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The technology of the middle class: Understanding the fulfilment of adoption intentions in Queensland's rapid uptake residential solar photovoltaics market

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ABSTRACT

Residential solar photovoltaics (PV), a once niche technology reliant on direct regulatory support to stimulate its adoption, has progressively become more competitive because of economies of learning and scale in production. Given its extraordinary market growth, a better understanding of the various market and social factors affecting residential consumers' PV purchasing decisions is required for policy makers to create efficient support mechanisms, by industry participants to better target marketing activities, and for more informed planning of centralised electricity generation and network infrastructure development. This paper reports on an analysis of the behavioural drivers of households as decision-making units fulfilling an intention to adopt PV. Drawing upon Rogers' diffusion of innovation theory and using a logistic regression choice model, the actual outcomes of the residential PV market are examined in the state of Queensland, Australia. A recent survey of more than 8000 households is used to investigate the difference in demographic and motivational factors among households with the stated intention to purchase PV with those that have already adopted the technology. Our findings suggest that PV is the technology of the middle class. This reasoning is made based on surveyees' stated concerns over rising electricity bills and survey data which indicates that economic life events have a significant influence over perceptions of affordability. Households need to be concerned with rising electricity bills to be motivated to adopt PV, but must also have access to sufficient capital to afford its upfront cost. Familiarity with the technology appeared to reduce adoption motivations based on self-sufficiency and intentions to go off grid.

1. Introduction

In coming decades it is likely that residential solar photovoltaic (PV) technology will play a key role in meeting the energy policy trilemma of equity, security and environmental sustainability [1]. PV technology improves environmental sustainability by reducing carbon emissions and can contribute to energy security by diversifying the primary 'fuel' mix through utilising the local and renewable resource of insolation to generate electricity. PV can also be used to improve equity by reducing the cost of electricity in areas without centralised infrastructure. To efficiently facilitate and regulate the uptake of residential PV, there needs to be a deeper understanding of the motivations behind households' PV adoption decisions.

The Australian National Electricity Market has witnessed a rapid uptake in residential PV over the past decade with a total installed capacity rising from 23 MW in 2008 [2] to an estimated 3,700 MW in 2015 [3]. By early 2016 the percentage of dwellings across Australia with solar PV had reached almost 16% [4], with the highest penetrations in South Australia (25%) and Queensland (24%) [5]. Of the states in the National Electricity Market, Queensland had the highest installed residential rooftop solar capacity and was forecast to have the highest rate of installed capacity growth to 2034–35 [4].[1] The growth of the market, since 2008, can be attributed to three major drivers:

1. increases in retail electricity prices over the period;
2. decreases in the installed cost of PV technology due to reduced silicon prices, increased economies of scale, learnings in production, improved conversion efficiency and a high Australian dollar over

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[1] These factors combined with the authors' access to survey data were the primary reasons why the Queensland market was selected for the analysis presented in this paper.

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much of the period; and
3. regulatory incentives in the form of an upfront cost rebate as part of the Federal Renewable Energy Target and state based feed-in-tariffs (FiTs) [6–8].

Energy stakeholders' understanding of the PV market is limited by the relatively short history of the technology's commercialisation and associated time series data. As such, forecasting the penetration of the technology among households and the resulting impact on grid electricity demand is difficult. Therefore, a need exists for a more thorough understanding of the drivers behind the adoption of PV technology. In-depth knowledge of PV adoption behaviour will be valued by system operators, network service providers, electricity retailers, generators, regulators, renewable energy policy makers, and businesses competing in PV importation or installation markets. The rapid uptake in rooftop PV has reduced wholesale electricity demand, which may undermine the revenue basis for centralised electricity generators, retailers and, to a lesser extent, network service providers, thereby increasing the risk of assets becoming stranded. Understanding the drivers of adoption in the residential market will assist these businesses in a more accurate modelling of adoption rates and consumer demand profiles. The improved accuracy in demand forecasts should enable more efficient planning and regulation of electricity infrastructure investment. For network service providers and their regulators, an understanding of the drivers of PV adoption will assist in the development and assessment of business plans and regulatory proposals. Renewable energy policy makers will benefit from an understanding of the rate of PV adoption under current policy settings and the influence of various market and social factors affecting consumers' choice of PV implementation when considering the adjustment of existing, or the development of new, renewable energy support measures. Finally, with greater market intelligence, potential new PV market entrants will be able to more carefully develop market growth projections and better tailor their marketing strategies.

