Wiring the Smart Grid for Energy Savings: Mechanisms and Policy Considerations

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ABSTRACT

The smart grid is often promoted as a pathway to save energy and reduce greenhouse gas (GHG) emissions. However, smart grid data, communications, and controls infrastructure only “enables” energy savings and renewable energy opportunities. This paper discusses energy savings opportunities through four key mechanisms: improved energy use information, dynamic pricing programs, automated diagnostics, and improved program delivery. We discuss technical challenges to achieving energy savings using the smart grid infrastructure across building types, such as the need for commercial buildings to have properly functioning controls. Against a backdrop of current smart grid policies, we discuss the relationship between smart grid and GHG emissions reductions from a policy perspective. These include understanding the GHG emissions reduction potential from smart grid, barriers to using smart grid to enable energy savings, and policies that might address these barriers. We conclude with a discussion of energy savings opportunities through smart grid. We aim to expand the dialogue on the intersection of smart grid and energy savings and to highlight opportunities for engagement by the efficiency community.

Introduction

Energy savings and GHG emissions reductions are cited often as significant benefits from a smart grid. Yet, there has been little focus on how this will happen. The smart grid is often seen as a specific technology, usually smart meters, which by the simple fact of their installation will achieve energy savings. However, smart meters are only tools for collecting information on how our buildings use energy. It’s what we do with the information that matters.

This paper provides clarity on the technical mechanisms through which energy savings in buildings can be achieved utilizing the smart grid infrastructure. We provide an overview of challenges to achieving these savings from a policy perspective and highlight options for moving forward. We conclude by summarizing new opportunities for energy savings, such as enhanced energy efficiency programs, that could transform the energy industry. Our aim is to contribute to a dialogue that may help steer smart grid deployments towards achieving deeper and more persistent energy savings. We limit the scope of our paper to energy savings, although renewable electricity and distributed generation are additional areas of smart grid potential.

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Background

Prior to outlining energy savings mechanisms and policy issues, we set the stage with a smart grid definition, describe the preparedness of buildings to integrate with the smart grid infrastructure, and provide a brief overview of policy issues.

Smart Grid and Energy Savings

The Electric Power Research Institute (EPRI) defines the smart grid as: "The overlaying of a unified communications and control system on the existing power delivery infrastructure to provide the right information to the right entity (e.g. end-user devices, T&D system controls, customers, etc.) at the right time to take the right action" (Electric Power Research Institute, 2008). Smart grid infrastructure falls into three categories (Global Smart Energy, 2008):

- Intelligent devices such as smart meters, sensors and grid aware equipment
- Networking technology for two-way communications, including pathways like cable, Wi-fi or power line carrier
- Advanced control and data management systems that provide automated decision-making on the supply and demand sides, and meter data management systems

A two-way grid will accommodate applications to manage generation, transmission, distribution, and electric loads. There are opportunities to save energy using the smart grid infrastructure in transmission and distribution networks (e.g., reducing line losses, optimized voltage control) and at the building level. This paper focuses on energy saving opportunities related to the smart grid from residential and commercial buildings.

Two recent reports, an EPRI study (EPRI, 2008) and a Pacific Northwest National Laboratory study (Pratt et. al, 2010), describe mechanisms for electricity savings from smart grid and estimate national level electricity savings potentials.

Readiness of Buildings for a Smart Grid

Smart grid infrastructure and applications have the potential to help save energy in buildings. However, to achieve these savings, buildings must function well and be controllable. Smart grid technologies will not save energy in buildings if a building's energy-consuming systems do not meet a minimum level of functionality, and if homeowners or building operators do not have the means to act upon the information they receive from the smart grid.

Using the smart grid to facilitate demand response programs will require well-performing buildings. Poorly operating control systems can reduce the effectiveness of demand response programs since the building may not be able to respond quickly or adequately to reduce demand when necessary. Furthermore, demand reduction schemes that are implemented in poorly controlled buildings may lead to occupant complaints.

The commissioning process for new and existing buildings addresses integration issues for building systems. As smart grid infrastructure is built, commissioning should be extended beyond the building to integrate a building's systems with the grid. Without this, demand response resources may not be reliable. Further, the automated diagnostics that will evolve with the smart grid requires commissioning expertise to find root causes of problems and fix them. The commissioning industry is well-positioned to help buildings work with the smart grid.

