The Smart Grid Is Not About Residential Energy Efficiency—Yet

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ABSTRACT

References to the energy-efficiency benefits expected to flow from smart grid deployments are commonplace. Not all actions that reduce the energy bill, however, constitute energy efficiency in the strict meaning of the term; many are properly classified as conservation or load shifting, neither of which intrinsically provides the reliable and long-lasting savings of energy efficiency. An examination of the components of the smart grid shows that the customer-facing elements will, in fact, primarily motivate conservation and load-shifting behaviors rather than energy efficiency.

Ideas are presented for using the smart grid as a platform to promote energy efficiency to customers. These include using the rich data available from the smart grid to target homes that present the most promising opportunities for investment, using bill disaggregation techniques to analyze the merits of upgrading particular end uses, and using web portals and individualized household reports to promote reinvestment of savings in permanent efficiency measures.

Introduction

"Smart Grid: A Must for Energy Efficiency," read the headline on a recent *Business Week* column (Apotheker 2009). "A smarter grid delivers end-use conservation and efficiency," according to a U.S. Department of Energy publication (DOE 2009). A LexisNexis search of published news sources finds over 300 articles in which "smart grid" appears within five words of "energy efficiency" or "energy efficient." References such as these to energy-efficiency benefits that are projected to flow from implementation of smart grid systems are commonplace in the mainstream media and in publications and statements from utilities, governmental officials, and vendors of smart grid hardware and software. These characterizations are surely serving to cement the image of the smart grid as an energy-efficiency innovation.

The smart grid promises a variety of efficiency gains for utilities. Operational efficiencies, such as reductions in meter-reading costs, improvements in outage restoration times, and diminished need for on-site service calls ("truck rolls") are among the most prominently cited benefits. Energy-efficiency gains are foreseen in utility transmission systems: For example, utilities will be able to reduce distribution line losses through minimization of reactive power and more precise voltage control (Siddiqui 2009). And the smart grid should enhance utilities' ability to monitor and measure the effectiveness of end-use energy-efficiency programs.

On the customer side of the meter, the smart grid is expected to provide opportunities to better manage energy costs. What remains unclear, however, is how the smart grid will promote energy efficiency—as opposed to energy conservation or load shifting—among residential customers. With smart grid rollouts proliferating, it is appropriate to examine whether utilities' and vendors' plans and visions for the smart grid will support and encourage residential end-use energy efficiency.

Background: The Meaning of Energy Efficiency and Related Concepts

Actions that consumers can take to reduce their energy consumption can be classified as *energy efficiency* or *energy conservation.* Energy efficiency and energy conservation also normally reduce the consumer's energy bill. Depending on the rate structure, bill reductions—but not consumption reductions—may also be achievable through *load shifting.* Loosely, all three actions may be considered means of achieving "energy savings." These actions, though, have different meanings.

Energy Efficiency

Implementers, researchers, and advocates of energy-efficiency programs have long attached a particular meaning to energy efficiency. The following definition is taken from York and Kushler (2005) and is representative of the consensus on its meaning: "*Energy efficiency* involves technology measures that produce the same or better levels of energy services (e.g., light, space conditioning, motor drive power, etc.) using less energy. The technologies that comprise efficiency measures are generally long-lasting and save energy across all times when the end-use equipment is in operation."

In the context of the home, energy-efficiency measures would include, for example, building-shell improvements that reduce heating and cooling costs; installation of appliances, furnaces, water heaters, and air conditioners that provide the same functionality but use less energy than standard or pre-existing units; and substitution of high-quality fluorescent or light-emitting diode (LED) lighting for incandescent lighting.

Energy efficiency allows a reduction in energy input without any loss in value or comfort. It results from investment in technologies or building improvements that silently, continually, and automatically work behind the scenes over long periods of time (measured in years) to save energy (and reduce bills and lessen environmental impacts) without inconveniencing anyone.

Energy Conservation

Conservation is distinct from energy efficiency: "*Conservation* involves saving energy and/or reducing demand by reducing the level of energy services (e.g., setting thermostats lower in winter and higher in summer, turning off lights, taking shorter showers, turning off air conditioners, etc.). It typically involves behavioral changes more than technology improvements and typically is not as lasting or reliable as efficiency measures" (York and Kushler, 2005).

