

H_1: Actively controlling capacitors distributed on a feeder can reduce the voltage drop (from high point to low point) by 50%.

H_2: If the average voltage on the project (treatment) circuits is reduced, then consumption (kW) will be reduced at an estimated rate of 1% energy savings for every 1% voltage reduction.

Step 11: Identify each experiment and describe how the experiment will be conducted.

Experiment 1: The Volt/Var Control (VVC) system will be operated so as to minimize voltage difference between the circuit's high-voltage and low-voltage points, while maintaining substation voltage at normal levels. Subsequent analysis will determine the voltage drop and the average circuit voltage, and the differences between measurements on alternating days with control on or off.

Experiment 2: The VVC system will be implemented to reduce consumption through the regulation of voltage across the entire circuit. Having determined the ability of the system to reduce voltage drop on the feeder, the voltage will be lowered at the tap on alternating days, while interval real and reactive power measurements are recorded. Subsequent analysis will use regression to estimate the reduction in real and reactive power associated with each percent of voltage at the substation.

5.4 Developing a Project Timeline

Step 12: Develop a detailed project timeline through project design, implementation, analysis, and reporting.

Table A-4
Detailed Project Timeline

Task	Deadline
Project Design	
Research Plan Development	
Establish baseline(s)	
Identify baseline measurements	
Schedule for baseline data gathering	
Document experimental design	
Identify hypotheses	
Test Plan Development	
Specify experiment schedules	
Experiment 1	
Experiment 2	
Experiment 3	
Data Collection Plan Development	
Data Collection Protocol development	
Data Storage Protocol development	
Data Retrieval Protocol development	
Data Screening Protocol development	
Smart Grid Technology Deployment	
Schedule for data gathering	
Schedule for data analysis	
Schedule for report results	

6. Establishing Measurement and Verification Protocols

6.1 Identify Data Collection and Verification Protocols for each baseline and experiment

Step 13: Define the physical measurements

Physical Measurements (kW, kWh, outage times, , etc.):

- **Baseline 1:** Power (W), Reactive Power (var), Voltage(V) (in VVC-off condition)
- **Baseline 2:** Power (W), Reactive Power (var), Voltage(V) (in VVC-off condition)
- …
- **Baseline N:**

- **Experiment 1:** Power (W), Reactive Power (var), Voltage(V) (in VVC-on condition)
- **Experiment 2:** Power (W), Reactive Power (var), Voltage(V) (in VVC-on condition)
- …
- **Experiment N:**

Step 14: Define the time intervals for measurement

Time Intervals over which measurements are recorded (minute, 15-minute, hourly, weekly, monthly, annually, event-based, etc.):

- **Baseline 1:** 15-minute interval with VVC off
- **Baseline 2:** 15-minute interval with VVC off
- …
- **Baseline N:**

- **Experiment 1:** 15-minute interval, with VVC on
- **Experiment 2:** 15-minute interval, with VVC on
- …
- **Experiment N:**

Step 15: Describe the external factors that will be accounted for to normalize the data sets

Table A-5
Corollary Data for Measurement

Baseline/ Experiment	Temperature	Humidity	Wind Speed	System Conditions	Abnormal Disturbances
Baseline 1 VVC-Off					As logged
Baseline 2 VVC-Off	Hourly @ Substation				As logged
…					
Baseline N					
Experiment 1 VVC-On					As logged
Experiment 2 VVC-On	Hourly @ Substation				As logged
…					
Experiment N					

Step 16: Identify data collection points and describe data collection instructions

- Feeder real and reactive power, voltage, measured in 15-minute intervals at the breaker
- Voltage, at each measuring device on the feeder, i.e., capacitors, reclosers, and regulators capable of reporting, and voltage sensors at points near critical low-voltage points on the feeder
- Tap position and voltage on the tap-changing transformer

Step 17: Identify data testing, screening, storage and retrieval protocol

- Data testing and screening protocols:

  [Readings from all sensors and meters should be tested to verify that the readings are valid and are consistent with the physical situation. If a detailed circuit model is available, the readings can be tested for reasonableness by comparing with model results. Ranges of validity for each data item should be set for routine comparison to raise alarms if readings begin to fall out of range.]

