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Renewable Energy Householders in the Sunshine State: Do They Perceive a Rebound Effect?

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Abstract

Rooftop solar PV installations have experienced rapid and unprecedented growth in Australia. However, one issue that contributes to inefficiencies in the electricity market is the 'solar rebound effect' which refers to the reduction in expected gains from eco-efficient technologies due to an increase in the use of the resource. However, little literature exists that incorporates consumers' cognitions into studies of the solar rebound effect in Australia. This study aims to bridge a research gap by examining consumer perceptions of the solar rebound effect after installing rooftop solar, along with the psychological factors that might play a role in mitigating the solar rebound effects. A quantitative methodology was adopted, and a pilot survey was administered to residents (n=68) in a regional city. Frequency distributions and non-parametric tests were undertaken. The results indicate significant differences between those who report a solar rebound effect and those who do not, relating to factors such as thermal comfort, bill consciousness and an environmental self-identity. Implications for future research and practice are outlined in the paper.

Keywords: Renewable Energy Adoption, Solar Rebound, Consumers' Attitudes, Climate Change

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1. Introduction

Australia has significant fossil fuel reserves which has resulted in a high reliance on fossil fuels for electricity generation (Simhauser, 2018). Australia's per capita emissions rate at 22.4 tonnes of carbon dioxide in 2018 was double the OECD average (Organisation for Economic Cooperation and Development (OECD) 2021), leading to a call for an energy transition to renewable resources (Byrnes et al., 2013). The state government has plans to promote renewable energy and achieve a 50% Renewable Energy Target (RET) by 2030 (Queensland Treasury, 2021). From a policy perspective, regional studies are vital in helping the Australian government meet its obligations under the 2015 UN Paris Agreement on Climate Change (Burnes, 2017), and ultimately achieve the goal of holding the increase in global average temperature to well below 2 degrees Celsius above pre-industrial levels, thereby reducing the impacts of climate change (United Nations, 2015). Australia's position as a world leader in rooftop solar makes its experience highly relevant for other countries (Best et al., 2019) and the findings of this study will assist policy makers in other countries who wish to increase the adoption of small-scale solar panels and battery storage.

Scholars conclude that the 'solar rebound effect' exists, which is defined as the percentage increase in total energy consumption resulting from the adoption of a PV (Toroghi & Oliver, 2019). Although studies suggest that rebound effects are modest (i.e. 5% to 15%) in the heating and electricity sector, it is still a problem since savings in emissions are eroded (Sorrell et al., 2020). Crucial to the process of an energy transition is the incorporation of the human dimension into energy studies and policy formulation. A greater understanding of consumers' perceptions of the solar rebound concept is essential to the design of interventions to promote electricity conservation.

2. Literature review

Factors driving the adoption of renewable energy

Australia has one of the highest per-capita rates of rooftop solar PV installation in the world (Mwampashi et al., 2021). Rooftop solar photovoltaic (PV) accounts for more than one-third of the renewable energy capacity in the NEM (AER, 2021). The adoption of rooftop by Australian households is not surprising. Australia receives above average solar radiation (Li et al., 2020) and technological advancements in photovoltaics (PV) have significantly reduced installation cost (Dincer, 2011).

In the state of Queensland, there has been a remarkable adoption of rooftop solar by households (Biggs, 2016; Sommerfeld et al., 2017). It is reported that 1 in 4 detached households in South-East Queensland have installed rooftop solar PV, and this adoption rate is amongst the highest in the world (Simshauser, 2016). Rapid adoption has mostly been explained by the premium feed-in-tariff or FiTs (Li et al., 2020). This is defined as a payment for exporting solar electricity to the grid (Queensland Government, 2018). For example a premium FiT of 44c was introduced in Queensland in 2008, for a duration of 20 years, but this dropped to 8c for new customers in 2012 and has been phased out in recent times (Li et al., 2020). There is a significant number of PV customers who will continue to receive the old rate until the end of the scheme in 2028 (Queensland Competition Authority, 2013).