Conservation may involve discomfort or sacrifice (such as making do with less cooling or heating than one desires) or, in less value-laden terms, adjusting one's expectations and behaviors regarding the appropriate level of energy services (Ehrhardt-Martinez and Laitner, 2008). It includes the reduction of energy waste through manual efforts to avoid consumption of energy services when they are not needed or valued. The words that perhaps best distinguish conservation from energy efficiency are "behavioral" and "impermanent." Conservation, as a rule, reduces both the total units of energy consumed and the energy bill.

Load Shifting

Load shifting—that is, choosing to shift operation of an energy-consuming load from one time to another—is an additional type of behavioral change. It may be undertaken as a cost-minimization strategy where customers are exposed to time-of-use prices or are charged for peak demand. It is also central to demand-response programs that involve short-term episodes of higher prices or penalty/reward schemes for temporarily adjusting consumption. The motivation for load shifting need not be financial: Consumers may, for example, defer consumption in response to public appeals during capacity shortages.

Load shifting is sometimes characterized as conservation. For example, the California independent system operator (ISO) includes a load-shifting strategy on its list of conservation tips: “Avoid using appliances during peak hours of late afternoon and evening, 4 [to] 7 p.m. being most critical” (California ISO 2010). Unlike conservation as defined above, however, load shifting does not necessarily decrease total energy consumption, and whether it reduces the customer’s bill is largely a function of the rate structure.

Combining and Comparing Strategies

Each of the three approaches to energy savings—energy efficiency, energy conservation, and load shifting—may have a role in a particular consumer’s portfolio of strategies. Although their savings effects are not strictly additive, electing one strategy for a particular end use does not preclude adding a second or third strategy for the same end use. For example, one might choose to replace a standard-efficiency clothes washer with an Energy Star–qualified model (an example of energy efficiency), switch to washing only with cold water (energy conservation), and run it only at night (load shifting). Doing the first two will result in end-use Btu savings; adding the third may increase dollar savings, depending on the rate structure.

From the consumer’s standpoint, the drawback to pursuing energy efficiency is that it typically requires some level of capital investment. (But note that the energy-efficient option does not *always* cost more, especially in new construction.) Conservation and load shifting are achievable without capital cost, but consumers may elect to invest in equipment that helps automate those behaviors (in which case their actions may cross over into the domain of energy efficiency; sometimes the boundaries are murky).

Energy efficiency is long-lived, barring equipment failure or removal. Because it is independent of consumer behavior, it continues beyond a household’s occupancy—it stays with the house, so to speak, when people move. Conservation and load-shifting behaviors may fade due to loss of interest or forgetfulness, and though periodic reinforcement of their value may help mitigate those phenomena, their long-term effectiveness is not guaranteed. Automation of conservation and load shifting can help maintain the durability of their benefits but can be defeated by manual overrides, depleted batteries, or failure to configure the automation device properly in the first place.

From the utility’s perspective, programs to promote and implement all three strategies may be cost-effective for purposes of achieving energy savings and/or peak demand reduction. Indeed, the fact that many conservation and load-shifting strategies can be implemented without capital investment often enhances their cost-effectiveness. In general, however, energy efficiency is especially desirable for its durability, predictability of savings, and amenability to quantitative evaluation.

Current Customer-Facing Elements of the Smart Grid

We can use the preceding concepts to classify what the smart grid offers to residential consumers. **Table 1** summarizes the typical customer-facing elements of the smart grid.