- Data storage and retrieval protocol:

[Specifies the data items, their duration, and their specific location, in either a special purpose database or among the various databases the utility maintains.]

Next Steps

In total, the process from the onset of a project to completion of a cost/benefit analysis should take place over a period of several years. These first seventeen steps of the process, which deal with the initial project design phases that set plans for collection of data for use in subsequent cost benefit analysis. The release of this volume is to assist with projects in those early stages, while further development of cost/benefit analysis methods and processes continues in parallel.

Appendix B: Cost-Benefit Analysis Templates

Cost/Benefit Analysis Process Checklist

☐ **Step 1:** Specify project information at a high-level

☐ **Step 2:** Provide a general description of the project purpose including 1) the problem or opportunity statement, 2) baseline description, and 3) project goals and objectives

☐ **Step 3:** Provide a high-level project summary

☐ **Step 4:** Provide a high-level project timeline

☐ **Step 5:** Define the research problem or opportunity that motivated and authorized the project

☐ **Step 6:** Describe any relevant programs or policies that are pertinent to the project

☐ **Step 7:** Describe the technologies to be deployed and the associated functions that will be enabled for the project.

☐ **Step 8:** Estimate project impacts

☐ **Step 9:** Describe the baseline(s) that are required to measure performance of the technologies and/or applications

☐ **Step 10:** Describe the formal hypotheses to be tested for each experiment

☐ **Step 11:** Identify each experiment and describe how the experiment will be conducted.

☐ **Step 12:** Develop a detailed project timeline through project design, implementation, analysis, and reporting

☐ **Step 13:** Define the physical measurements

☐ **Step 14:** Define the time intervals for measurement

- ☐ **Step 15:** Describe the external factors that will be accounted for to normalize the data sets
- ☐ **Step 16:** Identify data collection points and describe data collection instructions
- ☐ **Step 17:** Identify data testing, screening, storage and retrieval protocol
- ☐ **Step 18:** Calculate physical impact measurements by beneficiary group
- ☐ **Step 19:** Convert physical impact measurements to monetary values
- ☐ **Step 20:** Identify Smart Grid functions that create benefits for multiple beneficiaries
- ☐ **Step 21:** Estimate costs incurred by the customer per year for baseline and project
- ☐ **Step 22:** Estimate utility costs by function and classification for baseline and project
- ☐ **Step 23:** Summarize costs and benefits
- ☐ **Step 24:** Communicate results

2. Project Overview

2.1 General Information

Step 1: Specify project information at a high-level

Name of Project	
Lead Organization	
Other Participants	
Project Manager/Contact Information	
Planned Duration of Project	
Total Budget	
Federal Cost Share	

2.2 Project Purpose

Step 2: Provide a general description of the problem or opportunity statement, baseline, and project goals and objectives

2A) Problem or Opportunity Statement

2B) Description of baseline ("but for") case(s)

Baseline 1:

Baseline 2:

Baseline 3:

…:

Baseline N:

2C) Project Goals and Objectives

2.3 Project Summary

Step 3: Provide a high-level project summary

3A) Description of utility's service territory

3B) Describe the geographic scope of the project

3C) Description of project elements (technologies, devices, systems, etc.)

3D) Description of functions the project will provide

3E) Description of potential benefits expected

3F) Targeted customer groups (if relevant)

3G) Project Budget: $

3H) Key Project Partners & Collaborators

- Companies and Organization
- General description of roles and responsibilities

Role	Responsibility	Contact Name	Contact Information
EPRI Project Manager	•		
EPRI Lead Analyst	•		
EPRI Analyst	•		
Client Project Manager	•		
Client Technical Lead (per experiment)	•		
Baseline Test – Lead Contact	•		

- Co-funders

3I) Market Structure (if relevant)

3J) Regulatory Authorities

- Local, State & Federal (standards, land use, permits, zoning, etc.)
- Regulatory Commissions (Public Utility Commissions, FERC, etc.)