The policy-related factors driving the adoption of rooftop solar PV in Australia are well understood (Chapman et al., 2016). In addition to the FiT incentive, energy certificates which reduce the upfront cost of the solar system were a complementary incentive (Nelson et al., 2011). Payback periods are forecast to continue to decline in Queensland (Agnew et al., 2018). The term 'payback period' is defined as the year when the cost of the solar system is offset by cumulative savings, where savings represent the avoided cost of electricity consumption, plus any revenue received from the FiTs (Australian Energy Council, 2018). Current studies report that feed-in tariffs (FiTs) and socio-demographics help explain adoption of rooftop solar (Zander et al., 2019; Lan et al., 2020). As well as government incentives, authors report other factors that drive the adoption of rooftop solar such as demographics, property tenure and the peer effect (Abreu et al., 2019; Best et al., 2019; Noll et al., 2014). The desire to cut energy bills (Islam, 2014) and concern about increasing electricity prices is also a significant driver of solar PV adoption (Sommerfeld et al., 2017).

Although the FiT policy was very successful in promoting rooftop solar adoption, it has been criticized on social justice grounds (Sommerfeld et al., 2017), since it excluded renters and low-income groups and resulted in increased electricity prices and disconnections from the grid (Chapman et al., 2016). The FiT policy is also criticised on energy efficiency grounds. The FiT system, while successful in driving adoption of rooftop solar, did not provide any incentive to households to reduce power consumption in peak periods, or otherwise use electricity wisely (Li et al., 2020). Hence, it is important to analyse whether access to 'free' electricity resulted in inefficient use of electricity, such as a solar rebound effect, which is discussed in the next section.

The solar rebound effect, antecedents and mitigating factors

The benefits of renewable energy are clear, but there may be unintended consequences. The solar rebound is defined as the percentage increase in total energy consumption resulting from the adoption of solar photovoltaic (PV) (Toroghi & Oliver, 2019). Rebounds erode a significant proportion of the energy/emissions saving (Sorrell et al., 2020). Sekitou et al. (2018) conclude that consumers do not tend to conserve electricity after the installation of solar PV systems. Many economists seek to measure the rebound effect. In a study of households in the USA, focusing on green technologies, Spiller et al., (2017) estimate a rebound of approximately 9%. In a study of German households, in the context of individual mobility, Frondel et al., (2020) estimate the rebound to range between 3% and 10%. In a study of rooftop PV, focusing on 4,819 Australian households, Deng and Newton (2017) find a rebound of up to one-fifth of the carbon benefit of renewable energy. A Japanese study reports that people with residential PV systems end up using 3% more electricity, resulting in an emissions increase by 1.75% (Okuyama et al., 2022). A recent study on the solar rebound effect concludes that FIT schemes increase the consumption of electricity purchased from electricity companies (Tanaka et al., 2022). However, Oberst et al. (2019), in an online survey of German households, reports no significant increase in energy consumption due to the installation of solar PV systems.

In economic research, a direct rebound means that consumer demand increases when improving efficiency makes the provision of a service cheaper. Indirect rebound occurs if income freed up by efficiency gains is expended on other energy-consuming products and services (Seebauer, 2018). A direct rebound is explained by price effects and an indirect rebound is explained by psychological mechanisms such as moral licensing (Reimers et al., 2021). The concept of moral licensing suggests that when people have engaged in ethical behaviour, they feel entitled to engage in less climate-friendly action in the future (Reimers et al., 2021). This concept assumes that people track and balance environmental activities, and that 'good' deeds can compensate for 'bad' deeds (Santarius & Soland, 2018). For instance, if someone has already "done their bit" in a certain domain (for example purchased an electric car), then they may consider themselves permitted to consume more in other domains (such as holiday air travel) (Seebauer, 2018). It is hypothesised that those who purchase PV systems might use extra electricity since they perceive it to be 'free' (the price effect) or because of moral licensing (the psychological effect):

H1: Solar households are more likely to perceive a solar rebound effect.

