Examining the scale of the Behaviour Energy Efficiency Continuum

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Abstract

There is a burgeoning interest in the “human dimension” of energy use. As but one example, the second annual Behavior, Energy, and Climate Conference (co-convened by the American Council for an Energy-Efficient Economy, the Precourt Institute for Energy Efficiency, and the California Institute for Energy and Environment) exceeded capacity almost six weeks before the November 2008 conference date (see, for example, the conference website at http://www.BECCconference.org). At the same time, many analysts suggest that, yes, behaviour-oriented programs provide a nice way to help deploy smart technologies but that they are, essentially, boutique or niche strategies; they can only help round out a technology-based deployment effort. We suggest to the contrary; elements of the behaviour or human dimension may have a surprising scale which rivals a pure technology-based perspective in terms of expected efficiency gains.

In this paper we highlight the potential impact of changed habits, lifestyles and technology-based behaviours in terms of potential energy savings within the United States for the residential sector. We explore the level of potential savings along what we call a Behaviour Energy Response Continuum. In other words, we explore the energy savings if different motivations and habits drove a different behaviour, and if different lifestyles similarly drove a different behaviour as they all, in turn, affect energy consumption. Preliminary research suggests that changed behaviours might reduce household use of energy by about 22 percent within the United States. In this paper we characterize the elements along this behaviour continuum, estimate the potential impact, and describe potential next steps in the needed research.

Introduction

By the end of 2008 the United States had expanded its economic output by nearly 65 percent since 1990. Likewise, per capita incomes had grown by 35 percent. At the same time, however, the demand for energy and power resources had grown by only 23 percent. This apparent decoupling of economic growth and energy consumption is a function of increased energy productivity; in effect, the U.S. increased its ability to generate more energy-related services from each unit of energy consumed. Many would attribute this productivity gain to more productive investments in technology. Indeed, the evidence does suggest this to be a significant driver of such improvements (see, for example, Ehrhardt-Martinez and Laitner 2008). Yet the evidence also suggests an amazing variety of behavioural influences have also contributed to this success story —behaviours that *drive* new innovations and behaviours which, in turn, change the patterns of technology adoption and energy service demands (Laitner, Ehrhardt-Martinez and Knight 2009).

The real debate isn’t about whether behaviour has contributed to the dramatically reductions in energy consumption growth rates in the U.S. Instead it is about the scale of savings that should be attributed to changing behaviours, the potential scale of behaviour-based savings in the future, and the need to recognize behaviour as an important but often overlooked resource for achieving large-scale reductions in energy consumption and carbon emissions. Unfortunately, many analysts

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Table 1. Major Residential Energy End Uses in the United States for 2008

End Use Category	Energy Consumed (EJ)	Percent of Total
Space Heating	6.5	16.1%
Air Conditioning	2.5	6.1%
Lighting	2.4	6.0%
Hot Water	2.6	6.3%
Refrgeration	1.5	3.8%
Consumer Appliances	3.5	8.6%
Other Uses Note Specified	4.2	10.4%
Personal Transportation	17.4	42.8%
Total End Use Energy	40.6	100.0%

Source: Energy Information Administration (2008)

continue to suggest that while behaviour-oriented programs provide a useful way to help deploy smart technologies, they are best thought of as boutique or niche strategies which can only round out a technology-based deployment of more energy-productive investments. We suggest to the contrary; and in this paper we argue that elements of the behaviour or human dimension may have a surprising scale which rivals a pure technology-based perspective in terms of expected efficiency gains.

Past analyses by the American Council for an Energy-Efficient Economy (ACEEE), and by well-known researchers like Gerald Gardner, Paul Stern, and others suggest that understanding and shaping behaviours can provide a significant boost in the more efficient use of all energy resources. (See, Gardner and Stern et al. 2008 and Ehrhardt-Martinez 2008) Indeed, internal discussions among the professional staff at ACEEE indicate that "the behavioural resource" might provide as much as a 25 percent efficiency gain (possibly more) above normal productivity improvements — should we choose to recognize, invest in, and develop that resource. In this respect, policymakers and researchers increasingly recognize the importance of addressing behavioural change to reduce costly energy production and consumption and carbon emissions as most energy-efficient technologies require proper human interaction to achieve their promised savings.