The overarching research objective that led to the production of this paper was to empirically examine the behavioural drivers of fulfilling an intention to adopt residential PV by households as decision-making units. The analysis investigated the differences in demographics and motivational factors among households who intended to purchase solar PV and those who had already adopted the technology. These segments of the population were filtered from household survey data from Queensland, Australia, with a sample size of 8,137 households collected in 2014 and 2015. The statistically significant differences and their relative importance between the segments were determined by utilising binomial logistic regression analysis. The regression output provided insights as to the motivations behind households' solar PV purchase intentions and adoption decisions. The model of decision-making utilised to segment the data was adapted from Rogers' [9] diffusion of innovation theory.

The novel aspects of the present research stem from the authors' access to an extensive data source at the household level with demographic information and responses to survey questions designed to uncover attribute perceptions in the form of motivational factors. The sample size of the data enabled a focused comparison between households intending to adopt and those that have adopted the technology, rather than the conventional, broader comparison of adopters and non-adopters in previous literature. Vasseur and Kemp's [31] research recognised the variability of non-adopters with a segmentation analysis but they had an insufficient sample size to accurately analyse the critical transition from intention to adoption. The present research reduces the variability of the sample of non-adopters by segmenting those who are most likely to become adopters, with stated intentions to adopt. The reduced variability will enable the identification of more nuanced differences and further insight into previously inferred motivational factors that correlate with the successful transition from being a non-adopter to an adopter. Another distinguishing feature of the present research is the pursuit of parsimony in the empirical model specification; the aim being to provide clarity over complex phenomena [32], to avoid overfitting of the model, and to reduce data requirements [33].

The remainder of this paper is structured as follows. Section 2 provides a review of the relevant literature. Section 3 outlines the methodology and data utilised. The results of the model are reported in Section 4 along with a discussion of major findings. Section 5 summarises the contribution, findings, and implications of the research.

2. Literature review

Studies utilising empirical data to investigate the behavioural drivers of residential PV adoption were reviewed. The models developed in these studies have either focused on a class of predictors or a combination of classes including economic/financial, demographic, attitudinal or social predictors. Variables relating to cost and return on investment appear to have an influential and statistically significant effect on the residential PV adoption decision based on a wide range of empirical results in the academic literature. There were a number of studies that found financial considerations to positively influence adoption [10–16] or conversely act as barriers and limiting factors [12,13,17,18]. One of the most common barriers identified was the upfront cost of PV [11,13,18,19]. While there were broad similarities, there were also variations relating to the relative influence and statistical significance of specific financial factors. Schelly [16] concluded economic factors relating to the timing of life events and family circumstances were more important considerations than the payback period. In contrast, other studies found respondents were highly influenced by the cost of installation and payback period [20,21].

Variations in studies could be partially attributed to the point in the adoption process analysed and the maturity of the market. A study by Rai and Beck [15] suggests that as respondents moved through the decision process there was a diminishing influence of attitudes and perceptions of how other people typically behave, while perceived affordability and self-expectations of behaviour from internalised values increased in influence. The maturity of the market, indicated by the market segment adopting has also been found to impact the influence of factors in the decision-making process. Sigrin et al. [22] found that protecting the environment was less influential for recent adopters than for early adopters, whereas lowering total electricity expenditures and being protected from future price rises increased in influence for recent adopters compared to early adopters. Faiers and Neame [12] found the early majority were more influenced by financial considerations than environmental concerns. Financial factors are broadly expected to be influential and comparisons between studies requires the stage of the adoption process and market maturity at the time each study was conducted to be considered.

A review of the literature found variable influences of demographics on PV adoption. Rai and Robinson's [23] research into publicly available datasets determined that education, family composition, retirement status, race and political affiliation explained 36% of the variance in PV adopter attitudes. A study performed by Letchford et al. [24] concluded demographics, including household factors such as owner occupation, income and the number of bathrooms, to be statistically significant in the output of three alternative methodologies. In direct contrast, Chernyakhovskiy's [25] study found demographic characteristics were not significantly related to PV adoption. In a Californian study performed on a dataset from 2013 to 2014, adopters had higher incomes, were more educated, lived in larger homes and stayed in their homes for longer on average than their non-adopting peers [22]. Temporal variations were identified within this study, with recent adopters being more representative of general homeowners and being more politically moderate than early adopters. Texan PV adopters were also more educated and had higher than average incomes [14]. Age was found to be a prominent explanatory variable in Islam's [20] research in Ontario, where there were higher early adoption rates in younger