Energy 91 (2015) 491–506

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

A dynamic active energy demand management system for evaluating the effect of policy scheme on household energy consumption behavior

Biying Yu [a, *], Yaming Tian [b], Junyi Zhang [c]

[a] *School of Management and Economics, Beijing Institute of Technology, Beijing, 100181, China*
[b] *The Economic & Planning Research Institute of China Railway Corporation, No. 29 B, Beifengwo Road, Haidian District, Beijing, 100055, China*
[c] *Graduate School for International Development and Cooperation, Hiroshima University, 1-5-1 Kagamiyama, Higashi-Hiroshima, 739-8529, Japan*

A R T I C L E I N F O

Article history:
Received 15 December 2014
Received in revised form
30 June 2015
Accepted 27 July 2015
Available online xxx

Keywords:
Household energy consumption behavior
Policy scheme
DAEDMS (Dynamic active energy demand management system)
Timing effect
Dynamic simulation

A B S T R A C T

To reduce the continuously increasing energy consumption in the household sector, including residential and private transport sectors, it is important to design a proper policy scheme to regulate household energy demand. However, determining how to evaluate the collective effect of multiple countermeasures in one policy scheme on household energy related behavior is very challenging; furthermore, the potential interactions between policies due to the timing effect cannot be overlooked. Under these concerns, this study provides a quantitative methodology by developing a DAEDMS (dynamic active energy demand management system) that can evaluate the overall effects of urban planning, soft policies for improving household/individual awareness, technology-improvement/rebate policies, market end-use diffusion control, and social-interaction oriented policies. The timing effect is directly incorporated by allowing the free setting of the execution period for each policy. Building on this demand management system, the quantified policy schemes and the pathways that can reach the target of energy conservation become straightforward, providing helpful support for policy planning. Besides, the variant effectiveness of policy schemes due to different policy timings admonishes the policy makers to realize that the current fragmented regime of policy making between different departments is undesirable for capturing the genuine effect of all of the policies.

1. Introduction

With an emphasis on the concept of sustainability in the past few decades, governments, businesses, and scholars worldwide are paying extensive attention to energy consumption and carbon emissions. Energy consumption in households, in contrast to other sectors, continues to rise in part as a result of population growth and income increase [1]; and this is especially true of electricity [2] and motor fuel use [3]. Moreover, household energy consumption composed of residential and private transport consumption is directly determined by consumers' behaviors, which is difficult to control through regulation. In this sense, determining how to achieve the sustainability in the household sector to a large extent relies on whether sustainable energy consumption behavior is adopted or not [4].

Household energy-related behavior plays a core role in ensuring the effectiveness of energy conservation measures. This behavior could either be a one-shot behavior, for example, targeting the purchase of more-efficient technology and the replacement of the old technology, or repetitive efforts to reduce energy use by curtailment measures, such as reducing the usage on car, heating, or cooling, and lowering thermostat settings [5]. To date, many research studies have been performed to assess the efficacy of technology development as well as social and economic policies (e.g., urban planning, informational and educational campaign, price, and tax) on altering energy consumption behaviors. Several examples are given below to demonstrate how these policies act on household behavior.

* Corresponding author. Room 367 (C1-3), C-cluster, Kyoto-Daigaku-Katsura, Nishikyo-ku, Kyoto, 615-8540, Japan. Tel.: +81 075 383 3370; fax: +81 075 383 3371.
E-mail address: yubiyingjapan@yahoo.co.jp (B. Yu).

http://dx.doi.org/10.1016/j.energy.2015.07.131
0360-5442/

Technological innovations are always the favored strategy to save energy and reduce GHG emissions. However, the diffusion of efficient technologies strongly relies on the purchases of consumers together with their choices of products. In addition, the final energy savings often do not match with the full technical calculation because of the widely recognized rebound effects both in the transportation sector [6] and in the residential sector regardless of developing countries [7] or developed countries [8]. To a broad extent, household energy consumption behavior determines the gap between potential and actual energy efficiency levels. After controlling the rebound effect, the technological improvement will be approximately 40%–50% effective in reducing electricity consumption [9] and less than 90% for personal automotive transportation, based on the existing evidence summarized in Yu et al. [10]. However, these magnitudes vary remarkably between targeting countries and end uses, implying that the impact of technology must be gauged individually.

Urban planning has a long-term influence on household behavior. Households and individuals first decide their residential location, and then, based on neighborhood attributes, determine their lifestyles, of which, energy consumption behavior is one part. In this sense, urban planning on the residential neighborhood and surrounding environment is one of the key elements to shape and change household or individual energy consumption behavior. Brand et al. [11] found significant influence of urban/rural status, home to work distance, home to retail distance, and living spot on energy consumption and carbon dioxide emissions from motorized passenger travel in UK. Nässén [12] and Rahut [13] identified different domestic energy consumption patterns for rural and urban households in Swedish and Bhutan, respectively. Yu et al. [14] examined the effects of land-use policies on energy consumption for household appliances and vehicles. Not all land-use policies were found to have a positive influence. Among the seven designed scenarios, only increasing the number of recreational facilities and bus lines in the neighborhood can significantly reduce the household energy consumption, while increasing the number of supermarkets and restaurants in the neighborhood will inversely result in incremental usage.

