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Modeling and mapping domestic energy behavior: Insights from a consumer survey in France

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A B S T R A C T

Most works on the modeling of energy consumption in buildings make little headway in producing results that can be put to use in public policies. They reduce energy consumption to a quantity, without taking account of the behavioral processes and spatial variations that generate and explain them. The objective of our study is to reverse the perspective and to start from energy-related behavior rather than from intensities of consumption. Using regression methods and data from a survey on the energy lifestyles of 1950 households in the Île-de-France (Paris) region, we first model energy-related behaviors by looking at the characteristics of dwellings and buildings, as well as the socioeconomic and demographic characteristics of their occupants. Second, we investigate the relationship between behavior and energy consumption by using our models to simulate domestic energy consumption at national scale. Finally, we map energy behaviors at the scale of the Île-de-France region.

Energy-related behaviors turn out to be the product of complex interactions between habitat, inhabitants, and environment. Their spatial distribution is linked to territorial dynamics (metropolitanization, distribution of habitat types, etc.), as suggested by our cartographic analysis. But these results also highlight the complexity of the processes, insofar as there are no mechanical explanatory variables for behaviors.

1. Introduction

The last 10 years have seen the development of numerous quality labels and certifications (such as, in France, BBC [*bâtiment basse consommation* – low-consumption building] and BEPOS [*bâtiment à énergie positive* – energy-plus building]) intended to guide practice in building construction and renovation. These labels undoubtedly improve the energy efficiency of residential and tertiary buildings. However, a number of studies [1] have shown that constructing a building that meets the criteria of such labels is not enough to reduce energy consumption and greenhouse-gas emissions. Indeed there may be significant disparities between the consumption anticipated in the design stage and the actual consumption once the building is in place. Additionally, considerable differences in consumption may exist between constructions that are otherwise identical from a technical and architectural point of view [2]. Although location (climatic zone) can partially account for these variations, they cannot be explained in terms of geographical location alone. As some studies have shown, the behaviors of the occupants of dwellings and offices also have a significant impact.

The primary aim of most energy transition models that seek to take account of household behaviors is to predict the level of energy consumption in buildings, whether in the service or residential sectors. However, the models often have difficulty in producing results that can be put to use in public policies. They reduce consumption to abstract measurements that mask the reality of the social and spatial processes that generate them. The state-of-the-art review that follows will place this article within the complex universe of behavior modeling and contribute to an understanding of its contributions.

2. State of the art

As many studies have pointed out [2–4], when designing or refurbishing a building or a dwelling, the anticipated consumption dynamics are calculated on the basis of abstract considerations that keep the factors relating to actual energy behavior in a "black box". Research in this domain remains highly technocentric. Furthermore, the models proposed presuppose that lifestyles automatically adjust to technological innovations. It is no exaggeration to say that, from this perspective, occupants are depicted as passive recipients of an energy supply in purely technical terms.

In this article, we propose to move beyond technocentric approaches by involving other disciplines. With this in mind, we will take

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as our starting point the writings of Lopes et al. [5], and Fredericks et al. [6]. The former conducted an interdisciplinary review of the literature relating to energy-related behaviors and their modeling. The latter, in the conclusion to their literature review, open up avenues for exploration and investigation that are the basis of our research.

Lopes et al. [5] identify three fundamental approaches for the study of energy behaviors, from the domains of environmental psychology, sociology and sociotechnology. Psychology develops methods for understanding how specific individual factors mold behaviors, motivations, and energy representations (e.g. personal and social norms, beliefs and attitudes, motives and intentions, perceived behavioral control, cost-benefit appraisals) [7]. However, in focusing on the individual perspective, environmental psychology can fail to examine the influence of context on energy-related behaviors. Sociological investigations, for their part, seek to move beyond the individual scale to integrate energy consumption into societal processes that reflect experiences, social positions or demographic factors. In their article, Fredericks et al. [6] provide a comprehensive presentation based on two broad categories—sociodemographic factors and psychological factors—containing the variables that are potentially important in explaining variability in energy-consumption behavior. By focusing on the energy-related behaviors of individuals or groups, psychological, sociological, anthropological and geographical studies [8–16], appear to provide a complement to technocentric approaches. Sociodemographic characteristics of households, such as age, size, income [17–20], and family structures and their changes [21–23], are typically explored. Following on from this, some studies try to associate sociological and sociodemographic characteristics with housing practices [24–26], sometimes incorporating sensory, social, and functional factors relating to the built environment [27]. Other studies focus principally on the association between factors such as room temperatures, thermal control [28], window control [29], and energy consumption [30].