Policy Background

Title XIII of the Energy Independence and Security Act of 2007 (EISA) lays the foundation for federal smart grid activities. EISA describes smart grid infrastructure, and application and calls for the development of interoperability standards and the smart grid investment grants and demonstration projects.

Federal funding. The American Recovery and Reinvestment Act (ARRA) appropriated $3.4 Billion for the Smart Grid Investment Grant (SGIG) and $0.6 Billion for the Smart Grid Demonstration Projects (SGDP). The SGIG program funds smart grid projects in manufacturing, customer systems, advanced metering infrastructure (AMI), transmission and distribution (T&D), and cross-cutting systems. Roughly 90% of SGIG funding has been awarded to AMI and cross-cutting systems (which typically include AMI), and 10% for T&D. The SGDP provides $0.6 Billion for storage and regional demonstration projects, with 70% of the funding awarded to the latter. These projects will explore issues such as consumer energy use, cybersecurity, and PHEV integration. Data were taken from OpenEnergyInfo (2010). For context, ARRA provides $17 Billion for efficiency and renewable energy (Congressional Research Service, 2009).

Standards. The National Institute of Standards and Technologies (NIST) leads the development of interoperability standards. Interoperability allows different systems to integrate and communicate seamlessly, such as the ability for smart meters to communicate with energy management control systems. The NIST effort includes engaging stakeholders though a public process to identify relevant existing standards and set priorities; establishing a private-public partnership to develop standards; and developing a testing and certification framework. An interoperability roadmap and series of workshops are complete and the final stage should be complete in 2010 (NIST, 2010).

State and local. States and utilities are active in smart grid activities, particularly in the implementation of AMI. Roughly 30 states have AMI penetration of greater than 50%, with most remaining states at a partial deployment (Institute for Energy Efficiency, 2010). For regulated utilities, state public utility commissions approve AMI and smart grid deployments based on their costs and benefits. AMI deployments have been largely approved, despite the uncertainty in benefits, due to factors like uncertainty of consumer behavior (Hornby, 2009). Some local projects, such as Boulder’s SmartGridCity and Austin’s Pecan Street project, take a systems approach to smart grid and incorporate elements beyond AMI.

Mechanisms for Energy Savings through Smart Grid

We discuss four key mechanisms for saving energy with the smart grid infrastructure: information and feedback, dynamic pricing programs and price signal, automated diagnostics, and improved program delivery. Table 1 maps these mechanisms to approaches by building sector. Supporting information to Table 1 is provided in the subsections that follow.

Table 1. Energy Savings using Smart Grid Infrastructure by Building Sector

	Energy Information to Consumers	**Dynamic Pricing and Demand Response (DR)**	**Automated Diagnostics**	**M&V of Energy Savings**
Residential	Smart meters with web or in-home interface display total energy use & end-uses that are SG-integrated	Some HVAC energy savings due to DR	If thermostat & water heater data, can do some diagnostics. Difficult at whole home level due to variable use patterns.	Especially if disaggregate loads, M&V of energy savings can be good quality
Small/ Medium Commercial	Service contractor views and acts on smart meter data. Large chains may do this as internal function.	HVAC and lighting energy savings due to DR	Cooling/ heating efficiency, economizer, baseload, off-hours use, abnormal lighting or water heating (with thermostat and water heater status)	Same as residential
Large Commercial	Use smart grid products and services to improve use of existing interval data.	Same as small/ medium commercial	Hard to disaggregate loads from whole building meter data for complex systems, but simple diagnostics are still useful	M&V without disaggregation of loads if pre and post time period sufficient and savings are significant relative to model uncertainty.

Energy Savings from Information

Energy savings from the smart grid are most often credited to increased consumer awareness of energy use and consequent changes in behavior. Smart meters can be coupled with web-based energy use displays or other interfaces to provide constant feedback on energy use that may motivate consumers to change their behavior in order to waste less energy. Residential studies on behavioral programs have shown that frequent feedback raises energy awareness and lowers energy consumption by ~11% on average (Darby, 2006); however these savings are highly variable and the persistence of savings is unclear. As smart grid pilots and deployments become more prevalent, analysis is needed on the behavioral effects of improved energy use information, the best means for communicating data, and ways to achieve lasting savings.