In this paper we highlight the potential impact of changed habits, lifestyles and technology-based behaviours in terms of potential energy savings within the United States for the residential sector (including personal transportation uses within the control of households). We explore the level of potential savings along what we call a Behaviour Energy Response Continuum. In other words, we explore the energy savings that could be achieved if new energy-wise habits became the social norm, and if new energy-wise lifestyles were encouraged by smart policies oriented toward reducing residential energy consumption. Preliminary research suggests that changed behaviours offer potential reductions of 20-25 percent of current levels of residential energy consumption over perhaps a 5-8 year period within the United States. We characterize the elements along this behaviour continuum, estimate the potential impact, and describe potential next steps in the needed research.

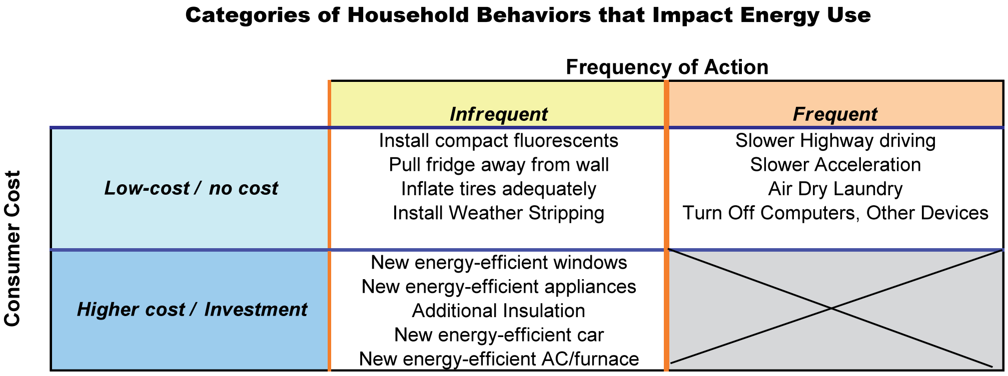
Methodology and Analysis

In 2008, there were an estimated 114 million households in the United States. Taken together, they consumed a total of 23.2 Exajoules (EJ) for all residential end uses whether space heating and cooling or lighting and appliances. The use of personal vehicles for work, shopping, errands and recreational activities added another 17.4 EJ of energy. Total energy use among residential users was an estimated 40.6 EJ in 2008 (EIA 2008). Table 1 highlights the energy use for these major end uses in 2008.

In a typical economic policy assessment, most economic modelers and analysts assume that changes in energy consumption will depend on some form of financial incentive (or penalty) to drive the changes energy consumption pattern. This might be in the form of increased energy prices and/or some form of financial enticement to encourage the adoption of energy saving technologies (Laitner 2009). Yet, behavioural actions might be motivated by a wide range of perceptions, beliefs, information, and changes in attitudes (Ehrhardt-Martinez 2008). In this regard, both the mix of conventional incentives and behavioural actions might provide a dynamic complement if policy makers better understood the impact and/or the potential scale of behaviourally-related outcomes.

For our purposes here, we define behavioural actions in two ways: (i) the frequency of actions and measures that might be taken by individual households, and (ii) the level of cost needed to bring about a more efficient use of energy (see figure 1). Both categories of behaviours (frequency of action and consumer cost) reflect actions that might be taken over a 5-8 year period of time. There is nothing that dictates a specific stretch of time within our analysis. Rather we chose this period of analysis as a means to emphasize short-term behaviours as without impacting the complete turnover of the existing capital stock under the immediate control of households.

By way of providing a reference point our 5-8 year time horizon, automobiles, for example, might have a typical life of 15-17 years. Residential heating systems might have an average life of 9-20 years, while refrigerators might last an average of 13 years. Hence, a 5-8 year period is on the order of about one-third to one-half of the effective life of nonstructural capital stock within the relatively easy control of households (i.e., other than the residential dwellings themselves). This period of time also reflects an expected simple payback that might motivate consumers to adopt a new behaviour that might be deemed "cost-effective." For example, a 5 year payback anticipates per-



Categories of Household Behaviors that Impact Energy Use

Consumer Cost	Frequency of Action: *Infrequent*	Frequency of Action: *Frequent*
Low-cost / no cost	Install compact fluorescents Pull fridge away from wall Inflate tires adequately Install Weather Stripping	Slower Highway driving Slower Acceleration Air Dry Laundry Turn Off Computers, Other Devices
Higher cost / Investment	New energy-efficient windows New energy-efficient appliances Additional Insulation New energy-efficient car New energy-efficient AC/furnace	☒

Figure 1. Categories of Household Behaviors that impact Energy Use: Frequency of action / Consumer Cost chart.