The solar rebound effect: mitigating factors

Previous research offers several concepts to describe and explain rebound behaviour, including pro-environmental values and frugality norms (Exadaktylos & van den Bergh, 2021; Chen et al., 2017; Seebauer, 2018). Pro-environmental values are important in counteracting rebound behaviour (Seebauer, 2018) as well as explaining intentions to adopt solar PV (Abreu et al., 2019). A high level of concern about climate change is associated with the acceptance of renewable energy technologies (Spence et al., 2010). Although solar households reduce their carbon footprint by using solar energy, they generally require electricity from the grid in the evening, and grid-supplied electricity is predominantly coal-fired in Australia (Byrnes et al., 2013). Hence we hypothesise that consumers with a pro-environmental identity will remain motivated to minimise electricity consumption after installing rooftop solar, and this will mitigate potential rebound effects:

H2: Consumers with a strong pro-environmental identity are less likely to perceive a solar rebound effect than those with a weaker pro-environmental identity.

A mindset of frugality and voluntary self-restraint may reduce rebound, although a study of electric vehicles adopters reports no discernible impact (Seebauer, 2018). Frugality reflects careful spending of money, and both restraint and discipline in acquisition (Lastovicka et al., 1999). Frugality, which reflects both a personality trait and a socio-cultural value, is associated with sustainable consumption, and a recent study concludes that frugality norms in Chinese culture have a significant, positive effect on the purchase intentions of electric vehicles (Chen et al., 2019). Since the literature is divided on the effects of frugality on sustainable consumption and the solar rebound effect, the current study aims to examine this factor. Rooftop solar buyers get the following benefits: (1) they enjoy subsidies from governments, which reduces the purchase cost of the solar system, and (2) they pay less for their electricity. Hence, adopters are likely to be frugal and frugality norms could mitigate the solar rebound effect. In addition, bill consciousness positively predicts energy conservation intentions (Chen et al., 2017). Based on the literature, the following hypotheses are proposed:

H3: Consumers with strong frugality norms are less likely to perceive a solar rebound effect than those with weaker frugality norms.

H4: Consumers who are conscious about their electricity bill are less likely to perceive a solar rebound effect that those who are less bill conscious.

Usage of electricity depends on the climate and the season, as well as the personal comfort needs of the individual (Bin & Dowlatabadi, 2005; Chen et al., 2017; Sweeney et al., 2013; Vakiloroaya et al., 2014). Thermal comfort, defined as the need for coolness and warmness, is shown to negatively influence energy conservation intentions (Chen et al., 2017). Since Queensland, the site of this study, lies in the tropics, it is expected that the desire for thermal comfort may stimulate people to use their air conditioners more, such as in the peak evening periods, and help explain the solar rebound. The following hypothesis is advanced:

H5: Consumers with a high perceived need for thermal comfort are more likely to perceive a solar rebound effect than those with a lower perceived need for thermal comfort.

Theoretical contribution

Understanding the inefficiencies that occur after the doption of renewable energy may help contribute to an energy transition, and the information gained from this study should be useful for policymakers and private companies when considering target markets for communications. The potential environmental benefits of installing rooftop solar may be reduced if households increase their electricity consumption in the peak evening periods when electricity is supplied by the grid. The existing literature focuses mainly on rational, economic models of behaviour to explain the solar rebound effect. According to Santarius and Soland (2018, p. 414): "Most of 35 years of rebound research has been analysed from micro- and macro-economic perspectives. Yet, microeconomic rebound research has so far investigated human behaviour only on grounds of simple rational choice models and static assumptions about consumer preferences".

These authors call more research from a behavioural perspective that addresses human knowledge, motivation and decision-making, which may help curb rebounds. This study aims to bridge a research gap by examining several factors that mitigate or increase the solar rebound effect. Although the present study focuses on variables examined in other studies, such as frugality norms and pro-environmental values (Chen et al., 2017; Seebauer, 2018), the focus is on a different domain (rooftop solar) and a different target audience (regional energy consumers in Australia). Figure 1 shows the variables examined in the study.

