Poster Abstract: Navigating Residential Heating Behavior Towards Renewable Energy Transition

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The transition to renewable and sustainable energy systems require a shift from conventional to renewable energy sources, which increases generation volatility and introduces more variable distributed renewable energy sources. As the heating sector undergoes decarbonization, it becomes increasingly electrified through the adoption of heat pumps and electric heating elements. Since a reliable electricity system depends on coordinated electricity use, this transformation creates both a high need and potential for demand-side flexibility. This doctoral research investigates how German households can be activated to provide heating flexibility to support renewable energy integration. The study employs a discrete choice experiment and a field experiment within the „D²HeaTEC" research project, examining three approaches: information provision, time-variable heating tariffs, and automated heating control. Expected contributions include evidence based policy recommendations for flexible heating programs and quantified insights into demand response effectiveness.

Additional Key Words and Phrases: policy design, household behavior, de-mand response, heating transition

INTRODUCTION

The heating transition towards renewable energy sources aims to achieve climate neutrality by 2050 [17]. However, fossil fuels still do-minate residential heating: 84% in European Union (EU) and 75% in Germany, with German heating relying on natural gas (46%) and oil (28%) while heat pumps contribute only 5% [2, 7]. Heat consumption represents approximately one-third of total household energy use in Germany, with room heating accounting for 70% of end energy consumption [19, 20]. This fossil fuel dependence makes heating a critical carbon footprint factor, contributing more emissions than electricity [5, 20]. As heat pump adoption increase, heating sec-tor electrification accelerates decarbonization [15]. However, this creates higher reliance on variable renewable sources, resulting in volatile generation patterns and requiring enhanced energy usage coordination [3, 8, 14]. These developments create increasing need and high potential for demand-side flexibility, positioning house-holds as „flexumers" who can contribute to grid stabilization [3, 11]. Flexumers offer advantages by acting without additional infrastruc-ture investments, unlike alternatives such as grid expansion [10]. Reduction and temporal shifting of heat consumption in households represent two possible ways to provide flexibility [12]. Effective strategies lie in decreasing consumption peaks or shifting them to periods of lower grid utilization or higher renewable energy feed-in [12]. However, household-level demand-side flexibility remains largely untapped, as it remains unclear under which conditions households accept flexibility heat ing contracts or services [3, 8].

2 RESEARCH QUESTIONS

This dissertation addresses the overarching research question:
How can German households be activated to provide heating flexibility?
through four complementary sub research questions:
Sub-RQ1: Which factors and tariff attributes influence the willingness of German households to participate in time-variable heating tariffs?
Sub-RQ2: Does the provision of consumption information and notifications about critical grid periods lead to adjustments in heating temperature settings?
Sub-RQ3: Do time variable heating prices lead to a temporal shift in residential thermal energy consumption towards periods of increased renewable energy generation or to a reduction during periods of low renewable energy generation?
Sub-RQ4: Can automated heating control within defined temperature ranges enable households to provide heating flexibility?

3 D²HEATEC - FIELD EXPERIMENT

Sub-RQ2, Sub-RQ3, and Sub-RQ4 will be investigated within the field experiment in the research project „Decarbonization of District Heating with techno economic control" (D²HeaTEC). The project provides access to two contrasting residential neighborhoods in Cologne, Germany: one with fossil fuel district heating and another with distributed heat pumps in renovated buildings with improved facades and higher glazed windows. Both neighborhoods consist of multi-family buildings with traditional radiator systems. All participating households receive smart thermostats and mobile application access to facilitate temperature control in 5-minute increments. The research runs from February 2025 to March 2028, spanning three heating seasons with ongoing recruitment targeting at least 70 households across both neighborhoods. The first winter (2025-2026) serves as a recruitment phase and, depending on recruitment success, additionally as baseline data collection without interventions. Experimental phases occur during the subsequent two heating periods (2026/2027 and 2027/2028), each comprising two intervention periods (November-December and January-February). Each intervention follows a structured protocol: 2-week pre-treatment baseline, 6-week treatment implementation, and 4-week post-treatment observation. Due to limited sample size, the study employs within-subject comparison design, analyzing individual behavioral changes across intervention periods. Data collection includes continuous smart thermostat monitoring of temperature setpoints per radiator, mobile app usage tracking, and external data (temperature, solar radiation, socio-demographic factors and electricity prices) at 5-minute temporal resolution as well as apartment level thermal energy consumption at monthly resolution.

4 RELATED WORK

Consumer acceptance and participation in demand response programs has been studied across different countries and contexts, revealing both opportunities and barriers for implementation. Research demonstrates a positive relationship between households' acceptance of time-variable electricity tariffs and their willingness to provide energy demand flexibility [18]. However, consumer responses vary across different energy domains. A Finnish study shows that consumers are more sensitive to electricity usage restrictions compared to heating limitations [16], while Swiss research reveals that prosumers with photovoltaic systems and electric vehicle owners show higher flexibility willingness than heat pump owners [11]. A German study indicates moderate acceptance of demand side flexibility, though it faces constraints from home environment interventions and comfort losses [3]. Despite these limitations, many households express willingness to participate when additional features are included in flexibility products [11]. Information and knowledge gaps represent the primary barriers to demand response participation [6]. Serbian field experiment shows that up to 70% of respondents prefer automatic Heating, Ventilation, and Air Conditioning (HVAC) system control to optimize demand response usage [6]. Transparency in information provision can help reduce barriers, though high monetary compensation requirements suggest actual participation may be lower than stated preferences indicate [3]. Parrish et al. [13] identify six key influence categories: financial aspects, familiarity and trust, perceived risk and control, complexity and effort, interaction with routines, and user characteristics. Financial compensation is the primary participation incentive, with Finnish research showing households require an average 78€ annual electricity bill reduction to choose real-time pricing [16]. German study indicates lower compensation requirements compared to previous research [3]. Beyond monetary incentives, households value CO_2 reductions at the power system level as environmental benefits [16]. Non-monetary features like advance notice and opt-out options also demonstrate positive consumer preferences [9]. Energy feedback interventions show variable effectiveness in influencing heating consumption. While most studies achieve energy savings through feedback, some report increased consumption due to rebound effects [1]. The sustainability of behavioral changes remains challenging, as energy savings from behavioral interventions tend to diminish over time [1]. However, actual household participation remains highly heterogeneous, with mixed results that underscore the complexity of consumer behavior in demand response contexts.