Table 1. Customer-Facing Elements of the Smart Grid

Element	Function	Relationship to energy-saving strategies
Rate design		
Time-of-use rates	• Impose higher prices during hours that normally have higher resource costs, and lower prices at other times	• May discourage some end uses during high-price periods (conservation) • Encourage routine load shifting
Dynamic rates (critical peak pricing, peak-time rebates, real-time pricing)	• Impose higher prices (or provide rebates) on an unscheduled basis when resource costs are high	• Discourage some end uses during episodes of high prices (conservation) • Encourage deferral of end uses (load shifting)
Information services		
Web portals	• Display near-real-time information on current and cumulative usage, current price, and cumulative bill • Provide tips on energy savings • Enable control of communicating devices	• Promote conservation and load shifting by highlighting price and cost of consumption • Enable load shifting of web-connected devices
Messaging via phone, email, SMS (text), and social networks	• Provide alerts when high dynamic prices are invoked	• Discourage some end uses during episodes of high prices (conservation) • Encourage deferral of end uses (load shifting)
Usage reports (hard copy)	• Present summary cost and usage information • Provide tips on energy savings • Benchmark consumption against comparable homes or peer groups • Identify high-usage devices	• Promote conservation by highlighting cost of consumption
Hardware		
Programmable communicating thermostats	• Facilitate scheduled conservation (e.g., night setback) • Respond automatically to high prices or capacity shortages	• Enable routine conservation • Enable conservation during episodes of high prices or system capacity problems
Energy-use displays	• Display near-real-time information on current and cumulative usage, current price, and cumulative bill	• Promote conservation and load shifting by highlighting price and cost of consumption
Smart plugs	• Enable control of end-use devices • Gather device-specific usage data	• Support conservation by gathering end-use consumption data • Enable conservation and load shifting when controlled by web portal
Smart appliances	• Respond automatically to high prices or capacity shortages • Gather device-specific usage data	• Support conservation by gathering end-use consumption data • Enable conservation and load shifting when controlled by web portal

“Customer-facing” is used here to refer to the products or devices the consumer would be expected to notice or interact with directly; thus, utility activities on the distribution system, such as conservation voltage reduction, are omitted because they are invisible to the consumer. Smart meters *per se* are also not listed because customers ordinarily do not interact with them directly; instead, the mechanisms for displaying data from smart meters are listed.

At a high level, what customers “see” of the smart grid may be grouped into three categories: rate design, information services, and hardware. The elements within each group and their relationships to energy-saving strategies are elaborated on below.

Rate Design

Smart grid plans usually include some form of time-varying rates. Basic time-of-use (TOU) rates, which vary on a predetermined schedule, are intended to promote load shifting. TOU rates may also have a conservation effect where the high prices are sufficient to discourage uses that cannot be deferred. For example, a high summer on-peak price may cause people to forego air conditioning on all but the hottest days.

Dynamic rate types, such as critical peak pricing, peak-time rebates, and real-time pricing, vary prices on an unpredictable schedule. Responses to temporarily high dynamic rates may be either conservation (e.g., deciding to forego air conditioning) or load shifting (e.g., choosing to do laundry later).

Rate design may create an *indirect* stimulus for energy efficiency. For example, a consumer who is subject to a high rate during summer afternoons may decide that a remedy for high cooling costs is to purchase a more efficient air conditioner. This is, on its face, a less direct strategy for supporting energy efficiency than, say, offering rebates to purchasers of high-efficiency air conditioners. Insofar as it promotes energy efficiency, it depends on consumers recognizing and understanding the factors that contribute to their total bill: the afternoon price, their use of cooling equipment, and the efficiency of that equipment. Dynamic rates—which are, by definition, less predictable than stable time-of-use rates—further complicate consumers’ analysis of opportunities to invest in energy efficiency.

