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Power to regional households: consumer attitudes towards electricity-saving, the solar rebound and the determinants of rooftop solar adoption

ABSTRACT

Solar energy is crucial to the transformation of the energy system, and it is important to promote 'green' energy technologies to achieve the 2015 UN Paris Agreement targets. This study takes a holistic view of consumers' energy-related behaviour by identifying the factors driving the adoption of rooftop solar photovoltaic and by distinguishing the electricity conservation practices of solar and non-solar households. We reveal a nuanced understanding of the rebound effect from a behavioural perspective, which may help solar energy policy formulation and efficient decarbonization pathways in Australia and elsewhere. The principal component analysis and binary probit analysis were used to investigate the intention to install rooftop solar photovoltaic panels using a face-to-face survey of 325 households in a regional city. The results show that home ownership, unwillingness to sacrifice personal comforts to save electricity, being pro-energy efficiency, and income are positively related to rooftop solar installation. In addition, different segments, such as the 'energy-efficiency advocate', the 'digital tool lovers' and the 'behaviour change advocates' were identified. Finally, recommendations for policy and practice are made to promote rooftop solar and more careful use of electricity in the residential sector.

Keywords

Rooftop solar PV adoption, residential electricity conservation, rebound effects, climate change

6160 words

Introduction

At the United Nations Climate Change Conference, COP 26, the Australian government adopted a net-zero target before 2050 and agreed to reduce emissions so that the rise in global average temperature can be limited to 1.5 degrees. For the first time, nations were called upon to phase out coal power and inefficient subsidies for fossil fuels (United Nations Framework Convention on Climate Change 2021). However, global efforts to mitigate climate change remain uncertain, with a dilemma facing policymakers between economic development and sustainable development. In relation to the energy sector, the outbreak of the pandemic stalled investment in the renewable energy sector, yet scholars are optimistic that the transition to renewable energy will accelerate. Factors supporting a transition include the preference for 'cleaner' energy to meet greenhouse gas (GHG) emission targets and Sustainable Development Goals (SDGs), the need to preserve energy security, to facilitate economic development and to exploit the digital transformation of the energy sector (Elavarasan et al. 2021; Ghosh and Vale 2006). This article focuses on the consumers' perspectives of energy, and the context is Australia since it is a world leader in the adoption of residential rooftop solar photovoltaic (PV), with 20% of households having solar panels (Zander et al. 2019). The research aims to identify the factors driving the adoption of rooftop solar and explore consumer attitudes towards household electricity conservation and energy supply in regional Australia. The study is important since it unearths differences in conservation beliefs between those who have adopted solar and those who have not. Since residential electricity consumption is expected to increase as more people embrace stay-at-home living patterns (Krarti and Aldubyan 2021), research on solar adoption and interactions with energy behaviours is important. This research can benefit other countries with the twin goals of promoting electricity conservation and solar PV as part of a climate mitigation strategy. While the focus of the study is on Australia, a study on the dynamics of PV adoption can be generalised to other countries that have implemented similar policy measures and have a high adoption rate of residential renewable energy. The authors recommend actions to support the post-pandemic transition to sustainable development.

Australia has vast fossil fuel reserves, a comparative advantage that has resulted in a high reliance on fossil fuels for electricity generation (Simhauser 2018). Australia's per capita emissions rate at 22.4 tCO2e/capita in 2018 is double the OECD average. It is one of the worst in the world (Organisation for Economic Cooperation and Development (OECD) 2021), leading to calls from scholars for an energy transition to renewable resources (Shi, Liu, and Yao 2016; Blakers 2000). Government incentives have been of paramount importance in promoting renewable energy at the residential level. As a Federal Government policy, Australia's renewable energy target (RET) has been operating since 2001, and it effectively subsidises individuals when installing small systems such as rooftop solar. This incentive occurs through small-scale technology certificates (STCs) granted at the time of purchase based upon a system's generation capacity. The certificates are tradable and place a legal obligation onto electricity retailers to source energy from renewable sources. In addition, state governments set up a guaranteed feed-in tariff (FiT), an incentive payment for electricity fed into the national grid (Li et al. 2020). However, a drawback of financial incentives is that they tend to be too generous and reward electricity users for the kWH generated and not energy savings (Bertoldi, Rezessy, and Oikonomou 2013). The economic rationale for such incentives has been frequently questioned, and the rebate is designed to expire in 2030 (Li et al. 2020). Most states or territories have reduced FiTs to as low as 20% of retail electricity costs, and the FiTs can be further changed without warning (Zander et al. 2019). As well as promoting solar, improving energy efficiency (i.e., the goal of using less energy to achieve the same outcomes) is one of the cost-effective ways of reducing emissions and enhancing energy security (da Graça Carvalho 2012). Policy actions related to energy efficiency, such as having regulations and labels for energy-efficient domestic appliances, are welcomed by governments since they can deliver greenhouse gas emission abatement without damaging the domestic economy or export industries (Berry and Marker 2015). System-wide transformations are required to mitigate climate change and shift to a low-carbon energy system. Crucial to this energy reform process is the incorporation of the human dimension into policy formulation.