Table 2. Range of Savings and Participation Rates by End Use Category

Major End Uses	Range of Potential Savings	Range of Policy-driven Participation	Expected Savings
Space Heating	18-36%	3-40%	27%
Air Conditioning	19-47%	2-75%	33%
Lighting	10-53%	20-80%	32%
Hot Water	6-26%	3-75%	16%
Refrgeration	17-55%	5-75%	36%
Consumer Appliances	6-20%	40-80%	13%
Other Uses Note Specified	12-24%	30-50%	18%
Personal Transportation	14-33%	30-80%	24%
Total End Use Impacts	18-28%	n/a	23%

Note: This set of energy end-uses and their associated range of potential energy savings are working estimates generated by the authors as they have drawn information from a set of 22 separate studies cited in the separate bibliography, "Data and Analytical References," identified at the end of this paper.

haps a 20 percent annual return on investment while a payback of 8 years might reflect an expected 12.5 percent return on investment. While this time horizon tends to constrain the impacts that might result from the evolution of longer-term behaviours, we adopt it here as a way to manage the analysis and to provide a context for policy makers.

The actions that we summarize for this paper include a range of behaviours which are influenced by habits, lifestyles, and a general awareness of environmental or climate-related impacts that are driven by energy consumption. These generally fall into the low-cost/no-cost category of actions. They can involve infrequent actions such as installing compact fluorescent lamps, installing weather-stripping around doors and windows, and inflating automobile tires to their correct pressures. The behaviours can also involve more frequent actions ranging from slower highway driving, slower acceleration and gentle braking to air drying household laundry and turning off unneeded lights, computers and appliances. Finally, behaviours also include more informed purchases or investment decisions such as buying more energy-efficient window and appliances, or purchasing a more fuel efficient or a smaller car.

Pulling from 22 different studies we were able to generate a range of estimates on potential energy savings for roughly 120 separate measures or actions that will result in varying levels of future energy savings. Drawing from that same literature, and in review with ACEEE professional staff and others, we then established a likely range of participation rates for each of the actions as well as a range of overall effectiveness. For example, Blasnik (2008) suggests that secondary refrigerators can use between 400 and 2,000 kilowatt-hours (kWh) per year. Other studies suggest that as many as 30 percent of households may actually have a second refrigerator.

A reasonable assumption is that within the next 5-8 years perhaps one-third to two-thirds of U.S. homes that have second refrigerators might be induced (through a variety of means) to get rid of those second units. As such, the eventual energy savings associated with this specific behaviour might range from 14 to 46 billion kWh. According to the Energy Information Administration (EIA 2008) it appears that total refrigerator electricity consumption approached 349 billion kWh in 2008. Hence, this single behavioural response might save anywhere from 4 to 13 percent of electricity associated with household refrigerators. Table 2 highlight the key range of savings expected from these 120 measures as they are aggregated and summed according to the eight major end uses defined in this analysis.

Several analytical points are worth noting in Table 2. First, the range of savings potential reflects the efficiency gains that might be possible within a given end use category. For example, we've identified approximately 12 different measures within space heating. The aggregate of those measures might lead to a possible savings of 18 to 36 percent of the 6.5EJ now used for that purpose. One can imagine both higher and lower values depending on other assumptions that might impact that end use. These might include different assumptions about the

Table 3. Potential Impact of Behaviour on U.S. Household Energy Use

Category of Actions	Potential Savings (EJ)	Percent of Total
Low-Cost/No-Cost	5.2	57%
Smart Investment Decision	3.9	43%
Total Energy Savings	9.1 ± 2.6	100% ± 29%

interaction of measures, for instance. If we dial down the thermostat, then actual energy savings are likely to be less for a more efficient furnace. Other influences include the quality of the housing stock, the assumption about cooling degree days, and the mix of furnaces and their requisite fuels used within the households. Second, the range of policy-driven participation rates reflects different levels of involvement as a function of individual measures. Again looking at space heating, the 3 percent value is the low-end of response for those who might have their chimney cleaned while the 40 percent participation might reflect those who insulate their heating duct or weather-strip their doors and windows. The expected savings is an approximate engineering estimate that we might anticipate given the full mix of actions and a likely pattern of activity involving the individual measures.

