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Analysis of Smart Meter Data With Machine Learning for Implications Targeted Towards Residents

Ali Emrouznejad, Surrey Business Shcool, UK
https://orcid.org/0000-0001-8094-4244

Vishal Panchmatia, Aston University, UK

Roya Gholami, University of Illinois System, France*

Carolee Rigsbee, University of Illinois, Springfield, USA
https://orcid.org/0000-0001-5948-2401

Hasan B. Kartal, University of Illinois, Springfield, USA

ABSTRACT

Previous studies examining the electricity consumption behavior using traditional research methods, before the smart-meter era, mostly worked on fewer variables, and the practical implications of the findings were predominantly tailored towards suppliers and businesses rather than residents. This study first provides an overview of prior research findings on electric energy use patterns and their predictors in the pre and post smart-meter era, honing in on machine learning techniques for the latter. It then addresses identified gaps in the literature by: 1) analyzing a highly detailed dataset containing a variety of variables on the physical, demographic, and socioeconomic characteristics of households using unsupervised machine learning algorithms, including feature selection and cluster analysis; and 2) examining the environmental attitude of high consumption and low consumption clusters to generate practical implications for residents.

KEYWORDS

attitude, Cluster analysis, consumption classification, demographic, households, physical, resident, smart meter data, socioeconomic

INTRODUCTION

Planning for energy availability is critical in this era of rapid global economic and technological growth and climate change. Energy use is predicted to increase by approximately 15% and 70% by the year 2050 for OECD and non-OECD countries respectively (U.S. EIA, 2019). Researchers estimate the cost to construct infrastructure to support peak load increases of 18% in the U.S. would

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*Corresponding Author

be approximately 180 billion dollars, assuming current infrastructure pricing (Auffhammer, Baylis, & Hausman, 2017). Nevertheless, the main issue is not even whether we will have enough fossil fuel, but whether we can afford to produce and burn the fossil fuel we have (Alexander, 2015). Experts warn the World will pass the crucial 2'C global warming limit and the carbon pledges from 147 nations to the Paris Climate Summit are not enough to stop such a temperature rise. As such, finding ways to not only plan for but also reduce future energy consumption are key.

While the industrial and transportation sectors will continue to consume the most energy globally, residential consumption also drives increased energy demand (U.S. EIA, 2019). Attitudinal and behavioral changes that reduce energy consumption could create needed 'quick wins' while longer-term systematic infrastructure upgrades are designed and implemented to address anticipated increased energy loads.

At the same time, data collection tools available for understanding current energy utilization have advanced. The use of smart meters enables the real-time data collection and more accurate billing, and facilitates unique insight on energy and water consumption behavior (Bhattarai et al., 2022; Ratner et al. 2022; Bhardwaj et al. 2022; Gohil et al. 2021; Dhanwani et al. 2021; Monks et al. 2021; Kumar et al. 2021; Ahuja and Khosla, 2019; Cango et al., 2018; Chaudhari and Mulay, 2021; Khosrojerdi et al., 2021; Kuhe and Bisu, 2020; Sharma and Singh 2015; Siepermann et al., 2021; Rathod and Garg, 2017; Agwu 2021; Baccarne & De Marez, 2021; Croci & Molteni 2021).

While Canada and the U.S. led the way in smart meter installation (30-40% current usage across North America), Europe is estimated to have around 72% installation in 2020 (IoT Analytics, 2020). This has led to the availability of large volumes of smart-meter generated data. For this reason, there is value in complementing traditional theory-driven research in energy consumption with research that uses machine learning techniques, or more broadly by artificial intelligence (AI)-driven approaches. Prior to the smart-meter era, studies tended to examine electricity consumption behavior using traditional theory-driven research methods, incorporating a limited number variables. The practical implications of the findings were predominantly tailored towards suppliers and businesses rather than residents.

To address these gaps in literature, the current study: 1) provides an overview of the findings from the studies on electric energy use patterns and their predictors in the pre and post smart-meter era; 2) combines unsupervised machine learning algorithms, feature selection, and cluster analysis for uncovering new, unexpected, or more nuanced insight into the determinants of energy usage, and patterns in its use, that might not otherwise have been predicted using conventional predictive research methods; and 3) analyzses the implications of smart meter data adoption for residential consumers by focusing on socio-economic characteristics, demographic characteristics, and pro-environmental behavior.

LITERATURE REVIEW

Pre-Smart Meter Era: Determinants of Energy Use

Prior to the advent of smart meters, household energy consumption research largely relied on data obtained through household member interviews and surveys. and secondary consumption details such as whether certain home appliances were in use or not in use (Klemenjak et al., 2019), examining the effects of "socioeconomic", "demographic", and "physical" determinants (Petersen and Gram-Hanssen, 2005). Some studies also examined attitudinal factors.

Socioeconomic Characteristics

Jones, Fuertes, and Lomas (2015) examined the relationship between *household income* and *electricity consumption* and found that higher household income is correlated with higher energy consumption. Cayla, Maizi, and Marchand (2011) examined the impact of income on residential energy consumption and found households with lower income were more restricted in their energy consumption.

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