This study investigates the factors driving the adoption of rooftop solar PV in regional Australia and evaluates consumers' attitudes towards electricity supply and conservation. Previous literature analyses the factors driving the adoption of rooftop solar PV (Abreu, Wingartz, and Hardy 2019) and scholarly interest in domestic electricity-saving behaviour is increasing (Wang, Lin, and Li 2018). However, it is argued that: 'currently, energy savings based on behavioural and attitudinal changes have been accepted as important blind spots in our understanding of residential energy demand' (Belaïd and Joumni 2020, 2). This study distinguishes between solar and non-solar households, identifies segments based on attitudes towards electricity conservation, and sheds light on the 'rebound effect', whereby efficiency gains lead to the increased consumption of a resource (Li and Lin 2017). The solar rebound effect has attracted interest from researchers (Boccard and Gautier 2021; Deng and Newton 2017), yet more understanding is needed about this topic. As noted by Chitnis and Sorrell (2015), the rebound effect is problematic as it has repercussions for the effectiveness of energy policy, and the greenhouse gas emissions (GHG) 'saved' by policy may be less than anticipated. This study allows policymakers to better understand how incentives can be targeted at particular segments and successfully implemented with sustainable outcomes. A consumer-oriented approach is important, given that technology-based solutions to climate change may fail to meet goals if the psychological drivers of energy behaviour are not well understood. In the words of Watson et al. (2020, 9):

Reflecting on how we leverage insights from the social sciences to create deep systems change is particularly important given the ambitious targets being set around sustainable consumption of water, energy, food, and the connections of everyday practices to low carbon transitions, within the Sustainable Development Goals.

Current studies on the adoption of solar PV tend to focus on a narrow facet of adoption, such as feed-in tariffs (FiTs) and socio-demographics (Zander et al. 2019; Lan et al. 2020). This literature is invaluable; however, the decision to install solar PV is not purely investment-led behaviour, and less is known about the psychological determinants of adoption and conservation by different consumer segments. Knowledge of the non-financial drivers of electricity-saving is essential to designing interventions to promote electricity conservation. Furthermore, this research takes place in a regional Australian context, where little research has been undertaken on domestic electricity saving practices (Webb et al. 2013). From a policy perspective, regional studies will be vital in helping the Australian government meet the Paris Agreement obligations on Climate Change (Burnes 2017) and the challenge of restraining global warming (United Nations 2015). Finally, the findings will assist policymakers in other countries who wish to use policy measures to increase the adoption of small-scale solar panels and promote electricity conservation.

Background and literature review

Installation of rooftop solar has the potential to deliver economic benefits to households and mitigate greenhouse gas emissions since electricity in Australia stems from carbon-intensive sources. Rooftop solar replaces electricity that would otherwise be supplied by coal-fired power plants (Nicholls, Sharma and Saha 2015). Furthermore, small-scale rooftop solar systems contribute to just 7% of Australia's total annual electricity generation (Clean Energy Regulator 2021) and the phasing out of coal-fired generation, implied by the COP 26 agreement, means that solar PV can play a dominant role in decarbonizing Australia's energy system.

Research on consumers' attitudes regarding rooftop solar has revealed numerous motivations for, and barriers against, the adoption of residential solar, including economic incentives, demographics, property tenure and the peer effect (Best, Burke, and Nishitateno 2019). The application of diffusion of innovation theory (Rogers 2003) to solar adoption has been valuable in understanding the demographics of early adopters, who are typically educated and higher in socio-economic status than the general population (Simpson and Clifton 2017) and the motives of adopters, such as awareness of environmental problems, peer effects, financial stability and desire to be self-sufficient and independent (Karakaya, Hidalgo, and Nuur 2015). A rich literature examines the factors driving the adoption of rooftop solar PV in Australia (Chapman, McLelland, and Tezuka 2016). In Queensland, the adoption of small-scale solar photovoltaic systems by households has been remarkable (Sommerfeld, Buys, and Vine 2017). It is reported that 1 in 4 detached households in Southeast Queensland have installed rooftop solar PV, and this adoption rate is amongst the highest in the world, which has been chiefly explained by access to government subsidies (Simshauser 2016).