Information Services

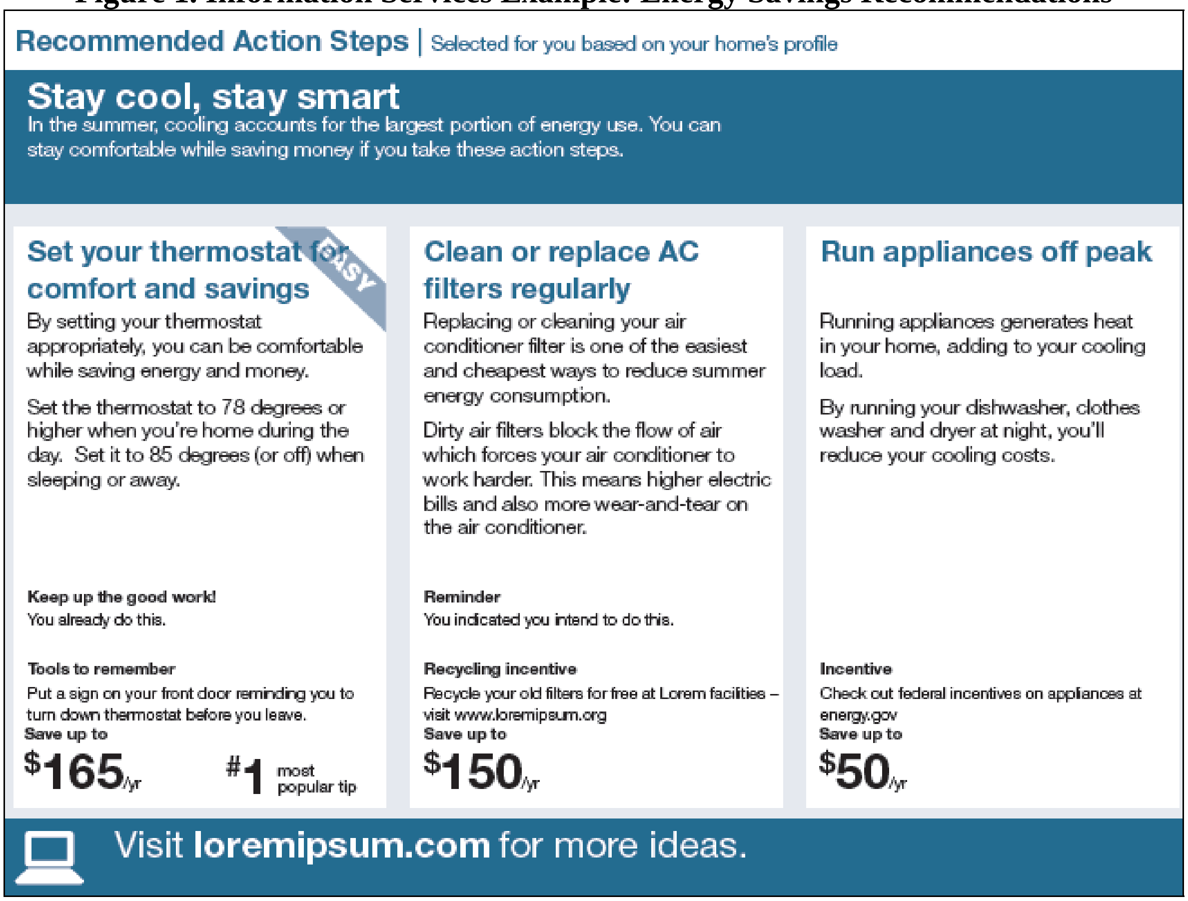
Smart grid deployments can offer information about energy use through several channels, principally web portals, usage reports, and message services.

Web portals, providing display of customer-specific data over the Internet, are the base offering for most smart grid systems. They present consumption and cost data in different time slices: historical (perhaps going back a year or two), prior and current billing period, previous day, and (in some cases) near-real-time. In some systems, customers’ usage and costs may be benchmarked against a peer group, such as similarly sized homes in the vicinity, and a performance grade or icon (e.g., a smiley face) may be awarded. Consumption and costs may be disaggregated algorithmically to reveal the cost of operating major end uses such as water heating and air conditioning. Tips for saving energy, possibly derived from analysis of the customer’s data rather than drawn from a generic list, may be offered. All of these functions serve to encourage energy conservation.

Where time-varying pricing is in effect, current cost and price data provided on web portals may stimulate load shifting. Where appropriate hardware (discussed below) is available, the web portal may offer control and scheduling of the thermostat and possibly end-use devices such as lighting circuits and pool pumps. Schedules may be specified based on date and time (e.g., don't run the water heater between 2:00 p.m. and 6:00 p.m. on weekdays), or by price levels (e.g., turn off the pool pump when the price exceeds 20 cents per kilowatt-hour). These control functions provide a mix of conservation and load-shifting benefits.