2.4 Project Timeline

Step 4: Develop a high-level project timeline

Task	Completion Date
1.	
2.	
3.	
…	
N	

3. Defining the Research Problem

3.1 Problems to be Solved or Opportunities to be Pursued

Step 5: Define the research problem or opportunity that motivated and promoted the project

Questions to be addressed for each problem or opportunity for improvement may include:

- What adverse impacts have been observed?
- What could be done to address observed impacts using current technologies?
- What new technologies are being considered?

3.2 Programs and Policies

Step 6: Describe any relevant programs or policies that are pertinent to the project

- What types of regulatory policies or business practices constitute barriers to overcome or opportunities for improvement?
- What rates, policies, programs or practices are required to achieve the result?

4. Identifying Technologies to be deployed

Step 7: Describe the technologies to be deployed and the associated functions that will be enabled for the project.

Smart Grid Functions
(See Table 4-1 and Table 4-2 for examples)

1.

2.

3.

N.

Smart Grid Technologies
(See Table 4-1 and Table 4-2 for examples)

1. Technology 1:
   - Intended Application:
   - Key Performance Data:
   - Expected Lifetime:
2. Technology 2:
   - Intended Application:
   - Key Performance Data:
   - Expected Lifetime:
3. Technology 3:
   - Intended Application:
   - Key Performance Data:
   - Expected Lifetime:
4. Technology N:
   - Intended Application:
   - Key Performance Data:
   - Expected Lifetime:

5. Developing a Research Plan

5.1 Identifying Potential Project Impacts

Step 8: Estimate project impacts

Table 5-1 maps Smart Grid assets to the functions they could be used to provide. Table 5-2 then shows the linkages between the Smart Grid functions to the impacts they could create.

Table 5-2
Linkage of Smart Grid Assets to Functions

Smart Grid Assets	Functions												
	Transmission Level		Distribution Level						Substation Level			Customer Level	
	Flow Control	Wide Area Monitoring and Viasualization	Adaptive Protection	Automated Feeder Switching	Automated Islanding and Reconnection	Automated Volt/VAR Control	Enhanced Fault Protection	Real-time Load Transfer	Diagnosis & Notification of Equipement Condition	Dynamic Capability Rating	Fault-Current Limiting	Customer Electricity Use Optimization	Real-time load Measurement and Management
Advanced Interrupting Switch							■						
AMI/Smart Meters						■						■	■
Controllable/regulating Inverter					■	■							
Customer EMS/Display Portal												■	
Distribution Automation			■	■	■	■		■					
Distribution Management System			■	■	■	■		■		■			■
Enhanced Fault Detection Technology							■						
Equipment Health Sensor									■	■			
FACTS Device	■												
Fault Current Limiter											■		
Loading Monitor								■	■	■			
Microgrid Controller					■								
Phase Angle Regulating Transformer	■												
Phasor Measurement Technology		■											
Smart Appliances and Equipment (Customer)												■	
Software – Advanced Analysis/Visualization		■								■			
Two-way Communications (high bandwidth)		■	■	■	■	■		■					■
Vehicle to Grid 2-way power converter													
VLI (HTS) cables	■												