Nevertheless, the feed-in-tariff (FiT) policy has been criticised for its adverse energy justice outcomes, such as increased disconnections from the grid (Poruschi, Ambrey and Smart 2018). It has been described as "a regressive form of taxation", since lower-income customers who could not afford to install the solar systems paid higher electricity prices to cross-subsidise the solar households (Nelson, Simhauser and Kelly 2011 113). Many scholars acknowledge the success of energy policy in developing the solar PV industry, but they have identified adverse impacts such as the solar PV policy being costly, socially regressive and environmentally ineffective (Chapman, McLelland and Texuka 2016). Since the early adopter segment was rewarded with premium feed-in tariffs, consumers were incentivised to export solar energy production as much as possible. This type of behaviour was likely to increase the electricity supply during off-peak periods (as most solar production happens during the central hours of the day). It also increased peak demand (i.e., electricity demand typically peaks in the early evening since residential use increases and rooftop PV generation falls), a major driver of network costs (Sommerfeld, Buys and Vine 2017). Network businesses face a range of technical challenges from high penetration of solar PV (Young, Bruce and Macgill 2019). Since solar power is intermittent, the large-scale installation of solar PV may increase systems' costs, such as the need for ancillary services (Batalla-Bejerano and Trujillo-Baute 2016). There is concern that exporting energy back to the grid at levels far exceeding demand will make the system unstable and lead to system faults or blackouts. In this scenario, system operators will simply curtail the ability of people to export solar power at certain times or use other options such as pricing signals to help stabilise the grid (Gallagher 2021). Compounding the problem for the network is the continued use of a flat-rate tariff structure, and load demand tariffs are proposed (Simshauser 2016) that may, in the long term, lead to a more conscious use of electricity and help avoid over-capitalisation in the electricity network.

In a broader sense, electricity conservation has been linked to socio-demographic variables, such as income, home ownership, dwelling type and size, family size, and family life cycle stage (Stigka, Paravantis, and Mihalakakou 2014). The link between education and electricity conservation is contested in the literature, with some scholars arguing that only partial support is found for the link between education and ecological knowledge, attitudes, and behaviour. However, it is noted that the maturity of the solar PV market has meant that lack of education is not necessarily a barrier to solar PV adoption (Paladino and Pandit 2019). The desire to cut energy bills (Islam 2014) and concern about increasing electricity prices is a significant driver of solar PV adoption (Sommerfeld et al. 2017). Pro-environmental attitudes also explain intentions to adopt solar PV (Abreu et al. 2019).

Energy is omnipresent in consumers' everyday lives, and numerous factors are related to energy consumption. Two types of behaviour are linked to electricity conservation, namely, curtailment behaviour and efficiency behaviour. Curtailment behaviour refers to how the occupant in a home interacts with energy regularly. Efficiency behaviour refers to purchasing decisions, which tend to be high-impact and save more energy (Gardner and Stern 2008). For example, energy-efficient lighting such as Light-Emitting Diode (LED) bulbs cost more than incandescent bulbs, but the light bulb does not have to be changed so often, and significant energy savings occur in the long term. Consumer sensitivity to rising electricity prices has led to an increase in the sales of long-life light bulbs (Belz and Peattie 2012). Careful use of high demand appliances (e.g. air conditioners, pool pumps and electric hot water) benefits households, yet taking action is likely to be difficult since Australian households vary in motivations, abilities and opportunities to manage their energy bills (Energy Consumers Australia 2018).

Although consumer behaviour, such as preferences for buying particular devices and everyday practices (e.g. heating, cooling, laundering), is critical to electricity consumption, rational economic models have failed to focus on actual consumer behaviour (Buys et al. 2015). Research into Australian households' electricity conservation practices is surprisingly sparse, with some exceptions (Hallin and Weyman-Jones 2018). Consumer lifestyles and material culture are strongly linked to energy use (Gardner and Stern 2008). Distinct segments have been outlined based on pro-environmental attitudes and socio-demographics. Thøgersen (2017) developed a housing-related lifestyle instrument, where he argued that people's interests, such as acquiring material goods for the home and engaging in home improvements, are reflected in energy-saving efforts. In a post-pandemic world, the home is likely to become an integrated living and working space for some lifestyle segments (Echegaray 2021), so research on the energy-related behaviours of particular segments will remain important.

Electricity consumption is different from most other consumer goods as it is invisible, abstract and untouchable. The invisibility of electricity means that feedback, beyond the monthly bill, is critical so that the consumer can understand which appliances use electricity, when electricity is used and how much is used (Fishcher 2008). Today, there is growing interest in the power of digital technology to transform the energy market. Smart meters are described as advanced meters or devices that digitally measure energy use, and that information can be sent back to the energy retailer remotely; they also allow the electricity supply to be remotely switched on and off without the need for a field technician (Australian Energy Regulator n.d). They have the potential to increase environmental awareness, triggering behavioural change (Fettermann et al. 2020), yet a recent study found that smart meters have limited effectiveness in reducing actual consumption (Geelen, Nugge, Silvester and Bulters 2019). Also, contextual factors, factors outside of the individual and household behaviour, play a role in energy consumption. The electricity usage depends on several factors, such as climate and the season, besides the individual's personal comfort needs. Scholars highlight factors such as 'green' building standards, the attributes of the home, the number of appliances, their efficiency and intensity of use, and climate change beliefs; energy prices and political ideology as factors influencing electricity consumption (Van Raaij and Verhallen 1983). Acceptance of renewable energy technologies is associated with a high level of concern about climate change (Spence et al. 2010), which, in turn, is shaped by political affiliation. Studying and modelling human behaviour sets consumption as an individual behaviour which implies that people make completely sovereign choices, thereby discounting the effect of social expectations such as those relating to proper care of the family, definitions of comfort and hygiene, and presumed social expectations of guests (Hazas and Scott 2011). It is recognised that social norms and structural factors serve as significant drivers or impediments to electricity saving (Thøgersen and Grønhøj 2010).