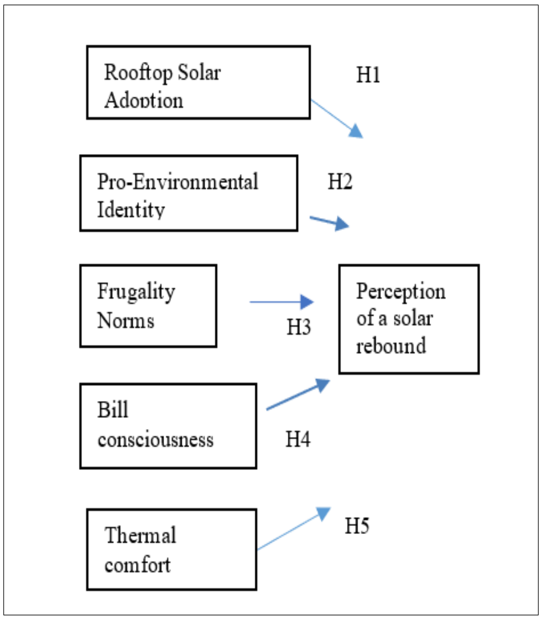

Figure 1-Conceptual Framework

3. Materials and methods

Research objectives and questions

This study aims to investigate perceptions of the solar rebound effect and the factors that exacerbate and mitigate solar rebound behaviours. The main research questions are as follows:

1) To what extent do solar households perceive a solar rebound effect?
2) What is the role played by cognitive and psychological factors (thermal comfort, a pro-environmental identity, frugality norms, bill consciousness) in distinguishing between households that perceive a solar rebound effect and those who do not?

Measurement

The survey questions and scales were informed by the literature. Questions probing reasons for installing solar PV were informed by a study from Bondio et al., (2018). The scale for measuring the direct rebound effect was taken from Galvin (2021) and the indirect rebound effect was adapted from Seebauer (2018). A sample item is as follows "Because I save with solar panels, I may allow myself some other things". The scales for measuring frugality, thermal comfort and bill consciousness were taken from Chen et al., (2017). The concept of environmental self-identity was operationalised by selecting four items used in studies by Barbarossa and De Pelsmacker (2016) and by Whitmarsh and O'Neill (2010). Sample items are 'I see myself as being an environmentally-friendly consumer', 'I think of myself as someone who is very concerned with environmental issues', and 'I would be embarrassed not to be seen as having an environmentally-friendly lifestyle'. Concepts were captured on a five-point scale with anchor points 1 = strongly disagree to 5 = strongly agree. In addition, an importance scale anchored by 1= not at all important and 5= very important) was used to measure attitudes. Finally, the survey included questions on socio-demographic variables, such as gender, age, income, educational level, and household size.

Questionnaire development, sample, recruitment of respondents

This study is based on primary data mostly collected through an online survey of staff at a regional University. Solar retailers were also asked to assist with the recruitment of solar households by providing a link on their social channels, and one retailer agreed to support the study. Ethical approval was granted by the Human Ethics Committee at James Cook University (H6601). Anonymity of respondents was guaranteed to reduce the social desirability bias. An incentive was used to encourage the completion of surveys. A total of 90 people replied to the survey, but after data cleaning and consideration of the exclusion criteria, a total of 68 usable surveys were analysed. Exclusion criteria consisted of people under the age of 18 and people who had not installed rooftop solar in their home. Data was collected in 2021.

Data analysis and statistical techniques

IBM SPSS, version 27, was used to analyse the data. Analysis of the data consisted of descriptive statistics, such as frequencies and means, which allows the researcher to become familiar with the data, prior to conducting more in-depth analysis (Field, 2013). Mann Whitney tests were then used which offer the ability to test group differences, allowing solar rebound effects to be compared on the basis of psychological factors.

4. Results

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

Summary statistics

A profile of the sample is shown in Appendix A. The summary statistics are as follows: there are more females (63%) than male respondents (37%) in the survey.

Overall, the sample has a high level of education and is well-off. Using a subjective measure of income, an estimated 38.5% are in the average income category, 42.4% are in the high-income category and 3% are in the highest income category. In relation to educational level, 36% of respondents report having a bachelor's degree and 40% report having a post-graduate qualification; this is well above the national average, where 28.4% of Australia's population has a qualification at bachelor's degree level or above (Australian Bureau of Statistics, 2020). Respondents are mostly middle-aged, with 27.9% in the under 45 age group, 34.3% are aged 46-55 and 23.9% aged 56 to 65 and 14.9% are aged 66 and over.