Table 5-2
Linkage of Smart Grid Functions to Benefits

Benefits			Functions: Transmission Level		Distribution Level						Substation Level			Customer Level		Energy Resources		
			Flow Control	Wide Area Monitoring & Visualization	Adaptive Protection	Automated Feeder Switching	Automated Islanding and Reconnection	Automated Volt/VAR Control	Enhanced Fault Protection	Real-time Load Transfer	Diagnosis & Notification of Equipment Condition	Dynamic Capability Rating	Fault Current Limiting	Customer Electricity Use & Optimization	Real-time Load Measurement and Management	Distributed Generation	Stationary Electricity Storage	Plug-in Electric Vehicles
Economic	Improved Asset Utilization	Optimized Generator Operation		■													■	■
		Deferred Generation Capacity Investments												■		■	■	■
		Reduced Ancillary Service Cost		■				■							■	■	■	■
		Reduced Congestion Cost	■	■								■				■	■	■
	T&D Capital Savings	Deferred Transmission Capacity Investments	■	■								■	■	■		■	■	■
		Deferred Distribution Capacity Investments								■		■		■	■	■	■	■
		Reduced Equipment Failures							■		■	■	■					
	T&D O&M Savings	Reduced Distribution Equipment Maintenance Cost									■							
		Reduced Distribution Operations Cost				■		■										
		Reduced Meter Reading Cost													■			
	Theft Reduction	Reduced Electricity Theft													■			
	Energy Efficiency	Reduced Electricity Losses						■		■				■	■		■	
	Electricity Cost Savings	Reduced Electricity Cost												■			■	
Reliability	Power Interruptions	Reduced Sustained Outages			■	■	■		■		■				■	■	■	■
		Reduced Major Outages		■			■								■			
		Reduced Restoration Cost			■	■			■		■							
	Power Quality	Reduced Momentary Outages							■	■							■	
		Reduced Sags and Swells							■								■	
Environ-mental	Air Emissions	Reduced CO_2 Emissions	■			■		■						■	■	■	■	■
		Reduced SOx, NOx and PM-10 Emissions	■			■		■						■	■	■	■	■
Security	Energy Security	Reduced Oil Usage (not monetized)				■					■				■			■
		Reduced Wide scale Blackouts		■					■			■						

5.2 Establishing the Baseline

Step 9: Describe the baseline(s) that are required to measure performance of the technologies and/or applications.

Number of Baselines needed
(One for each major project goal or experiment)

Baseline 1:

Baseline 2:

Baseline 3:

…:

Baseline N:

5.3 Specifying the Experimental Design

Step 10: Describe the formal hypotheses to be tested for each experiment.

Step 11: Identify each experiment and describe how the experiment will be conducted.

-
-
-

5.4 Developing a Project Timeline

Step 12: Develop a detailed project timeline through project design, implementation, analysis, and reporting.

6. Establishing Measurement and Verification Protocols

6.1 Identify Data Collection and Verification Protocols for each baseline and experiment

Step 13: Define the physical measurements

Physical Measurements (kW, kWh, outages, losses, asset utilization, etc.)

Baseline 1:

Baseline 2:

Baseline 3:

…:

Baseline N:

Experiment 1:

Experiment 2:

Experiment 3:

…:

Experiment N:

Step 14: Define the time intervals for measurement

Time Intervals over which measurements are recorded (minute, 15-minute, hourly, weekly, monthly, annually, event-based, etc.)

Baseline 1:

Baseline 2:

Baseline 3:

…:

Baseline N:

Experiment 1:

Experiment 2:

Experiment 3:

…:

Experiment N:

Step 15: Describe the external factors that will be accounted for to normalize the data sets

Baseline/ Experiment	Temperature	Humidity	Wind Speed	System Conditions	Abnormal Disturbances
Baseline 1					
Baseline 2					
Baseline 3					
…					
Baseline N					
Experiment 1					
Experiment 2					
Experiment 3					
…					
Experiment N					

Step 16: Identify data collection points and describe data collection instructions

Step 17: Identify data testing, screening, storage and retrieval protocol

- Data testing protocol
- Data screening protocol
- Data storage protocol
- Data retrieval protocol

Appendix C: Definitions and Acronyms

Acronyms

AMI: Advanced Metering Infrastructure

CBA: Cost Benefit Analysis

DOE: United States Department of Energy

DER: Distributed Energy Resources

EMS: Energy Management System

EPRI: Electric Power Research Institute

FACTS: Flexible Alternating Current Transmission Systems

HTS: High-Temperature Superconductor

O&M: Operations and Maintenance

RTU: Remote Terminal Unit

SG: Smart Grid

VLI: Very Low Impedance

VVC: Volt/Var Control

VVO: Volt/Var Optimization

Definitions

Baseline: A counterfactual scenario or data series corresponding to what would have been, but for the experimental treatment

Goals: A long-term, general description of what is to be achieved

Objectives: Associated with a specific goal, but includes a short-term tangible action that can be measured

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Together...Shaping the Future of Electricity

Programs:

PDU Demonstrations

Smart Grid Demonstrations

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