After compiling information for the full set of the 120 action items, we set up a Monte Carlo simulation to determine the range of likely outcomes. Such simulations belong to a class of computational algorithms that rely on repeated random sampling to estimate their net effective outcomes. Such methods are often used when replicating physical and mathematical systems. Monte Carlo methods are especially useful for modeling phenomena with significant uncertainty in assumptions or inputs, such as the calculation of risk in business; or in this case, such as the likelihood of adopting energy efficiency improvements and/or the level of actual energy savings from those improvements or measures. While there is no single "Monte Carlo method," the approach used here followed five separate steps:

- Defines a domain of possible energy efficiency measures or actions that might be undertaken by households.
- Characterizes a range of energy savings that might likely follow the adoption of those measures or actions.
- Anticipates the likelihood of adoption or use of a given energy efficiency measure within 5-8 years.
- Maps the possible range of interaction effects that might reduce the net energy savings.
- Aggregates the results of the individual computations into the set of outcomes.

The simulation uses an upper and lower range of participation in each of the identified measures, and incorporates a range of potential savings, and accounts for potential interactive effects associated with appropriate measures. The final estimates of the potential behaviour-related energy savings were estimated by running 1,000 individual calculations to determine the magnitude of impacts that might result from a well-designed set of behavioural programs. The results of that effort are summarized in Table 3.

Implications

As suggested in Table 2 our "engineering estimates" suggested a 23 percent savings potential from among all of these end use savings. In fact, the reported Monte Carlo simulation suggested a 22 percent savings with a plus or minus 29 percent interval. The end result of this preliminary analysis indicates the potential for a 9.1 EJ energy savings within U.S. households, including both residential and personal transportation savings. The actual range of potential savings might be as low as 6.5 EJ or as high as 11.7 EJ. In short, cost-effective behavioural responses should be recognized as a significant energy efficiency resource. Even if we constrain our definition of behavioural resources to include only those practices associated more with lifestyles, habits, and the conservation ethic, one can reasonably argue that a 5.2 EJ impact (that is, the impact shown in row one of Table 3) is still a very large opportunity to be pursued. And by including investment-related decision-making among the relevant behaviour mix, then the scope of the behaviour opportunity is even broader.

But, is the scale of these savings worth pursuing? How big is 9.1 EJ (±29%)? As previously noted, when compared to direct household savings, 9.1 EJ is about 22 percent of the current residential and personal transportation energy needs in U.S. households today. That represents about 12 percent of total U.S. delivered energy use in 2008. It is also equivalent to 600 gallons of gasoline savings per household. From a climate perspective these energy savings would equal the amount of energy that might be generated by about 240 medium coal-fired power plants. And from an international comparison, it is roughly equal to the total annual energy consumption of either Brazil or South Korea, and just slightly less than total annual energy consumption in the United Kingdom (10.6 EJ), France (12 EJ), and Germany (15.3 EJ).

At this point the question naturally arises as to how this information might be useful to policy makers? Generally we suggest perhaps two aspects of value to this initial analysis. The first is that it might inform economic policy modellers in their effort to evaluate future energy or climate policies. The second is that it might spur greater interest to understand the kinds of non-price motivations and perceptions that might drive a greater response to future energy and climate policies.

In the case of economic policy modelling, a standard assumption is that a change in energy prices will reduce overall energy use. Economists typically adopt the assumption of an elasticity that captures such behaviour. For example, if a 10 percent increase in energy prices reduces energy use by 2.5 percent, the price elasticity is said to be on the order of -0.25. And this response is generally assumed to be invariant over time. Should the policy makers want to reduce energy use to 75 percent of current consumption, then the economic models might suggest that prices would have to increase by nearly three times the

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current levels to achieve that result. However, if we understand that better information, a greater awareness of energy alternatives, or a growing concern about growing climate problems might change perceptions about the need to act, consumers may generate the same magnitude of response with a much smaller prices signal. For example, if behaviours were to change such that the measured elasticity is not -0.25 but perhaps -0.5, then prices may need to increase by only 80 percent to achieve the same reduction to 75 percent of current consumption. In other words, additional research in this area could inform economic policy models about a more dynamic and a richer set of outcomes that may possibly show a more beneficial economic impact as a result of an improved characterization of energy-related behaviours (Laitner 2009).