Although the topic of domestic electricity practices has generated a considerable body of academic work, there are gaps in our knowledge, and it is accepted that more research on how occupants interact with buildings is needed (Delzendeh et al. 2017), particularly in solar households, where the solar rebound effect has been clearly demonstrated (Boccard and Gautier 2021). Therefore, this article contributes to the energy literature by providing insights into the adoption of rooftop solar and attitudes towards electricity supply and conservation, leading to targeted, therefore, more effective communication strategies.

Research questions and methods

The research questions are as follows:

(1) Is the decision to install rooftop solar PV linked to socio-demographic variables and psychological factors?
(2) Do attitudes towards electricity conservation vary between those who have installed solar and those who have not?

Scales

Information was collected through a survey, and the type of questions are outlined below. Adoption of rooftop solar was captured by current status ('I currently have rooftop (photovoltaic) at home'). A series of statements were developed to measure respondents' attitudes towards climate change, energy resources, and scales were informed by the literature. A few items were specifically developed to capture relevant issues to Queensland. A five-point Likert scale was used to capture attitudes with anchor points 1 = strongly disagree to 5 =

strongly agree. A total of 17 statements were devised to capture the diversity and perceived importance of electricity conservation practices in the home as there are many ways to save electricity in the home. Some of these items were informed by the scholarly literature, such as buying energy-efficient light bulbs, controlling the temperature of devices, switching off lights. Items were also informed by government websites and energy-saving tips and guidelines from energy retailers designed for people living in the tropics. An importance scale (anchored by 1= not at all important and 5= very important) was used to measure attitudes. Questions also captured barriers and facilitators to electricity-saving, such as personal comfort, effort and price-related concerns. Sample items are as follows: "I am not willing to sacrifice some personal comforts to save electricity" and "reducing my electricity usage is not worth the trouble". Finally, questions on socio-demographic data, such as gender, age, income, educational attainment, employment status and political party affiliation, were included. Structural conditions related to household electricity consumption (Thøgersen and Grønhøj 2010) such as home ownership, type of dwelling, household size and number of appliances were included in the survey.

Questionnaire development, sample, recruitment of respondents

Ethical approval was granted by the Human Ethics Committee of the authors' university. We used mixed methods in the sampling process and conducted an intercept survey in key locations of Townsville, a regional city in Queensland. The city was chosen due to ease of access to respondents. In addition, the targeted population is likely to be familiar with debates about climate change and the need for a transition to renewable energy. However, the role of the threatened mining industry as a generator of employment and wealth in the economy is strongly valued (Tranter and Foxwell-Norton 2020). An online questionnaire link was also emailed to the participants who wished to complete the survey in their own time. Traditional face-to-face distribution methods were used to overcome potential biases in sampling that may be introduced in pure online surveys, such as access to more technologically aware, well-off people or those employed in certain jobs (Curry et al. 2005). An incentive (the chance to win an iPad) was used to encourage the completion of surveys. A total of 362 people replied to the survey, but after data cleaning, 325 usable surveys were analysed.

Methods and data analysis

Two types of methodological analyses were used in this article. First, econometric modelling was used to identify the factors that influence the adoption of solar PV and identify segments. Second, the psychological drivers for rooftop solar adoption were highlighted by descriptive analysis. STATA was used to analyse the data.

For econometric modelling, the first step involved principal component analysis (PCA) identifying segments. PCA reduces dataset dimensionality, increases interpretability, and minimises information loss (Pothitou, Hanna, and Chalvatzis 2016). It is useful for exploratory data analysis to inform researchers about patterns within the data sets and identify clusters of variables (Greene 2002). In the second step, predicted variables from PCA were calculated and employed in the binary Probit model to model the factors that predict the adoption of rooftop solar. The binary Probit model has its origins in biostatistics and is widely used in the social sciences today. It is a practical technique to analyse the effects of multiple explanatory variables on a binary outcome (Greene 2002). A binary Probit model is conceptualised to indicate whether or not a household adopts rooftop solar.

$$Y = \gamma X + \varepsilon \tag{1}$$

Where Y=1 represents household adopt rooftop solar, otherwise Y=0. In this study, several explanatory variables in Table 1 were used and tested, such as income, education, age, gender, home ownership, housing type, household size, number of children and other attitudinal variables to predict the probabilities of rooftop installation. A likelihood function was developed and maximised for γ to obtain the maximum likelihood estimates (MLE) $\hat{\gamma}$ (Baum 2006). ε is the error term in the regression of the latent dependent variable, which follows a standard normal distribution. A fundamental assumption is the independence of predictor variables, so multi-collinearity was tested. However, the technique has some drawbacks, such as the complexity of interpreting the results (Chen and Hughes 2004).