Consumer applications of energy information require a data interface, education on how to use the information to manage energy, and ideally, automated means for implementing consumer preferences. Where only whole building/home data are available, consumers may not know the reason for the increased energy use or what they can do to curb it. If smart appliances and submeters are integrated into building energy management systems, consumers may gain a more clear understanding on how to reduce end-use energy consumption.

The means for achieving energy savings due to improved information varies by building sector. For residential, the penetration of smart meters with home area networked loads is early in its adoption and is a more likely path for higher income households. In small commercial buildings without energy management staff, there are opportunities for heating, ventilation and air conditioning (HVAC) service contractors to aggregate smart grid data, and review and benchmark energy use across multiple sites. Energy information for large commercial buildings may be easier to obtain since most of these buildings already have interval meters (one-way communication from building to utility of 15 minute energy data). However, analysis of this data and feedback to building owners is not common. In the future, large commercial buildings could also benefit from using smart grid data management tools and systems to improve the utilization of existing interval meter data or data from new smart meters.

Energy Savings from Dynamic Pricing Programs and Price Signal

Utility pricing programs give consumers a role in managing their energy use based on the cost of power at a given time. In addition to demand reduction, energy savings can be achieved through demand response programs, but only if electricity consumption is not simply shifted to another time. Although demand response programs haven't traditionally been designed to lower energy consumption, time of use and critical peak pricing in the residential sector resulted in an average of 4 percent energy savings (King and Delurey, 2005).

The magnitude of energy savings from dynamic pricing programs depends on two main issues: 1) how high prices peak, which will drive energy use behavior, and 2) the type of loads that are managed and whether these loads will be used at the same level at a later time. The latter effect (i.e., load shifting) depends on the operating schedule, duration of peak pricing, and climate. The simplest example of energy savings due to demand reduction occurs with lighting. Occupants do not use more lighting later and there is a net conservation effect. Conversely, reducing electric dryer loads during peak times only shifts demand to a later time.

Energy Savings from Automated Diagnostics

Smart grid capabilities may help achieve energy savings through the widespread deployment of automated diagnostic algorithms for both commercial and residential buildings. While the two-way communications feature of a smart grid is not required for diagnostics (these tools can be implemented at the building site with local data), it is useful to think about what benefits the smart grid might bring to this emerging field. Having ubiquitous interval meter data for all buildings on a common platform is a major advancement, especially for smaller buildings.

New tools will be needed to process continuous streams of data. Whole-building meter data, which will be readily available with a smart grid, can be used to detect certain types of building energy waste by identifying baseload and peak operation patterns, off-hours usage, relative cooling/heating efficiency, and when outside air is not being leveraged for free cooling. By augmenting the meter data with equipment status data, end-use loads can often be disaggregated. For instance, if thermostat heating or cooling status and electric water heater status were available, those loads could be disaggregated from the whole building energy usage to provide finer granularity for diagnostics. Residential and small commercial applications are most amenable to this load disaggregation approach. Large commercial systems are generally too complex to be treated with this method, however, the diagnostics attainable using solely whole building interval meter data would still be useful for large commercial buildings.

Savings Related to Improved Program Delivery

Smart grid rollouts could lead to energy savings by enhancing the delivery of efficiency programs. For this paper, energy saving programs include utility programs, government programs, and energy management programs run by owners for portfolios of buildings.

By analyzing the electric data that will be available through a smart grid infrastructure, program planning, implementation, and evaluation activities can be streamlined to reduce cost and improve available information. Potential avenues include:

- Assessing potential energy savings in key target markets that can influence program design
- Tracking energy benchmarks by building sector over time to save time preparing market impact assessments or to incorporate into benchmarking tools to augment Commercial Buildings Energy Consumption Survey (CBECS) data for comparison groups
- Using data for energy measurement and verification (EM&V) of savings from energy efficiency programs, which may lead to significant cost savings compared to conventional on-site evaluation processes. The extent of applicability of site-level EM&V using interval meter data depends on how consistent the building energy consumption is over the baseline and post periods and the percent savings to be measured.
- Going beyond savings verification to track energy performance over time. Current program designs focus on the immediate gains of efficiency and conservation; there is a need to ensure persistence of energy savings.