The solar rebound effect and factors driving or mitigating the solar rebound effect

Most statements capturing the direct and indirect rebound effect achieved a mean below the midpoint of 2.5, signifying disagreement (see Table 1). There was little evidence of a solar rebound effect and hypothesis 1 was not confirmed. When asked about electricity conservation efforts after installing solar, the mean response was 2.79, signifying a moderate change (1= no change at all and 5 = a great deal of change).

Table 1- Solar rebound perception

Attitudinal Scale Item (n=67)	Mean	Std Dev
Solar rebound - direct		
With solar panels, I use more electricity than I did previously without the panels	2.07	1.14
With solar panels, I undertake more electricity-intensive activities than I did previously with the panels	2.09	1.16
Compared to before the solar panels were installed, I now turn on the air conditioners more often when I am warm.	2.51	1.29
Prior to the installation of solar panels, I turned on the fans when I was warm. Now, I turn on the air conditioner instead	1.94	0.96
Solar rebound – indirect		
Because I save with solar panels, I may allow myself some other things.	2.22	1.12
I am already doing my part with the solar panels; therefore, it is not that important to restrict myself (more) in other areas	1.81	0.99
It does not matter how much energy you use if you have solar panels.	1.66	0.95
Perceived change in electricity use		
To what extent you change your electricity - consuming activities to match electricity production from the rooftop solar system (i.e., using devices by day, using less hot water at night).	2.79	1.25

Table 2 summarises the cognitive and psychological factors that characterise solar households. Results indicate that frugality, bill consciousness, and a pro-environmental identify are descriptive of the survey respondents, with most agreeing with the statements (4= agree). The results indicate that the perceived need for thermal comfort is not high amongst the respondents, with the average response situated in the neutral category (3=neither agree nor disagree).

Table 2- Frugality norms, bill consciousness, environmental self-identity, and thermal comfort

Items (n=67)	Mean	Std Dev
Frugality Norms		
I think that wasting things is bad	4.51	.612
I feel regretful if I waste things	4.34	.641
I think that it is not good to waste anything	4.27	.687
Bill consciousness		
I pay attention to energy-saving tips to reduce my electricity bills	4.07	.724
I keep track of my electricity bills	4.22	.850
I am motivated to keep my electricity costs under a reasonable amount.	4.09	.690
Environmental identity		
I think of myself as someone who is concerned about environmental issues	4.31	.528
I see myself as being an environmentally friendly consumer	4.06	.625
I would be embarrassed not to be seen as having an environmentally friendly lifestyle	3.33	1.021
Buying energy efficient appliances makes me feel that I am an environmentally friendly consumer	3.96	.806
Thermal comfort		
I find I cannot relax or work well unless the house is air-conditioned in the warmer months.	2.84	1.31
I have trouble falling asleep at night without an air-conditioner on	2.97	1.517
While others might turn off their air-conditioners in the cooler months, my own need for being cool is high.	1.40	.818

Comparative analysis was undertaken between those who had indicated a solar rebound effect (agreed or strongly agreed with statements) and those who did not (neutral, disagreed or strongly agreed with statements). A dummy variable was created, and the median value was used to distinguish between the two groups. A Mann Whitney test was conducted to see if there were any significant differences in cognitive and psychological factors between people who had reported a solar rebound effect (n=34) and those who had not (n=33).

Those who had reported a solar rebound effect were more likely that those who had not reported a solar rebound effect to agree with the following statements about thermal comfort: "I find I cannot relax or work well unless the house is air-conditioned in the warmer months" (U=264.5, z=-3.836, p<.001, median = 3); "I have trouble falling asleep at night without an air-conditioner on" (U=329.5, z=-2.991, p<.003, median = 3). They were more likely to disagree with the statement "while others might turn off their air-conditioners in the cooler months, my own need for being cool is high" (U=440.5, z=-2.075, p<.038, median = 1). Furthermore, solar rebound respondents were more like to agree with the following statement about electricity bill consciousness, "I pay attention to energy-saving tips to reduce my electricity bills" (U=710, z=2.095, p<.036, median = 4). Respondents who had reported a solar rebound effect were more likely that those who had not reported a solar rebound effect to agree with the following statement: "I see myself as an environmentally friendly consumer" (U= 755.00 , z = 2.799 , p<. 005 , median = 4).