Usage reports, provided in print as part of the regular bill or delivered periodically as a standalone product, serve many of the same energy conservation functions as web portals, emphasizing display of historical and recent billing-period data, disaggregation of consumption and cost across end uses, benchmarking against a peer group, performance grading, and energy-saving tips. Recommendations encourage behavioral changes that, ideally, are specific and relevant to the household; see **Figure 1** for an example.

Figure 1. Information Services Example: Energy Savings Recommendations



Courtesy: OPOWER

Messaging services that may be offered in smart grid deployments are intended to alert consumers to imminent periods of high prices, as when critical peak pricing is invoked or a real-time price exceeds a certain threshold. Alerts can be delivered via phone, text message, social network, or other channel. Messaging services promote short-term conservation and encourage consumers to make on-the-fly load-shifting decisions (e.g., delay doing laundry when notified that critical peak pricing is in effect).

Like rate design, some types of information services may provide indirect stimuli for energy efficiency. Time-series data showing rising energy bills may spur a consumer to request an energy audit or to opt for energy-efficient equipment in future purchase decisions. Benchmarking analyses that provide unflattering comparisons to a peer group may have similar effects. In each case, though, it is left to the consumer to untangle the cause of high energy costs: Is it inefficiency in the structure and its equipment, behavioral factors, or both? Such information does not make a clear-cut case for investing in energy efficiency.

Hardware

This category is a mixture of controls and controlled devices that may be used in various combinations in smart grid deployments.

Foremost is the programmable communicating thermostat (PCT). Like the simpler programmable thermostats that have been available for decades, PCTs enable automated conservation according to a schedule. The addition of communications capabilities allows remote adjustment of setpoints and schedules, typically via a web portal. Further, communications received from the utility can cycle air-conditioning operation or raise the cooling setpoint, triggering unscheduled conservation.

Though PCTs that are under end-users' control are basically conservation devices, they could enable load shifting in some circumstances. For example, prior to the start of a high-price period, a PCT could be programmed or signaled to lower the cooling setpoint so that the house is "pre-cooled" with cheaper energy.

Energy-use displays, also known as in-home displays, provide some of the information capabilities of web portals in devices that are, for many, more convenient and accessible than home computers. Generally, these devices promote conservation by displaying current and cumulative data on consumption and costs for the home as a whole. Where time-differentiated pricing is in effect, display of rates and costs may encourage load shifting.

Smart plugs (which might be more descriptively called "smart outlets") serve two purposes: The first is that they gather information about the energy consumption of devices that are plugged into them. This information may be processed and displayed on home energy portals or in printed usage reports in order to encourage conservation. The second is that, if enabled with two-way communications capabilities, smart plugs provide control of connected devices for scheduled and episodic conservation and load shifting.

Smart appliances are appliances with built-in communications capabilities. In effect, they have the conservation and load-shifting functionality of smart plugs built in, rather than provided by an add-on device. They may also facilitate additional non-energy services, such as remote diagnostics.

Implications of Current Smart Grid Functionality for Energy Efficiency

The conservation and load-shifting benefits of the smart grid are important and worthwhile. But the emphasis on these strategies in the customer-facing portions of the smart grid and the comparatively diminished role of customer energy efficiency in smart grid deployments are sources of concern. Energy efficiency and its durable benefits may be crowded out by the messaging around conservation and load shifting and the capabilities provided to implement those strategies. If utilities' resources and managerial attention are allocated toward supporting those functions of the smart grid, their role in supporting energy efficiency could recede.

As noted earlier, there is a tendency to use “energy efficiency” as an umbrella term for the features of the smart grid that can lower customers’ bills. The failure to differentiate energy efficiency (strictly defined) from conservation and load-shifting strategies is another concern. If energy efficiency is used to connote all bill-reducing actions, then the attributes that make efficiency a uniquely valuable resource—the same or better level of energy services, the automatic, built-in benefits, the durability—lose their potency, and effective advocacy on behalf of energy efficiency becomes more difficult. At the highest levels of utility management, or in the public-policy arena, energy efficiency might not be given the attention or resources it deserves.

How the Smart Grid Could Provide Better Support for Energy Efficiency

The role of the smart grid in reducing consumers’ energy bills need not be confined to conservation and load shifting. Ideas for using the smart grid as a platform to promote energy efficiency are presented below. Some of these ideas are in the early stages of implementation, while others are more speculative, potentially building upon known or expected smart-grid capabilities but not currently incorporated into announced business plans.