Insert Table 1 here

Results

The next section of the article summarises the key findings from the survey.

Summary statistics

A profile of the sample is shown in Table 2. The summary statistics are as follows: there are slightly more females (54.5%) than male respondents in the survey. Income levels are diverse. An estimated 13% have a total household income of less than \$30,000. Seventeen per cent report a total income of \$30,000-\$64,000; 20.4% are in the \$65,000-\$99,000 bracket and 31.8% earn more than \$100,000. The remainder report 'nil' or 'do not know/prefer not to answer'. Drawing on historical census data, which was a comparative period, the Australian Bureau of Statistics data shows that the mean gross household income in 2017-18 was \$116,584, so our sample is reasonably diverse (ABS 2020a). There are more homeowners (55.2%) than renters (39.8%) in the sample. About education, 26.8% reported a bachelor's degree as their highest educational attainment. The result reflects the national average. Statistics show that 28.4% of

Australia's population had a qualification at bachelor's degree level or above in 2019 (ABS 2020b). Respondents come from all age groups, with most (67%) aged 20 to 49 years. Half the sample (50.8%) are in full-time employment, and respondents work in various industries. Regarding political ideology, respondents who support the main political parties are captured in the sample, although many respondents choose not to answer this question.

Insert Table 2 here

Adoption of rooftop solar photovoltaic

The respondents were asked if they currently have rooftop solar systems. A quarter of the sample (24.3%) stated that they had installed rooftop solar PV. The results show that home ownership, unwillingness to sacrifice some personal comforts to save electricity, income, and being an 'energy efficiency advocate', are positively and significantly related ($p<0.05$) to the installation of rooftop solar PV (Supplement 1). The term 'energy efficiency advocate' refers to consumers who are willing to purchase devices and adopt new technology to improve electricity efficiency. Education is not positively related to the adoption of solar PV. The 'new energy supporters' (i.e., supporters of geothermal, hydrogen fuels and battery storage) are likely to adopt rooftop solar PV. However, this variable is not statistically significant. In contrast, people who worry about the prices of energy-efficient devices, who enjoy monitoring their electricity usage ('monitor/digital tools lovers') and who are willing to change their habits to save electricity, even if it is inconvenient to do so ('behaviour change advocates'), are not likely to install rooftop solar PV. It is noteworthy that the respondents who do not want to reduce their electricity consumption are more likely to adopt rooftop solar PV, which suggests the existence of a rebound effect, which describes a situation where a solar consumer might consume more electricity than before when the electricity price falls (e.g., with the aid of solar PV installation).

Electricity conservation: perceived importance and behaviours

Respondents were asked to indicate the importance attached to a broad range of electricity-saving practices. Table 3 below represents the results based on frequency analysis, t-tests and PCA. Independent t-tests were used to distinguish between solar and non-solar households. The figures are mean values (where 1= not at all important and 5 = very important). Nearly all items were seen as important, with switching the light off getting the highest score, and using an in-home display or smart meter getting the lowest score. It shows that easy behaviours are likely to be performed by many people. The data shows that participants who had installed rooftop solar PV attach less importance to electricity conservation than those without solar. For example, people who adopt rooftop solar attach less importance to buying LED lights; using a solar hot water system; setting air conditioners at the right temperature; buying electrical goods with a high energy star rating; using ceiling fans rather than air conditioners; ceiling insulation; being conscious of peak periods; limiting the use of air conditioners; doing energy-intensive tasks at times when electricity was cheaper and using an in-home display/smart meter than those who did not. The data findings indicate that the solar rebound effect may exist.

Insert Table 3 here

Several key segments were identified according to their response to the importance of electricity saving. Segment 1 consumers are mainly 'monitor/digital tools lovers' who have positive attitudes towards using a standby power controller, in-home energy displays and smart meters that provide feedback on electricity usage. Segment 2 consumers are 'behaviour change advocates' who are willing to bear the inconvenience of electricity saving behaviour, such as waiting for a full load before doing the laundry, using a clothesline instead of a dryer and limiting air conditioner usage. Finally, segment 3 consumers are 'electricity efficiency supporters' who adopt new technology to improve electricity efficiencies, such as buying LED lights, appliances with a high energy star rating, and ceiling insulation. There are two tendencies among the respondents, as mentioned previously. One is electricity conservation (i.e., Segment 1 and Segment 2), which involves using less electricity by adjusting their behaviours and day-to-day habits. These segments seem to embrace the lower cost, minimum consumption route to energy management in the home. The other is electricity efficiency (i.e., Segment 3), which involves using new technology and energy-efficient devices that require less electricity to perform the same function. This segment seems to embrace the higher cost, higher consumption route to energy management.