Improved program delivery may achieve indirect energy savings in two ways: 1) Cost savings from reduced program costs could be invested to achieve more energy savings, and 2) Through improved confidence that energy savings have materialized, there may be more willingness to incent hard-to-calculate measures, or measures with complex interactive effects.

Policy Issues

This section describes smart grid policy considerations, mainly from a national environmental policy perspective. We restrict our discussion to GHG emissions reductions and end-use energy savings, although these are just two aspects of environmental impact.

Greenhouse Gas Emissions Reductions

Reducing GHG emissions is an important and currently debated environmental priority. Understanding the mitigation potential from smart grid technologies and their costs, relative to other technologies, is important for setting national energy and climate policies. It is challenging, though, to estimate GHG emission reductions and energy savings from smart grid. First, the underlying assumptions are characterized by uncertainty and variability on factors such as consumer adoption of technologies. Secondly, understanding the additional benefit of smart grid for enabling energy efficiency requires an assessment of what becomes possible through smart grid; this is complicated because there is no single smart grid definition or an understanding of how much "smartness" is in the grid currently. Understanding additionality is important if smart grid policies are meant specifically to promote energy efficiency or reduce GHG emissions.

The EPRI (EPRI, 2008) and PNNL (Pratt et al., 2010) reports provide first-order estimates of potential GHG emissions reductions and electricity savings from a smart grid. The exact measures and methods between the studies differ, but the broad categories of measures considered are similar (e.g., reduced line losses through voltage control, energy savings from information to consumers). A key difference is that EPRI assumes a range of smart grid market penetration rates (resulting in a range of estimates), while PNNL assumes full market penetration. Neither study estimates costs or energy increases from smart grid.

Table 2 lists the estimated electricity and electric sector carbon dioxide (CO_2) emissions reductions in 2030, on a normalized basis. The PNNL study also reports "indirect" savings from reinvesting the financial savings of smart grid measures that do not directly reduce CO_2 emissions. Normalized CO_2 and electricity reductions are identical in the PNNL study; in the EPRI study, some measures reduce CO_2 emissions but not electricity use.

Table 2. Potential U.S. electricity and CO_2 reductions in 2030 [1]

	EPRI				**PNNL: CO_2 & electricity reductions**
	Electricity reductions		**CO_2 reductions**		
Measure	**Low (%)**	**High (%)**	**Low (%)**	**High (%)**	**(%)**
Diagnostics / commissioning	<0.1	0.2	<0.1	0.2	3
Optimized voltage control	0.1	0.6	0.1	0.5	2
Behavior change from energy information	0.8	2	0.7	2	3
Impacts on EE programs	0.2	0.8	0.2	0.8	1
Peak load management	<0.1	0.1	0.0	0.1	<0.1
PHEVs / Elec vehicles	--	--	0.3	2	3
Integration of renewables	--	--	0.6	1	<0.1
Total	1	4	2	7	12
End-use efficiency total	1	3	1	3	7

[1] Electricity savings and CO_2 savings are normalized to the Annual Energy Outlook 2008 baseline for 2030
Sources: Electric Power Research Institute (2008) and Pratt et al., (2010)

Potential reductions of CO_2 emissions and electricity use from end-use efficiency (excludes load management, optimized voltage reduction) are estimated at 1-3 % (EPRI) and 7% (PNNL). The savings are distributed among all measures, although the savings from consumer behavior change are highly ranked in both studies. Roughly half of the potential CO_2 emissions reductions are from end-use efficiency measures. End-use efficiency opportunities are significant but are only a component of GHG emissions reductions potential from smart grid. It is important, also, to keep smart grid savings in perspective with broader energy efficiency approaches that offer significant potential for reducing GHG emissions. For example, an EPRI study (Electric Power Research Institute, 2009) estimated 27% technical, 11% economic, and 5-8% achievable savings of U.S. electricity demand in 2030 from end-use efficiency. McKinsey estimated an economic potential of 25% in 2020 (Granade, 2009).