As noted by Lopes et al. [5], "*only a small number of studies quantify the impact of energy behavior on potential energy savings or CO_2 emissions*." In other words, such studies represent a minority in the wide panorama of research on energy behaviors. Their review identifies nine studies, though a number of more recent publications can be added to this group [17,24,31–34]. Moreover, as indicated in Guerra Santin et al. [24], little work has been undertaken on this topic using models based on statistical techniques that incorporate the characteristics and behaviors of building occupants.

A few authors have tried to model these behaviors. Lopes et al. [5] identify different types of modeling as follows:

- Energy modeling that quantifies energy use. These models generally rely on bottom-up statistical approaches (logistic regressions), with the aim of predicting the energy consumption of buildings. Swan et al. [35] and Kavgic et al. [36] have published detailed reviews of different kinds of energy models. The conviction—which we share—that emerges from the conclusion of these studies is that these models can be very effective for large-scale simulations and for the production of predictive algorithms on consumption intensities, but that they are less effective in including and, above all, explaining the behavioral and sociotechnical aspects of energy consumption.
- Energy behavior modeling, including quantitative and qualitative approaches to predicting behaviors. This is the category of models within which our contribution seeks to find a place. However, unlike the studies listed by Lopes et al. [5], the aim of our work is not to establish profiles of users based on energy measurements in order to identify individualized load profiles [37], or to conduct data mining in order to establish patterns of energy consumption [38,39]. Indeed, it seems to us that, even when these studies place energy-consumption behaviors at the forefront of their approaches, they nevertheless remain too focused on quantifying demand and encouraging changes in behavior. For this reason, they are more interested in promoting the development of attitudes considered to be "virtuous" than in determining the social and spatial processes that determine those behaviors. The result is that they resemble "black boxes" in which behaviors are based more on assumptions than on empirical verifications. Because of this explicatory weakness, they are ineffective as tools that can be used to support public territorial planning policies within the context of energy transition. Our aim, by contrast, is for this article to be relevant with regard to three characteristics of energy behavior—context, scale and heterogeneity [40]—and to contribute to the development of the prospects opened up in the conclusion of the article by Fredericks et al. [6], i.e. the production of a "*systematic and consistent framework validated by empirical evidence that would enable researchers, policy-makers and industry experts to better predict*" how different types of energy behavior are likely to impact energy consumption in different contexts and at different points in time.

3. Subject and objectives

The aim of this article is to reverse the prevailing logic by seeking to model not the energy consumption of homes, but the domestic energy-related behavior of households. The expression "energy-related behavior" refers to actions performed within the residential space that affect the level of energy consumption. From this perspective, energy demand and housing practices are social outcomes that result from compliance with norms and conventions [13–16]. This calls for the production of behavioral models that operate at the level of energy consumption, and the kind of modeling of social behavior that is generally addressed by qualitative studies. This approach entails a threefold challenge. The first challenge lies in combining qualitative information and numerical models [41]. The second is verifying that a domestic energy-behavior model will enable both a better understanding of energy uses and more robust simulations of consumption. The third is being able to use these models to simulate energy behaviors from a spatial perspective. Our hypothesis is that the spatial distribution of behaviors is closely linked to the distribution of buildings, dwellings, and households and, consequently, with the socioterritorial dynamics that partly explain them.

This method represents a dynamic interpretation of behavior (i.e. one that is not temporally and spatially static). That is to say that the model will incorporate behavioral flexibility, taking into account variations in the characteristics of households and dwellings in space and time. To give an example, the model will take account of whether households are settled, ageing, or changing in their composition (e.g. as children leave home), or whether the same type of housing is occupied by households with different characteristics (depending, among other things, on the social marking of territories).

To summarize, this research pursues three aims:

- to identify and model predictors of domestic energy-related behavior;
- to investigate the relation between that behavior and energy consumption;
- to pave the way for simulations of the impact of changes in these behaviors over time (i.e. to predict the movement of populations within a single area) and in space, by mapping behavior on the basis of models. This mapping seeks to improve understanding of those behaviors in the light of territorial dynamics.

This research is therefore resolutely interdisciplinary. It aims first of all to go beyond qualitative approaches by modeling behavior in order to simulate its impact on consumption and its development in time and space. It also aims to go beyond modeling approaches centered on energy demand by modeling behavior rather than intensity of consumption.

Our approach stands at the interface between different disciplines: sociology and anthropology, engineering sciences and geography. It