Discussion

This study examines the factors driving the installation of rooftop solar and attitudes towards electricity conservation and supply amongst different segments. A high percentage of the sample (24.3%) had installed rooftop solar PV. This figure reflects recent studies and is not surprising given the falling cost of solar PV and the generous FiTs provided by state governments (Zander et al. 2019; Berry and Marker 2015). Previous studies have highlighted the rapid uptake of rooftop solar by postcodes in low-income Australia and regional and rural communities (Crowley and Jayawardena 2017). The finding that home ownership is positively and significantly related to the adoption of rooftop solar PV is aligned with previous literature, indicating that the ability to take advantage of government subsidies is an essential factor in adoption (Chapman et al. 2016).

Interestingly, price-related concerns are not the main driver for solar PV adoption in this research, despite studies linking solar PV adoption with concerns about a rise in future electricity prices (Sommerfeld et al. 2017). Instead, rooftop solar adoption is influenced by emotions, such as an unwillingness to sacrifice personal comfort for electricity savings. In addition, positive attitudes towards energy efficiency are positively and significantly related to rooftop solar PV installation ($p<0.05$). In other words, the households who install solar PV attach importance to purchase-related activities (such as buying LED lights, installing ceiling insulation) rather than curtailing their use of electricity (such as limiting the use of air conditioners). This behaviour makes sense if the solar system is producing more power than the household is consuming and if the feed-in tariff for solar exports compensates for energy use in the evening when electricity is drawn from the grid. The finding may also reflect the dependence on air conditioners in a tropical climate and the lack of motivation to turn off these appliances simply to save money. This finding is aligned with prior research that highlights that the more demanding electricity-saving habits are not likely to be performed by people, reflecting variations in motivation and resources (Thøgersen and Grønhøj 2010).

About demographics, this study found a positive correlation between income and the adoption of rooftop solar PV. However, education was not found to be an influential factor driving rooftop solar adoption, which conflicts with prior studies. For example, earlier studies on solar PV adoption found that households with higher levels of education were more likely to find it easier to access information on residential solar PV systems (Macintosh and Wilkinson 2011) and evaluate complex information to make a decision (Guidolin and Mortarino 2010).

The study provides an insight into the importance of a wide range of electricity conservation practices in the home. The results show that the consumers who had installed solar PV are less engaged with electricity conservation than those without solar PV, strengthening previous findings that some households show active energy conservation efforts (such as controlling home amenities). Others show less active involvement (Van Raaij and Verhallen 1983). It indicates that similar solar rebound effects may exist in regional Australia as it does in the

United States (Qiu, Wang, and Xing 2021). Solar rebound effects are important when evaluating the environmental benefits because the adopters' behavioural responses to electricity conservation may reduce the expected gains from adopting solar PV. This finding is concerning since electricity consumption may increase further with the rise in telework for white-collar jobs and the growing acceptance of work-from-home arrangements by companies (Krarti and Aldubyan 2021). Therefore, it is critical to learn from past consumer behaviour and avert or reduce the potential rebound effect. This study adds new evidence to the literature on the 'rebound' effect or offsetting behaviours (Druckman et al. 2012) by highlighting that some segments avoid electricity saving practices because they do not want to sacrifice personal comfort. Non-financial drivers of behaviour, such as the desire for comfort, are an often-overlooked cause of the solar rebound effect. Hence, the work proposed here is distinct from prior studies on the rebound effect, since the rebound effect is traditionally defined as an economic response through which potential energy savings from efficiency improvements are partially offset by increased use of appliances because the energy cost of using them is lower (Toroghi and Oliver 2019). Prior studies have demonstrated a direct solar rebound effect, such as the higher utilisation of energy services within the home after solar PV installation and in response to generous feed-in tariffs in Australia (Deng and Newton 2017) and after oversized solar installations (Boccard and Gautier 2021). Previous work also outlines negative spillovers due to moral licensing (Sorrell, Gatersleben and Druckman 2020) and the indirect solar rebound effect, which may shift consumption to goods and services with higher environmental impacts (Druckman et al. 2012).

Also, the study revealed that the use of smart solutions received the lowest score out of all electricity saving practices. This finding is not surprising since smart home technologies are not mainstream, and it is generally the early adopters who respond positively to these services (Wilson, Hargreaves, and Hauxwell-Baldin 2017). Therefore, a priority for solar retailers is to educate electricity consumers on the benefits of using smart meters and prepare consumers for the digital transformation of the energy sector.