Challenges to Realizing Energy Savings from Smart Grid

Several barriers and challenges may prevent the realization of energy savings from smart grid. We describe technical, financial, consumer behavior, and regulatory/institutional challenges. The list is not comprehensive but underscores that both technical and non-technical challenges must be addressed.

Technical.

- Interoperability standards may not keep pace with smart grid deployments
- Utilities may face data management and mining challenges to using smart grid generated data
- Cybersecurity concerns and incompatibilities among utility software systems, such as billing and operations, may limit the flow of energy data

Financial. Financial constraints may prevent the smart grid implementer (e.g., utility) from including the tools beyond AMI needed to save energy, such as home energy monitors

Consumer behavior.

- Behavior change may not be as deep or persistent as anticipated
- Residential consumers and commercial building managers may not adopt smart grid ready gadgets or allow outside entities to control end uses
- Consumer advocates may object to certain smart grid functionality (such as remote disconnect) and new rates in the interest of protecting disadvantaged consumers

Regulatory/ institutional.

- Relevant parties may not have access to data to enable energy savings mechanisms
- Appropriate rate structures and other policies may not accompany smart grid rollouts
- Organizational stovepiping may prevent a systems approach to smart grid design

While smart grid may provide an infrastructure to enable some energy savings mechanisms, those mechanisms are unlikely to happen through market forces alone. The availability of cost-effective technology does not alone promote wide-spread adoption of energy efficiency. Market barriers to energy efficiency exist —lack of information, principal agent/ split incentives, high cost, and behavioral factors (Jaffe and Stavins, 1995). Smart grid may help remove some barriers to energy efficiency, perhaps by providing information on energy use, however, most traditional barriers to energy efficiency still apply in a smart grid world.

Policies to Leverage Smart Grid for Energy Savings

The mere existence of a smart grid infrastructure won't automatically generate energy savings. Policy action at multiple levels is needed to target smart grid specific barriers, as well as traditional market barriers to energy efficiency. We highlight a few possibilities.

Some federal activities are attempting to address technical challenges and consumer issues as the smart grid advances, such as the NIST interoperability effort. The ENERGY STAR program is beginning to integrate smart grid elements through the development of a combined specification for home energy monitors and programmable communicating thermostats (Kaplan, 2010). The federal government could potentially, also, help gather and disseminate information on the costs, benefits and lessons learned from current smart grid deployments.

Action at the local, state and utility level is needed for steering smart grid deployments to promote energy savings. It is important to realize is that the policies and actions needed to address barriers to energy efficiency are essential for reaching the savings we propose. For example, a portfolio of policies and programs that align consumers' and utilities' incentives, such as decoupling, and certain rate structures (such as inclining block rates) are likely to favor energy efficiency (National Action Plan for Energy Efficiency, 2008).

Coupling smart grid rollouts with energy efficiency programs, tools, knowledge, and workforce training would also increase the likelihood of realizing energy savings through smart grid. An example may include developing a workforce training program specifically on automated diagnostics that leverage smart grid data (to scale up deployment of these tools). Smart grid rollouts could simultaneously deploy benchmarking tools, such as those offered by ENERGY STAR or O-Power (Austin Energy, for example, is implementing Portfolio Manager in their Pecan Street smart grid pilot). Using smart grid energy information, it may be possible also to develop a national-level energy use database. Having easily accessible public information in aggregate form may bring multiple policy benefits that have yet to be conceptualized.

With so much financial investment in smart grid, a careful and urgent analysis of the actual costs and benefits, and implementation challenges should inform policy development. Both state and federal policies to ensure energy savings from smart grid generally lag smart grid deployments, rather than guide them (Regulatory Assistance Project, 2009). An acceleration of activities to address fundamental barriers to energy efficiency and a plan to access energy savings opportunities should accompany ongoing and future smart grid deployments.

New Opportunities

This section outlines new opportunities made available by smart grid, through the application of the energy saving mechanisms outlined previously, that could potentially change how the energy efficiency industry operates. Innovations in service-based models coupled with utility and government incentives can have a big role in spurring the action needed to translate smart grid into energy savings.