5. Discussion

The purpose of this study is to analyse the solar rebound effect. Although the rebound effect is well documented in the energy literature (Qiu et al., 2019), we find little evidence of it in this study. Most respondents disagreed with statements about using more electricity after installing solar panels. This finding may be explained by the frugal nature of the respondents and their consciousness of the electricity bill. This finding conflicts with the general literature, but is aligned with the study of Oberst et al., (2019) who found no significant increase in energy consumption due to the installation of solar PV systems. It is proposed that installing a solar PV system or switching to a green tariff might lead to lower electricity consumption due to positive spill-over effects, where a response to one sustainable action spills over to another (Sommer, 2018).

The findings reveal two main groups of respondents based on their responses to the rebound effect. The need for thermal comfort distinguishes the two groups of respondents. This finding is aligned with the literature on the barriers to energy saving (Thøgersen & Grønhøj, 2010) and prior research showing that the need for thermal comfort has a negative influence on electricity conservation (Chen et al., 2017). Interestingly, those who report a solar rebound effect are more likely to see themselves as environmentally friendly consumers, which suggests that moral licensing is salient. In other words, buying rooftop solar (a 'good deed') may result in people feeling they can use as much electricity as they need (a 'bad' deed). Respondents who report a solar rebound effect pay attention to energy-saving tips to reduce their electricity bills. This finding is surprising since rebound effects suggest inefficiency, and prior research shows that bill consciousnesses positively predicts energy conservation intentions (Chen et al., 2017). It may be the case that these respondents simply see tips as being useful in helping them to cut their electricity consumption. It is assumed that they are using more solar in the daytime when they are not drawing electricity from the grid and are also using it at peak evening periods and are motivated to save money.

6. Policy Implications and Limitations

This study is aimed at exploring householders' perceptions of the solar rebound effect and the factors that influence the solar rebound effect. Private companies, along with utilities, should continue to offer energy-saving tips to consumers after they have installed rooftop solar to mitigate the rebound effect. The study shows that the need for thermal comfort has some impact on energy consumers. Hence, educational campaigns should focus on the small number of actions that can make a real difference to efficiency, without sacrificing personal comfort, such as installing efficient air conditioners, performing regular maintenance, setting the air conditioner at the right temperature, and cooling the home by day. The study reveals that consumers are frugal and conscious of the electricity bill. The study also shows that consumers modify their electricity use after installing solar. This behavioural change is promising, since it is argued that consumers need to shift some of their electricity use from peak periods to solar generation hours, thereby reducing peak-hour demand (Mwampashi et al., 2021).

Some limitations of the research should be recognised. The lack of self-awareness is a potential limitation in survey research on the solar rebound, hence there may be an under-estimation of energy use after installing rooftop solar. The reliance on self-reported data is a limitation, however access to electricity consumption data via meters or electricity bills was not possible. The survey is based on a convenience sample, rather than a large, representative sample of households. This limitation, shown by low variance in socio-economic factors such as education and income, should be taken into consideration. The sample size is small which makes this study a pilot study. To assess the robustness of the conclusions, the intention is to build on the study and enlarge the sample, covering the state of Queensland. Further research comparing adopters and non-adopters of rooftop solar would help in the analysis of renewable energy decisions and the rebound effect more deeply.

7. Conclusion

Given the need to reduce greenhouse gas emissions associated with the energy sector, it is important to understand the factors driving the rebound effect. This paper, therefore, makes one original contribution to the energy literature. It provides an insight into the psychological drivers of the rebound effect, which can lead to targeted and therefore, more effective communication strategies from a policy and marketing point of view.

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Declaration of interest

The author declares no conflict of interest.

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