Remote Diagnosis and Targeting of Homes in Need of Energy Efficiency Services

The highly granular data about home energy use made available through the smart grid should allow utilities to target homes that have greater-than-average potential to benefit from energy-efficiency improvements. This would be similar to the peer-comparison approach but would go beyond that analysis, combining usage data with information on structural characteristics (say, square footage and age of dwelling, as obtained from property tax records) to try to identify those homes that could best benefit from permanent improvements, then use that information as a starting point for selling the homeowner on a package of efficiency services.

Some energy providers are indicating that they hope to move in this direction. A recent newspaper article quoted an executive with Direct Energy, a Texas electric retailer, as follows: “I’m going to look at that information [from the smart grid] in a way that’s never been reviewed before, and say, ‘Why is Mrs. Smith using four times the amount of energy that her neighbor is using?’And I’m going to send the vans I have, my people, who go in to install efficiency, and say, ‘Mrs. Smith, can we come to your house to help you lower your bill?’” (Souder and Torbenson 2010).

Analysis of Individual End Uses and Efficiency Opportunities

In principle, the stream of data provided by the smart grid could enable both detailed analysis of individual end-use devices’ consumption and the development of pertinent efficiency recommendations. Data at the end-use level might be generated by smart appliances or through smart plugs, or it might be obtained through algorithmic analysis of the “signatures” of devices (their voltage and current characteristics) and disaggregation of the loads through comparison to a database of known signature types.

Some activity along these lines is already underway. Energy software company OPOWER is using statistical analysis of daily meter readings and weather data in the Puget

Sound Energy service territory to estimate the portion of customers' energy costs attributable to heating (St. John 2009). Another software company, Energy 2.0, is emphasizing use of highly granular data—collected at intervals as short as five seconds—to enable more precise disaggregation of consumption (Weldon 2010). Taking this work to the next level—development of costs and paybacks for replacing equipment or upgrading the building shell—is, no doubt, a significant analytical challenge, but one utilities could embrace and support.

When consumers do make energy-efficiency investments, this analytical approach could potentially provide feedback on the cost savings being realized every month. Such after-the-fact support could help motivate the consumer to make further investments and help create "buzz" among friends and neighbors about concrete efficiency actions.

Conversion of Behavioral Conservation to Permanent Savings

Programmable thermostats, even ones of the communicating variety, are basically conservation devices rather than energy-efficiency investments because their energy-saving effectiveness is so easily defeated by failure to program properly, user override, and the like. Perhaps technology could convert the unreliable, impermanent benefits of thermostat conservation to more certain, long-lasting savings. Energy service company EcoFactor is piloting a service with Oncor, the Texas distribution utility, using broadband communications in conjunction with savings algorithms to continually monitor and adjust smart thermostats as often as every minute. Savings of 20 to 30 percent on heating and cooling costs without any noticeable impact on comfort are claimed (Fehrenbacher 2009).

Energy Savings Investment Accounts

Web portals and usage reports can display cumulative figures on the dollar savings that consumers have achieved through all means, behavioral and otherwise. Utilities could orient the presentation of that information toward promoting energy-efficiency investment. For example, suppose a utility were to track cumulative savings in a virtual "energy savings investment account." Messaging via the portal or usage report could encourage the consumer to invest the savings in an energy audit or in qualifying energy-efficient equipment, either of which might be offered at a discount through participating providers.

Concluding Thoughts

The current direction of the smart grid suggests that energy efficiency, so often touted as an outcome, is not prominent in smart grid systems' customer-facing elements, which mostly promote conservation and load shifting. Although those behaviors are of value to utilities and their customers, they do not intrinsically match energy efficiency's reliability, durability, and amenability to quantitative evaluation.

Some players in the smart grid arena are exploring technologies and analytical techniques that could leverage the information flowing from the smart grid to promote end-use energy-efficiency investment. Utilities, energy-efficiency advocates, and regulators should carefully consider whether these approaches should be included in current and upcoming smart grid deployments.

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