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Transition to low-carbon economy: Assessing cumulative impacts of individual behavioral changes

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ABSTRACT

Changing residential energy demand can play an essential role in transitioning to a green economy. Environmental psychology suggests that behavioral changes regarding energy use are affected by knowledge, awareness, motivation and social learning. Data on various behavioral drivers of change can explain energy use at the individual level, but it provides little information about implications for macro energy demand on regional or national levels. We address this challenge by presenting a theoretically-based and empirically-driven agent-based model to track aggregated impacts of behavioral changes among heterogeneous households. We focus on the representation of the multi-step changes in individual energy use behavior and on a quantitative assessment of their aggregated impacts on the regional level. We understand the behavioral complexity of household energy use as a dynamic process unfolding in stages, and explore the barriers for utilizing the full potential of a region for emissions reduction. We suggest a policy mix that facilitates mutual learning among consumers.

1. Introduction

Anthropogenic greenhouse gas (GHG) emissions continue to rise (UNEP, 2017). Keeping average global temperature below a critical limit of 1.5 °C above pre-industrial levels calls for ambitious emission reduction efforts. To reduce carbon intensity economies throughout the world rely on social and technological changes. The distributed nature of renewables, increasingly competitive costs of renewable technologies, and new developments in smart grids and smart homes further help energy consumers to become active players in this domain (EC, 2017). Prevailing social norms, which shape individual decisions and which are shaped by them, could be a response to global environmental problems (Nyborg et al., 2016). A need to understand the role of individuals in a transition to low-carbon economy, calls for quantitative analysis of behavioral changes with respect to energy use.

Residential energy use accounts for almost 24% of GHG emissions in Europe. Early assessments indicate that behavioral change alone can remove between 4% (McKinsey, 2009) and 5–8% (Faber et al., 2012) of the overall CO_2 emissions. Quantifying aggregated impacts of household behavioral change is, however, a challenging task. The quantitative tools to support energy policy decisions range from assessment of macro-economic and cross-sectoral impacts (Kancs, 2001; Siagian et al., 2017), to single sector analysis of costs and benefits (Kumar, 2016), and detailed micro-simulation models for a specific technology (Bhattacharyya, 2011; Hunt and Evans, 2009). Yet, behavioral shifts among households are often modeled in a rudimentary way assuming a representative consumer (a group), a perfectly informed choice based on rational optimization, and instantly equilibrating markets. Going beyond a stylized representation of a perfectly informed optimizer requires a theoretically and empirically solid alternative. The growing body of empirical literature in social sciences (Abrahamse and Steg, 2009; Bamberg et al., 2015; De Groot and Steg, 2009; Poortinga et al., 2004; Wall et al., 2007) acknowledges complex behavioral processes among households who consider changes in their energy consumption and decide on related investments and use practices. A range of theories in environmental psychology consider attitudes, norms, perceived behavioral control, awareness and responsibility to be vital in the process of individual decision making regarding energy use (Abrahamse and Steg, 2009; Adnana et al., 2017; Karatasou and Santamouris, 2010; Onwezen et al., 2013). Importantly, these studies differentiate between intentions and actual changes in individual behavior, and highlight the role of awareness, information and social peer influence on this process (Abrahamse and Steg, 2011; Frederiks et al., 2015). Omitting these behavioral factors, which may serve as drivers or barriers, could be misleading when studying the role of the residential sector in a transition to a green economy.

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Table 1
Overview of energy-related behaviors in the housing sector.

Energy-related behavioral changes	Examples	Last related factsheets
1. Investment (Action 1)	- Installing solar power system - Installing thermal solar power system - Roof/floor insulation - Installing efficient appliances - Installing smart meters	Abdmouleh et al. (2018) Deng and Newton (2017) Buchanan et al. (2016) Rai and Henry (2016) Buryk et al. (2015) Ameli and Brandt (2015) Rai and Robinson (2015) Tran (2012) Chappin et al. (2007)
2. Energy conservation (Action 2)	- Turn off extra devices - Consciously use less electricity - Run only full load washing machines - Tolerate lower (higher) temperature in winter (summer)	Thøgersen (2017) Amouroux et al. (2013) Faber et al. (2012) Mills and Schleich (2012)
3. Switching a supplier (Action 3)	- Switch conventional to green supplier - Switch to greener supplier	He and Reiner (2017) Rommel et al. (2016) Yang (2014) McDaniel and Groothuis (2012) Tran (2012)