Conclusion and policy implications

This study integrates consumer sentiment on rooftop solar and electricity conservation and therefore provides a broader view of consumers' energy-related behaviour and the rebound effect. This study provides valuable information for policymakers when considering 'target' markets for communications. For instance, scholars point out that:

Mass communication interventions might provide opportunities for policymakers to promote beneficial changes in behaviour, directly by targeting people concerned by particular problems or indirectly by promoting change in overall public behaviour (Abroms and Maibach 2008, cited in Pietsch and McAllister 2010, 231).

Findings from this study indicate that efforts to accelerate rooftop solar adoption should target homeowners who have above-average incomes and who do not want to sacrifice personal comfort. These consumers appear willing to make an upfront investment to manage electricity consumption better but do not wish to curtail their consumption on a day-to-day basis. Hence, price signals (e.g., time-of-use tariffs) may not effectively influence their energy-related behaviour in peak periods. In addition, to achieve acceptance for electricity saving by the 'energy efficiency advocates', we recommend marketing communications to remind consumers that they can still conserve electricity and maintain their lifestyle.

The finding of the solar rebound effect in this study shows the importance of educating people who have adopted rooftop solar and emphasising the need to continually engage with electricity conservation, use smart meters and divert peak-load usage of electricity. Education campaigns are critical so that pre-pandemic behaviour does not become entrenched. The installation of solar is a critical 'change point' or a window of opportunity to reframe behaviour (Watson et al. 2020). Campaigns should focus on the small number of actions that can make a real difference to efficiencies, such as using air conditioners in a prudent manner. Home owners should be reminded that energy consumption takes place during the evening and at night-time when their solar system cannot generate energy. Policy instruments that appeal to rational, economic motives, such as setting a low feed-in tariff to counter the rebound effect (Tanaka, Wilson, and Managi 2021), adjusting the tariff schedule and rewarding consumers for energy savings (Bertoldi et al. 2013), may work for some segments, such as the 'monitor/digital tool lovers' and 'behaviour change advocates'. Since some consumers have an appetite for in-home energy displays for energy management, policymakers should consider promoting smart meters as a tool to shift energy use to off-peak periods and manage system security risks. For other segments, the 'energy efficiency advocates', generous FiT schemes are not warranted.

Higher consumption of electricity could also be offset by the uptake of battery storage systems, particularly since people are adopting more flexible working arrangements in the post-COVID scenario. Solar retailers will no doubt play a role in the marketing of battery storage. The move to battery storage (and electric vehicles) is expected to support the network by countering the mismatch in timing between solar generation and the evening demand peak (Australian Energy Regulator 2021). Despite the rapidly falling cost of battery storage, the current business case for installing PV and battery storage is marginal, except for larger battery sizes or a move to demand pricing (Shaw-Williams, Susilawati, Walker and Varendorff 2019). Battery rebates and low-interest loans are being introduced in most states of Australia (Australian Energy Foundation 2020). Some schemes are targeted at low-income households (Government of South Australia 2021), and this policy is well targeted since the ability to pay is a crucial driver of renewable energy adoption. Scholars argue that Australian policy support should be reoriented away from owner-occupiers towards low-income households, such as renters and hardship customers, thereby increasing the economic, environmental and social payback from deploying solar PV (Dodd and Nelson 2022). Scholars are calling for policies considering broader benefits such as social justice and the protection of the vulnerable from energy insecurity (Sovacool et al. 2020). This work concurs with this point, and policy that incentivises the adoption of solar and battery storage should target a diverse range of households in the light of the benefits to the network, social equity and the environmental impacts of reducing carbon emissions. A holistic approach to electricity policy should be considered when promoting solar PV and battery storage. Therefore, understanding the whole electricity system is as important as exploring public attitudes towards solar PV installation.

This study has its limitations. First, although diverse, the sample is a convenience sample of mostly urban North Queensland residents. Thus, the survey sample was opportunistic and not a randomly selected subset of the population in regional Queensland. However, it is argued that only people who want to complete surveys will do so and that the self-selection bias, along with cost pressures, justify the sampling approach used to solicit respondents. Second, the study measures attitudes and not behaviour; thus, it cannot be concluded that positive attitudes towards electricity conservation will translate into action that mitigates climate change.

Given the global need to reduce greenhouse gas emissions associated with the energy sector and promote sustainable development, it is crucial to understand the factors driving the adoption of rooftop solar PV and influencing residential electricity conservation. This article, therefore, makes two original contributions to the energy literature. Firstly, it identifies the factors influencing solar PV adoption in a regional context, thus advancing our understanding of the adoption of energy technologies theoretically and practically. Secondly, it provides an insight into different consumer segments and their attitudes towards electricity conservation, shedding light on the solar rebound effect. Therefore, policymakers are advised to address consumers' non-financial motives for adopting solar PV, such as more effective communication strategies from a policy and marketing perspective.