Utility Programs Service the Consumer Differently

The rollout of smart grid infrastructure raises many questions for utilities. How far will utilities go into providing diagnostic services for consumers? How far will utilities see into end uses? Will consumers want utilities to "see" and control their end-uses through smart grid ready appliances, thermostats, and system submetering? These issues will be resolved in the coming years as utilities strategize on how to serve the consumer side of the meter.

Utilities could integrate related program offerings to provide a one-stop shop for the consumer. In general, smart grid pilots are not being combined with other incentive programs.

However in the future, demand response, energy efficiency retrofits, operational improvements, and distributed generation programs may be combined to a single integrated offering, with performance tracking services to promote persistence.

Automated Data Analysis Opportunities

As the energy efficiency industry grows, automation is one lever to achieving energy savings in scalable ways. As described earlier, the energy efficiency industry could benefit from the automation of data analysis as follows:

- Finding specific problems in energy-consuming systems through automated diagnostic tools;
- Screening buildings to prioritize cost-effective energy savings;
- Augmenting benchmarking tools with automated diagnostics in order to spur action toward improved benchmark scores;
- Streamlining M&V processes to save money and provide more confidence in energy savings.

Automated diagnostic tools for commercial buildings have been available commercially for over a decade but have low market penetration. These tools have been installed on a building-by-building basis, often with complex set-up processes to integrate with existing building control systems. Simpler diagnostic tools exist in the market today that use interval meter data to model energy use and alert users when energy is higher than predicted by the models. By adding the diagnostic ability to detect specific energy conservation measures using this same data, these tools can become more actionable. With the rollout of AMI, the market for these kind of diagnostics may increase dramatically.

There are also opportunities to improve commonly used benchmarking tools by augmenting them with diagnostic features and whole building interval data. For example, ENERGY STAR Portfolio Manager, the mostly widely used commercial benchmarking system in the U.S., could provide customized savings recommendations automatically reported to sites with smart meters. If the smart grid rollout provides a standard data and communications platform and if utilities or benchmarking systems offer these diagnostic services, diagnostic tools may finally gain market share.

In addition to building-level diagnostics, there are opportunities to use smart meter data for mass screening of energy-savings opportunities on a portfolio level. Diagnostic algorithms could be used as a screening tool to direct more detailed investigations to specific buildings that show evidence of problems. And, as the smart grid infrastructure becomes more widespread, the data could be used to document the energy intensity of sectors over time. This kind of nuanced prioritization of efforts could help achieve much more cost-effective energy savings for utilities and building portfolio managers.

As discussed previously, using the smart grid infrastructure to automatically collect baseline and post-implementation data for the purposes of EM&V could be another significant development for utility energy efficiency programs. The implication is that measure-based incentives may be replaced with whole building approaches to implementing programs, since savings would be reported on the whole building level.

Deeper and Hard-to-Reach Energy Savings

The smart grid could have an impact on achieving deeper savings on hard to reach savings, especially in the residential and small commercial markets. Smart grid implementation coupled with monitoring and load controls could facilitate remote data management services for small commercial customers, which are often underserved. Further, the availability of energy use information could make behavior change programs mainstream. The behavioral programs of the future will include web-based (and smart phone) applications for monitoring and controlling energy use in homes and businesses, as well as streamlined portfolio management.

Conclusions

The smart grid is an enabling infrastructure only. The environmental (and other benefits) depend on what we do with this infrastructure. The mechanisms for energy savings using smart grid data include behavior changes due to improved information, savings as a byproduct of dynamic pricing, automated detection of problems in buildings, and improved cost-effectiveness of program delivery. Energy savings may be maximized only if state, federal, and utility policies and programs are designed to encourage the application side of the smart grid infrastructure toward these energy savings mechanisms. While some studies suggest significant potential energy savings are enabled by smart grid, several challenges and existing market barriers to energy efficiency must be overcome. Only with focus, proper planning, and thoughtful policies can smart grid investments enable additional energy savings that have not been previously feasible, opening up new opportunities in the energy efficiency industry.

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