The importance of the social influence coming from the recommendation or disqualification by relatives, friends, or opinion leaders; rumors from other households; or information from the market is well discerned on changing people's behavior outside the energy policy domain [15]. Some scholars have introduced this concept to encourage the pro-environmental behavior of households, such as the incremental adoption of clean energy technologies or efficient lifestyles, and their results emphasized that such non-price interventions (e.g., IPTED (Integration of Persuasive Technology and Energy Delegate) [16], rumor propagation [17], and eco-feedback systems [18]) can substantially and cost effectively change consumers' behavior. Allcott [19] evaluated a series of programs run by OPOWER, which sends Home Energy Report letters that compare a household's electricity use to that of their neighbors to households. An average of a 2.0% energy reduction is obtained from all programs, which is claimed to be equivalent to that of a short-run electricity price increase of 11%–20%.

Continuing debate exists as to whether environmental awareness, attitude, and belief necessarily result in pro-environmental behaviors with regards to energy conservation [20–22]. A growing body of research indicates that household environmental concerns do promote energy savings [23], but with sometimes being less influential for specific groups of households, such as low-income households [24]. However, other literature reports that households having positive environmental concerns and attitudes do not always choose to purchase energy efficient appliances [25] or consume less energy [26]. Because the targeted areas, the analysis methods, and the survey data used in the existing studies are quite varied, it is difficult to conclude the precise relationship between these psychological factors and energy consumption. Nevertheless, it is plausible that changing such unobserved factors, for example, awareness and attitude, by informational or educational campaigns could be an alternative means to reduce energy use for a portion of households.

Examining the state of the art of energy demand analysis, one can conclude that most of the literature addresses the influence of a single policy on energy conservation. However, the policy scheme, in practice, is always composed of a series of countermeasures. To portray the real situation, an active demand management system is a prerequisite to represent how people simultaneously respond to multiple policies [27]. Khansari et al. [28] proposed a concept (named as the CLIOS (complex, large-scale, interconnected, open, and sociotechnical) process) for modeling the impact of smart cities on household energy consumption behavior in a systematical way. They emphasized that the combination of changes of renewable technology, awareness campaigns, social norms, city structure, and comparative information can collectively drive a change, both in consumption behavior as well as in the adoption of renewable energy systems, thus contributing to reduced environmental impact. However, only conceptual modeling was presented in their work and scarce attempts were made to systematically couple these insights into a quantitative framework. As a result, a serious methodological gap exists between the perceived importance of closing the loop from the energy demand side and quantitative modeling frameworks or even policy scheme analysis.

Nevertheless, when considering the integrative effect of a policy scheme, another concern arises: are there any interactions between different policies? Gomi et al. [29] highlighted three types of relationships between policies: (1) policies that have an accelerating effect on other policies; (2) policies that are the prerequisite policies for others; and (3) policies that are the parallel policies. However, there might also be a hindering effect between different policies in reality, perhaps due to the inappropriate time sequence of the policies. For example, if the measures for improving people's environmental awareness is implemented in advance to a rebate program, one of the interactions between these two policies could be that more people utilize the rebate, while another result could be that because consumers have already contributed to energy savings by altering their lifestyle as the incremental awareness, they are hindered from participating in the rebate program, and vice versa. In this case, the rebate policies that are supposed to increase the technology efficiency will not work as expected. This behavior could also occur between socio-norm related policies and technology improvements. Sometimes, such hindering effects are not easily perceived, resulting in the failure of the planned policies. Therefore, when a series of policies are implemented together, the overall effect should not be calculated as the sum of the effects of every single policy; instead, the system that can reflect the policy interactions from the consumers' behavioral perspective is required.

Consequently, because of all of the concerns mentioned above, this study is a trial analysis to address the methodological gap by presenting a simulated dynamic active energy demand management system (abbreviated as DAEDMS). DAEDMS evaluates the collective effects of a set of non-price policies, including urban planning, soft policies for improving household/individual unobserved factors (such as environmental awareness, attitude, and belief (AAB)), technology improvement/rebate programs, market end-use diffusion control, and social norms, on changing household behavior and the accompanying energy consumption in residential and private transport sectors, along with in-depth behavioral description. The timing effect of each policy is also considered in the simulated DAEDMS, on the one hand to account for the interactions between the policies, and on the other hand to output