Modelling household energy consumption to understand sustainable energy behaviour

Namazkhan, Maliheh

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Summary

Household energy consumption represents a major contributor to emission of greenhouse gases that cause climate change and global warming, which has been a major concern to governments and the public. To mitigate climate change and help achieve a sustainable energy transition, it is important to understand which factors affect the likelihood that people engage in behaviours that limit climate change. The aim of this PhD thesis is to understand which factors affect sustainable energy behaviour, as this provides important insights in how to promote sustainable energy behaviour. We study three types of sustainable energy behaviours that have a relatively high impact on greenhouse gas emissions and climate change and that have so far been understudied: the use of natural gas, that plays an important role in the Dutch energy system; the adoption of sustainable energy sources, notably the installation of photovoltaic systems (PV); and the sustainable use of PV.

In this thesis, we considered a wide range of factors that may affect these types of sustainable energy behaviours that have typically been studied in isolation. Specifically, we proposed an integrated framework to enhance the understanding of factors influencing household gas consumption, PV ownership and sustainable PV use, including socio-demographics and psychological factors together. Additionally, we study to what extent building characteristics are related to gas use (behaviour), as building characteristics are particularly relevant for heating demand, and thus gas use. We apply a variety of statistical approaches that have not or hardly been used in this field, but that seem relevant to understand which factors affect gas use, gas use behaviour, installing PV, and the sustainable use of self-generated electricity by PV. The techniques we employ are the proportional odds model, multinomial logistic regression analysis, decision tree method and generalised additive models.

In Chapter 2, we test an integrated framework to examine to what extent building characteristics, socio-demographics and psychological factors affect actual gas use of Dutch households, as recorded by smart meters. We illustrate how decision trees can explain household gas consumption. The results showed that household gas consumption is uniquely related to buildings characteristics, socio-demographic variables, and psychological factors. Specifically, house size, building age and residence type (building characteristic), household income and employment status (socio-demographics), and most notably egoistic values, hedonic values,

environmental self-identity, perceived corporate environmental responsibility of the energy provider, and social norm (psychological factors) predicted total actual household gas consumption. Therefore, in order to get a comprehensive understanding of gas use, it is important to consider building characteristics, socio-demographic variables and psychological factors, as they all predict unique variance in household gas use.

In Chapter 3, we examine to what extent building characteristics, socio-demographics and psychological factors are related to a specific gas use behaviour that has a major impact on total gas use: room temperature settings. We performed a proportional odds model which, to our knowledge, has not been employed yet to understand household energy use, while it is a very appropriate approach to examine predictors of temperature settings. Similar to Chapter 2, we found that building characteristics, socio-demographic and psychological variables are all three important and reliable predictors of room temperature settings during daytime and night-time. More specifically, residents of newer buildings are during daytime and during night-time more likely to have higher room temperature settings than residents of older buildings. People living in detached houses, semi-detached houses and terraced houses tend to have lower room temperature settings during daytime than those living in apartments. Older respondents, larger households, stronger egoistic, altruistic, and hedonic values are associated with higher room temperature settings during daytime. Stronger biospheric values are associated with a lower room temperature setting during daytime as well as night-time. Besides, stronger egoistic values are more likely to set high temperature during night-time.

In Chapter 4, we examine to what extent socio-demographics and psychological factors explain whether people installed PV, intend to install PV versus do not own nor intend to install PV. As the dependent variable includes discrete categories at three levels (i.e., own PV, intention to own PV, and no (intention to own) PV, a multinomial logistic regression is performed. As in Chapter 2 and 3, we again found that both socio-demographic and psychological factors are uniquely related to sustainable energy behaviour, in this case the likelihood that households install PV. More specifically, younger people, larger households, higher income groups, people with a stronger sustainable energy use goal, and people with weaker altruistic values are more likely to intend to install PV. Moreover, people with a higher income and stronger personal norm to reduce energy use are more likely to actually have installed PV. Our result further showed that variables explained intentions to install PV better than actual PV ownership.

In Chapter 5, we consider to what extent socio-demographics and psychological factors are related to the sustainable use of PV, by reducing electricity demand from the grid and delivering electricity to the grid, as reflected in lower net electricity use from the grid. We employ a novel method, a generalised additive model, to study whether and which socio-demographic and psychological predictors can uniquely explain sustainable PV use, which we defined as net electricity consumption, reflecting the difference between electricity consumed from the grid and delivered back to the grid of households who installed PV, by relying on actual energy use data obtained from smart meters. We found that besides time of the day and the year, a range of socio-demographic variables and psychological factors explain sustainable household PV use, but not always in expected direction. Specifically, a higher age, being female, stronger biospheric values, stronger egoistic values, stronger hedonic values, and having a stronger personal norm to reduce energy use are uniquely associated with a lower net household electricity consumption. Yet, larger households, higher educated people, households with a higher income, stronger altruistic values, a stronger sustainable energy use goal, a stronger environmental self-identity and a higher outcome efficacy are uniquely related to higher levels of net household electricity consumption.

The findings of this PhD thesis consistently suggest that variables from all three types of predictors are relevant in predicting household energy consumption. Therefore, it is important to consider all three types of factors when developing policies aimed to promote sustainable energy behaviour. Specifically, interventions could be implemented to encourage and enable people to insulate their (older) houses for example by providing financial incentives, regulations, standards or energy-efficient technology. Besides, interventions could target high income groups or people living in large or (semi-)detached houses, as they have a relatively higher gas consumption. Alternatively, environmental self-identity can be strengthened, for example by making people aware of their previous sustainable actions. Next, people can be enabled to act in line with their biospheric values by providing households with feedback on their gas use, facilitating reductions in gas use. Such strategies may be particularly effective as psychological factors and building characteristics can be more easily changed and addressed in policy than socio-demographic factors such as age and gender, making these a particular promising target for energy policy. Furthermore, policy could strengthen people's sustainable energy goals by indicating why it is important to reduce fossil fuel use, install PV, and how this would help mitigate climate change, to enable people to act in line with their sustainable energy goal. Furthermore, personal norm can be strengthened by increasing individuals' awareness of the positive environmental consequences of installing PV. Besides, interventions could try to make people prioritize biospheric values more, and by

helping people to act in line with their biospheric values by facilitating and enable sustainable PV use. For example, households could be provided with feedback on their net electricity use, so they understand when they would need to reduce their energy demand as to prevent using energy from the grid.

Our findings clearly signals that an integrated approach is needed to understand sustainable energy behaviours, such as the use of natural gas, the installation of PV, and the sustainable use of PV, as considering only one type of predictor will provide a limited understanding of sustainable energy behaviour.