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Table 1. Categories and definitions of independent variables in the regression model

Socio-economic category	
Income	Annual household income
Education	Highest educational qualifications attained
Age	Respondent's age group
Gender	Dummy variable: 1 if the respondent is a male
Ownership	Dummy variable: 1 if the respondent owns the living place
No of people	Number of people are there in the household
No of children	Number of kids below 12 are there in the household
House	Dummy variable; 1 if the respondent lives in a house
The respondents' attitudes	
Sacrifice	Dummy variable: 1 if not willing to sacrifice some personal comforts in order to save electricity
Trouble	Dummy variable: 1 if reducing the electricity usage is not worth the trouble
Worry	Dummy variable; 1 if worry about the prices of energy-efficient devices
Busy	Dummy variable; 1 if too busy to be concerned about saving electricity
PC21	Loading of the 'monitor' advocates
PC22	Loading of the 'behaviour change' advocates
PC23	Loading of the 'energy efficiency' advocates
PC41	Loading of the 'energy transition' advocates
PC42	Loading of the 'fossil fuel champions'
PC43	Loading of 'regional resource defenders'
PC51	Loading of the new energy technology supporters
PC52	Loading of traditional energy technology supporters
PC53	Loading of others

Table 2. Profile of sample

Item		Percentage
Gender (n=321)	Male	45.2
	Female	54.5
	Other/Prefer not to say	0.3
Age (n=321)	Under 20	5.3
	20-29	22.1
	30-39	22.7
	40-49	22.1
	50-59	15.3
	60 or over	12.5
Work situation (n=319)	Full-time	50.8
	Part-time	9.1
	Seeking work	3.4
	Retired	6.3
	Home Duties	4.1
	Student	19.7
	Other	6.6
Industry	Retailing and wholesaling	6.5
	Electricity, gas, water or waste	0.3
	Education	19.2
	Mining	1.7
	Agriculture	4.5
	Manufacturing	2.1
	House construction	4.1
	Health Services	10.3
	Arts, sports or recreation	2.7
	Not applicable	28.5
	Other	19.9
Education (n=317)	No qualification	1.9
	Year 10 or 12 certificate	18
	Trade Certificate/apprenticeship	6.9
	Certificate or Diploma	25.9
	Bachelor Degree	26.8
	Post-graduate degree	20.5
Total household income (n=314)	Nil	5.7
	Less than $30,000	13.1
	$30,000-$64,000	17.2
	$65,000-$99,999	20.4
	$100,000-$149,999	17.2
	$150,000-$199,999	11.1
	$200,000-$249,000	2.9
	$250,000-$299,999	0.6
	Do not know/Prefer not to say	11.8
Housing ownership (n= 322)	Owned (by you) outright	25.8
	Owned (by you) with a mortgage	26.4
	Being rented/shared	39.8
	Defence Housing Australia	1.9

	Housing Services	1.6
	Other	4.7
Political affiliation (n=310)	Australian Greens	10.6
	Australian Labour Party	20

Table 3. The importance attached to electricity conservation and energy segments

Item	Sample Mean (n=324)	Std Dev	Rooftop: Installed (n= 76)	Roof Top: Not Installed (n=237)
How important - Switching the light off when not needed	4.58	.586	4.55	4.64
How important - Buying compact fluorescent light bulbs	4.17	.894	4.15	4.33
How important - Buying LED lights	4.25	.885	4.19	4.46
How important – Start using a solar hot water system	4.01	1.038	3.86	4.35
How important - Setting air conditioners at the appropriate temperature	4.30	.977	4.18	4.63
How important - Buying high Energy Star rating electrical goods	4.30	.895	4.23	4.51
How important - Using ceiling fans instead of air conditioners to save energy	4.30	.915	4.25	4.51
How important - Waiting for a full load before doing the laundry	4.20	.948	4.17	4.26
How important - Washing clothes without heating water	4.17	.969	4.13	4.24
How important - Using ceiling insulation	4.37	.860	4.31	4.57
How important - Using a clothesline instead of in a clothes dryer	4.48	.856	4.47	4.50
How important – Using water-efficient shower heads	4.03	.972	4.00	4.11
How important - Aware of peak periods of electricity usage	3.88	1.007	3.76	4.26
How important - Limiting air conditioners usage	4.32	.936	4.24	4.59
How important - Doing energy-intensive tasks when electricity is cheapest	3.71	1.061	3.54	4.19
How important - Installing an in-home display or smart meter that gives feedback on electricity usage	3.42	1.125	3.30	3.79
How important – Using a standby power controller	3.58	1.121	3.50	3.85

Note: Items in bold font indicate a statistically significant result.