In a different vein, if policy makers believe that behaviourally-related responses have a sufficient magnitude of impact, they may be willing to invest more time and effort to explore improved ways of expanding those positive returns. As one example here, a variety of studies have suggested that positive feedback might increase energy savings from 5 to 15 percent over prior levels of consumption. In other words, if consumers are able to know through their monthly utility bills or through real-time metering of energy use within there homes that, compared to their neighbours or others within their income class, their energy savings are below some level of performance, then they are more likely to take actions which modify energy use in ways that still maintain their quality of life. If one kind of feedback generates only a 5 percent response, an improved understanding of consumer motivation and learning might generate instead a 15 percent response –without requiring higher prices or other financial incentives. In effect, expanding the behavioural response may increase the benefits of energy saving opportunities in a highly cost-effective manner (Ehrhardt-Martinez 2008).

Further Research Needs

If we take a step back and relax our assumptions about the nature and role of behaviour and its potential contribution to the adoption of more productive technologies, then results we show here are not quite so surprising. The question then becomes one of how we close the gap between current choices and levels of (in)efficiency and developing the full opportunity to become much more energy-efficient. To that extent we now suggest several areas of inquiry which may help us understand and confirm the prospect of a more robust and a significantly more energy-efficient future.

A first area is to expand the range of inquiry so that we better understand people as more than economically rational actors. This is critically important if we want to fully comprehend what motivates human behaviours. People are more complex and there are many other dimensions that are equally if not more important in determining how to encourage an optimal level of energy-efficiency. For instance, while economics will clearly play an important role in the adoption of future energy efficiency measures, improved perceptions about the contribution of energy efficiency technologies in reducing air pollutants and greenhouse gas emissions can accelerate the adoption of more productive energy technologies. And consumer attributes like convenience and perceived social status associated with new technologies can further accelerate the adoption of energy efficiency measures (See Ehrhardt-Martinez and Laitner 2009, Ehrhardt-Martinez 2008, and Ehrhardt-Martinez et al. 2008).

A second area of inquiry is to build on the research reported here and to place these results into a larger context to quantify and give policy makers a real sense that the behaviour resource can play a significant contribution in addressing critical issues such as energy and climate change policies. Gardner and Stern (2008), for example, have used a different methodological approach to determine what they call "the behavioural wedge" at the household and level (also including personal transportation). This refers to the segment of efficiency improvements that can be made without further incentives or without waiting for new technologies, but that depend instead on more informed decision-making and a greater awareness of impacts that follow from the choices typically made within households.

Both this paper (which focuses on the economy-wide impacts) and the "wedge paper" –while generating comparable analytical results– examine only direct household and personal vehicle savings associated with the behavioural resource. We think there are still more opportunities to be included in future assessments of this kind. If properly evaluated, we believe the full spectrum of efficiency gains would grow to perhaps 30 percent or more over perhaps a 10 year period (Laitner 2009). This compares to the 22 percent savings identified by these two current research efforts. Overlooked are producer behaviours that might amplify consumer response. Also not included are the potentially very large indirect savings that accompany a host of consumer decisions ranging from a changing size of households to the recycling and dematerialization of most consumer goods and services. The potential contributions and synergies from more "productive behaviours" in the commercial and industrial sectors are also overlooked. Finally, choices that help move the international community to emphasise the transition to a greater service economy, as well as integrating broadband technologies and services that promote more flexible work schedules, greater levels of telecommunication and teleworking, and different patterns of industrial production flexible work schedules can all help change patterns of energy consumption and production.

Conclusion

Unfortunately, many economic policy analysts continue to suggest that while behaviour-oriented programs provide a useful way to help deploy smart technologies, they are best thought of as boutique or niche strategies which can only round out a technology-based deployment of more energy-productive investments. We suggest to the contrary. Changed patterns of behaviours might reduce household use of energy by 22 percent within the United States. Indeed, a greater understanding of behaviours, and an improved categorization of behavioural responses might expand that potential magnitude of savings. When expanded to the non-household sectors, and including a wider array of consumer options not included in this assessment, the economy-wide impact of the behavioural wedge might grow to a 30 percent efficiency gain or more. Should we take the time to understand the behavioural perspective, and if we recognize its full "resource potential," it can be a very big deal – but only if we choose to develop it.

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