Empirical data about various behavioral drivers of change is essential for understanding energy use choices at the individual level. Yet, it provides little information about implications for macro energy demand and for the corresponding emissions footprint on regional or national level. Proper aggregation methods are in demand. Agent Based Modeling (ABM) is a simulation approach to study aggregated dynamics emerging from actions of heterogeneous individual agents, which make decisions and interact with each other according to theoretical and data-driven rules. Boundedly rational agents, their potential to learn, and an ability to unfold a decision process in stages, allows ABMs to accommodate the complexity of human behavior in energy systems (Rai and Henry, 2016). ABM departs from using system-level equations explicitly representing the behavior of energy consumers, such as households, using a range of theories. This method is actively used in energy applications to study national climate mitigation strategies (Gerst et al., 2013), energy producer behavior (Aliabadi et al., 2017), renewable energy auctions (Anatolitis and Welisch, 2017), consumer adoption of energy-efficient technology (Chappin and Afman, 2013; Jackson, 2010; Palmer et al., 2015; Rai and Robinson, 2015), shifts in consumption patterns (Bravo et al., 2013), and changes in energy policy processes (Iychettira et al., 2017). ABM receives much attention currently in climate change mitigation discussions (Stern et al., 2016). Yet, many ABMs still either lack a theoretical framework (Groeneveld et al., 2017) or relevance empirical data, especially when studying energy-related behavior of households (Amouroux et al., 2013; Chappin et al., 2007).

This paper aims to quantitatively explore the impact of behavioral factors on the energy use of individual households and the aggregate dynamics of residential energy demand in a region., Its innovative contribution to the literature is threefold. Firstly, we extend individual energy demand modeling based on economic factors alone, by explicitly accounting for potential behavioral drivers and barriers in a formal model. Secondly, while acknowledging the importance of solid empirical behavioral data collected in harmony with recent findings in environmental psychology, the article introduces a simulation method that allows to aggregate individual behavioral and economic heterogeneity and captures dynamics in the aggregated regional trends looking beyond a snapshot of a survey. Thirdly, this article uniquely contributes to the growing body of literature on energy ABMs by focusing on the multi-step representation of individual energy use choices in a fully modeled energy market relying on theoretically and empirically-grounded agent rules. This combination of behavioral data collection via a survey with a simulation modeling allows us to address the main research question: how do different cognitive stages and psychological and social processes affect individual energy choices, cumulative regional energy demand and corresponding CO_2 emissions?

The article proceeds as follows. By drawing on critical insights on behavioral change from environmental psychology, we illuminate the key factors of energy-related behavior (Section 2) and present the design and summary of our survey (Section 3.1). We apply ABM to assess the cumulative impacts of individual behavioral changes with respect to energy use, accounting for socioeconomic heterogeneity, psychological factors and social network influence (Section 3.2). While grounding the model in these psychological and economic micro-foundations, we focus our analysis on the emerging macro properties (Section 4). The latter include macro trends in the diffusion of energy related practices among households (investments in energy efficient technical means, conservation due to changes in energy use habits or switching among energy sources), aggregated changes in shares of renewable energy consumption and corresponding CO_2 emissions at the regional level. We argue that understanding the behavioral complexity of energy-related households' decisions as a dynamic process unfolding in stages, uncovers barriers for utilizing the full emissions reduction potential of a region and calls for a policy mix that facilitates mutual learning among consumers (Section 5).

2. Human energy-related decision process

There are a number of actions households may pursue individually which impact their energy footprint. We categorize them into three main types of energy-related behavioral changes (Table 1). A household could make an investment (Action 1): either large, such as in solar panels and house insulation, or small, such as buying energy efficient appliances (A++ washing machine or light bulbs). Alternatively, households may save energy by changing their daily routines and habits (Action 2): by adjusting their thermostat or by switching off the lights. Finally, households could switch to a supplier that provides green(er) electricity (Action 3).

Empirical studies in psychology and behavioral economics show that consumer choices and actions often deviate from the assumptions of rationality: there are persistent biases in human decision-making (Frederiks et al., 2015; Kahneman, 2003; Niamir and Filatova, 2016; Pollitt and Shaorshadze, 2013; Stern, 1992; Wilson and Dowlatabadi, 2007). It implies that people do not necessary pursue the 'optimal choice' even if it is economically beneficial for them to do so. Unfolding a decision-making process in stages may potentially reveal where different biases and barriers start to play a role and how they may impact a decision.

Environmental psychology reveals various behavioral factors that are essential for understanding individual energy use decisions.