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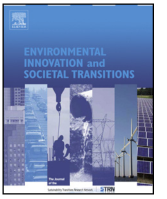

Adoption and diffusion of heating systems in Norway: Coupling agent-based modeling with empirical research

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A B S T R A C T

Sophisticated modeling techniques can help policy makers examine technology interventions aimed at addressing climate change mitigation and other environmental issues. Since adoption of a new technology is not only based on technical properties, policy makers must also consider human behavior. This paper presents a model for simulating heating system adoption processes from an end-user perspective. A literature review was carried out to identify potential decision-making variables and their relationships. An empirical survey was then conducted to test the variables and their interconnections as well as to derive model parameters. The empirically grounded agent-based model is able to reproduce the general patterns of heating system diffusion observable in Norway. The results suggest that increased adoption of wood-pellet heating is dependent on improved functional reliability and the improvement of fuel stability. Price volatility of both wood-pellets and electricity are important variables. Spatial results indicate that wood-pellet adopters are those closeby wood-pellet suppliers.

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1. Introduction

Norwegian energy policy aims at diffusing alternative heating systems because space heating represents the largest share of total energy use in households (Enova, 2003). Given the ample supply of inexpensive hydropower in recent decades, electric resistance heating dominates the Norwegian residential heating market. Periods of low precipitation combined with high demand for energy due to long, cold winters, such as 2002–2003 and 2010, led to high energy prices and inability to meet the demand in Western and Central Norway. In order to reduce electricity dependency and household exposure to high energy-price volatility, the Norwegian government started in 2003 to subsidize citizens' investment in air-to-air heat pumps and wood-pellet stoves (Bjørnstad et al., 2005). Electricity market models show, that on one hand, reducing household electricity use makes more electricity available for industry, charging electric cars and exported electricity in which the electricity imported from Norway replaces electricity produced abroad based on fossil energy sources. On the other hand, the use of alternative heating systems in households contributes to the attainment of the governmental goal of CO_2-neutral heating (Randers et al., 2006). While the subsidy for heat pumps has been successful, the subsidy for wood-pellet ovens did not lead to a substantial diffusion of wood-pellet heating in Norway. Three years after the introduction of the subsidy scheme, only 0.3% of households used wood-pellets and market development was sluggish. With this paper, we propose a model simulation to investigate the effect of various interventions toward the adoption of wood-pellet heating, which is presumed to be more sustainable in Norway. The model documented in this paper is an agent-based model (ABM) with a decision-making process derived from empirical research and parameterized through a survey.

Adoption and diffusion of a new technology have been widely studied from different perspectives. Many studies in adoption and diffusion of innovation are rooted in the work of Bass, who formalized the aggregate level of penetration of a new product emphasizing two processes of communication: external influence via mass media and internal influence via word-of-mouth (Bass, 1969). The decision is described as the probability of adopting a new product and is assumed to be linearly dependent on these two communication processes and fits very well with the real data for durable goods. While the Bass model is very useful for forecasting the initial adoption of a product, the model assumes a homogeneous consumer group as it does not specify micro-level decision-making. It also assumes perfect mixing in which all consumers have the same probability of connecting with other consumers without specifying how consumers communicate and influence each other. Social and behavioral research, meanwhile, has focused on the micro-level drivers of adoption, which contribute to the understanding of micro-level factors determining the adoption by individual consumers (e.g., Rogers, 2003). These studies emphasize that technical features do not entirely explain the diffusion dynamics of new technologies and highlight the relevance of the human factor. Furthermore, other studies have indicated that not only agent heterogeneity (Andrews and DeVault, 2009; Delre et al., 2007) but also social influence and network configuration (Kuandykov and Sokolov, 2010; Bohlmann et al., 2010; Delre et al., 2010) affect diffusion of innovation. Consequently, both social and psychological factors need to be considered when describing and predicting the behavior of consumers.

ABM, which is typically a bottom-up approach, is capable of capturing those factors. It starts from modeling consumer's decision-making and simulates the diffusion as an aggregate process of individual adoption decisions. This is a suitable approach when information exchange in a social network and individual heterogeneity play a role (Rahmandad and Sterman, 2008). Despite its capability, ABM has mostly been applied as an experimentation tool to demonstrate diffusion patterns resulting from simple decision rules followed by different artificial agents in the system (e.g., Janssen and Jager, 2002; Andrews and DeVault, 2009; Delre et al., 2007, 2010). Other studies (Bergman et al., 2008; Schilperoord et al., 2008) applied ABM to understand the mechanism underlying transitions from sailing ships to steam ships in oceanic transport in the 19th century. These simulation models were developed as abstract models and parameterized using historical narrative. Although the models were able to reproduce historical data patterns, they relied on simple behavioral models that were neither empirical nor validated.

The present paper fills a methodological gap by developing an agent decision-making model for ABM from a survey that was also used to parameterize the model. The model is thus based both on