5 METHODOLOGY

5.1 Sub-RQ1

To address Sub-RQ1„„Which factors and tariff attributes influence the willingness of German households to participate in time-variable heating tariffs?", this study employs a discrete choice experiment using the random utility theory to analyze household preferences for time-variable heating tariffs. The methodological approach utilizes statistical modeling of choice behavior to quantify the willingness to-pay and identify preference structures among German households. The analysis incorporates latent class analysis to segment households based on their socio-demographic characteristics and calculate class specific willingness-to-pay estimates for different tariff configurations. This segmentation approach enables the identification of distinct household groups with similar tariff preference profiles, providing insights into targeted tariff design strategies. These attributes of the tariffs include price ranges reflecting the variability in time variable tariff structures, the frequency of price changes indicating how often prices can change during a day, price guarantees that provide households with cost certainty and control mechanisms distinguishing between automatic and manual heating adjustments.

5.2 Sub-RQ2:

To address Sub-RQ2, the intervention within the „D²HeaTEC" project employs a mobile application that provides households with an overview of temperature setpoints. This digital platform serves as the primary interface for information delivery and user interaction with their heating systems. The treatment consists of notifications delivered through the mobile application, informing households about current grid conditions by highlighting periods of high and low renewable energy generation and providing corresponding behavioral recommendations (e.g., to increase or decrease their radiator temperature settings). These notifications aim to increase household awareness of grid dynamics and encourage behavioral adjustments during critical periods. Data collection focuses on one primary metrics: temperature setpoints per radiator [°C]. This data collection enables detailed analysis of household responses at 5-minute resolution temperature settings. The analysis framework employs a within-subject design, conducting statistical analysis through pre- and post-treatment comparisons of temperature settings. This approach should allow for the isolation of treatment effects while controlling for household socio-demographic characteristics and external factors (outside temperature, solar radiation) that might influence heating behavior. The post-treatment period further allows for the analysis of possible fade-out effects.

5.3 Sub-RQ3:

To address Sub RQ3, the intervention within the „D²HeaTEC" project implements time-variable heating prices, that are directly linked to dynamic electricity prices and renewable energy availability. The pricing structure is designed to reflect grid conditions, with lower prices offered during periods of high renewable energy generation to incentivize thermal energy consumption, and higher prices implemented during periods of low renewable energy generation to discourage thermal energy consumption. Price communication is facilitated through an hourly price signal curve delivered via the mobile application interface, ensuring that households receive information about current pricing conditions. Data collection and analysis framework follow the same methodology as described in Sub-RQ2, focusing on temperature setpoints per radiator [°C] on 5-minute resolution. The within-subject design with pre- and post-treatment comparisons enables identification of price responsive behavioral changes at individual heating level. Based on monthly thermal energy consumption data, an estimation of hourly estimation of the energy consumption [kWh_{th}] will examine how households adjust their heating behavior in response to time-variable pricing signals.

5.4 Sub-RQ4:

To address Sub-RQ4, the intervention within the „D²HeaTEC" project implements automated heating control within household defined temperature ranges that can be adjusted at any time by the participants. The system operates on an opt-in basis, offering automated optimization within individually specified comfort ranges, while maintaining an opt-out possibility that allows households to return to manual heating control whenever desired. This flexible approach ensures household autonomy while enabling automated demand response capabilities. The default configuration in the opt-in approach defines a temperature adjustment range of 1°C around government recommended thermal comfort standards [4]. Range definition can be overridden by households with specified temperature comfort zones, expressed as acceptable deviations (±X °C) from their preferred temperature settings. This personalized approach allows each household to define their individual comfort boundaries within which the automated system can operate. Data collection focuses on temperature setpoints per radiator [°C] during both manual and automated control periods. The analysis framework employs a within-subject design, comparing manual versus automated control periods. To quantify flexibility through automation, the study measures the change of temperatures and the override. Based on monthly thermal energy consumption data, hourly energy consumption $[kWh_{th}]$ will additionally be estimated to assess how effectively automated control systems can provide grid flexibility while maintaining household comfort levels.

6 OUTLOOK

This dissertation addresses „How can German households be activated to provide heating flexibility?" through four complementary approaches. The research contributes empirical evidence on household preferences for time-variable heating tariffs and quantifies behavioral nudging effectiveness through consumption feedback and grid notifications. It investigates price responsive behavior to determine whether time-variable heating prices shift consumption toward high renewable energy periods and evaluates automated heating control within user defined temperature ranges. These findings will establish policy recommendations for activating the flexibility of household heating that balances technical requirements of the network with user acceptance and comfort preferences.

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