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ORIGINAL ARTICLE

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Managing the energy trilemma of reliability, affordability and renewables: Assessing consumer demands with discrete choice experiments

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Abstract

In response to the looming climate crisis, many countries are adopting technologies to reduce the accumulation of greenhouse gases. However, national energy policies are often multiobjective and resolution deeply divisive. The result is a policy trilemma between the energy mix and the trade-offs with other policy objectives, including cost and reliability. Utilising a discrete choice experiment (DCE), the objective of this study is to explore Australian household preferences for alternative electricity contracts containing features reflecting changes in future energy policy. The first set of features include investments in renewable generation and community-based energy storage. The second set of features reflect demand-side management policies, including installing smart meters and consumption limits being imposed on households during peak demand. Two versions of the DCE were developed to obtain both willingness to pay and willingness to accept estimates for the same features. In line with the literature, differences in the two sets of estimates were observed, with the willingness to accept estimates being statistically larger for some features. These dollar value measures can be used to support public policy decision-making – the choice of which depending on the context of the policy problem being considered.

KEYWORDS

Australian National Electricity Market, community battery storage, demand-side management, discrete choice experiment, renewable energy

JEL CLASSIFICATION

Q40, Q41, Q51

1 | INTRODUCTION

Climate change and energy policy are inextricably linked (Bollen et al., 2010). Climate policy remains fragmented internationally with some jurisdictions (e.g. countries, states and cities) setting ambitious targets to reduce greenhouse gases (CO_{2e}) to achieve net zero carbon emissions by 2050 (United Nations Framework Convention on Climate Change, 2021). Other jurisdictions have become mired in the politics of jobs in resource extraction, resource revenues associated with coal, shale oil or oil sand projects (e.g. Australia, USA or Canada), reliability of energy systems or lost economic growth. These issues contribute to the idea that energy policy is a deeply divisive political issue in these countries (Pearce et al., 2017). Achieving energy security while meeting sustainable development targets further complicates the policy agenda (Nepal & Paija, 2019).

Investment in technologies such as wind and distributed photovoltaic generation has become a central platform of climate and energy policy of many countries (Silva et al., 2019). To achieve this transition, governments have adopted feed-in-tariffs, subsidies and renewable energy generation targets to support investment in renewables (MacDonald & Eyre, 2018; Nelson et al., 2021), which is counter to the push for efficiency and liberalisation of energy markets (Roques & Finon, 2017).

However, the increasing proportion of wind and solar being supplied into the national energy market presents additional challenges to be managed in the Australian context. Large and sudden shifts in supply can be addressed through fast-response alternatives such as gas, hydro and large-scale investment in batteries (Australia Energy Regulator [AER], 2021a). Power system security can be remedied with synchronous condensers and other emerging technological solutions (Australian Energy Market Operator [AEMO], 2020a). These latter solutions have cost implications. Recently, the AER has identified the potential for an expanded role for demand-side approaches as a cost-effective means of reducing peak demand (AER, 2021a). While there have been recent decreases in electricity prices in Australia (e.g. see Australian Energy Market Commission [AEMC] (2021) which notes an average 5.7% decrease in 2020–21 across Australia), there has been a sharp increase in the level of energy bill debt of households entering hardship programmes (AER, 2021b).

The purpose of this study was to investigate the acceptability of different electricity contracts with a set of Australian households. A stated preference (SP) approach was used as there are potentially nonmarket values associated with moving to greener technologies. Australia still has a relatively low proportion of renewable energy generation (compared with OECD countries, see International Energy Agency (2016)), and there has been minimal use of policies to manage demand-side responses. As such, a market-based, observational approach is not appropriate as these contract features are outside the experience set of most consumers.

The scenarios and features developed for the survey involved the use of willingness to accept (WTA) in the form of lower cost increases and willingness to pay (WTP) treatments in a discrete choice experiment (DCE). Including these treatments allows us to test whether a WTP–WTA disparity exists when considering residential electricity contracts. It has been observed in numerous studies that there is a disparity between the two measures, so much so that several meta-analyses have focussed solely on identifying the causes of these differences (Horowitz & McConell, 2002; Sayman & Öncüler, 2005; Tunçel & Hammitt, 2014).

Our contribution to the literature is across several areas. Foreshadowing our results, we find that despite a decade of rising prices between 2008 and 2018 (Australian Competition and Consumer Commission [ACCC], 2018), Australian households are still willing to pay more to support reliable green electricity network. Also households are willing to engage with some demand-side management policies. Finally, we provide a double WTP–WTA framework for modelling residential electricity contracts and provide evidence to suggest that the WTP–WTA disparity persists when considering residential electricity contracts, a finding that we have not identified in previous studies.

Initially, we provide an overview of the literature and some context of the energy issues in Australia. The relevant components of the multiple-treatment survey are described in the Section 3, including details of the attributes in the DCE, the differences between treatments, the payment scenario constructed, the sampling strategy and the experimental design. Next, the econometric models are described and results presented. Finally, the policy implications of the results are discussed.

2 | BACKGROUND

2.1 | Literature

Policy goals focussing on increasing the proportion of renewable generation in the energy mix, maintaining or increasing energy security, and minimising cost constitute the energy trilemma (Brügger et al., 2015; Demski et al., 2017). It has been shown in numerous studies that consumers have a positive WTP for increased renewable energy generation technologies (Borriello et al., 2021; Ma & Burton, 2016; Mewton & Cacho, 2011; Soon & Ahmad, 2015; Sundt & Rehdanz, 2015). The Appendix S1 lists papers post-2011 highlighting the factors influencing the WTP for green energy with a consensus that households on average have a positive WTP for renewables. Given existing energy generation technologies, two of the three goals in the trilemma can be achieved (e.g. high level of reliability combined with a high proportion of renewables); however, the challenge is to achieve this while maintaining affordability. For example, a more reliable network with increased renewable energy generation can be achieved through coordinated investment and systems planning (AEMC, 2020a). Alternatively, costs could be held constant by maintaining the existing, coal-powered baseload generation and network infrastructure. This may, however, reduce the pace of growth in renewable energy generation and has the potential to affect the stability of the network over time. This begs the following questions: are households willing to accept less investment in renewable energy generation in exchange for lower electricity price growth (or willing to pay for an increase in renewable energy targets)? Are households willing to accept a less reliable system in exchange for more renewables or lower overall costs?

An alternative is demand-side management policies in the form of consumer information on utilisation. Consumption information, through the installation of smart meters for each household, can address the salience of prices and intermittency problems associated with infrequent billing (Gilbert & Zivin, 2014). Several studies have shown a positive preference for smart meters, suggesting that households value these meters in the same way they value other energy saving measures, such as solar light outdoors versus indoor energy saving technologies such as insulation (e.g. Banfi et al., 2008; Kwak et al., 2010). Recent papers suggest that smart meters are a way for households to reduce electricity bills in exchange for sharing of user data with external parties (Richter & Pollitt, 2018).

Other demand-side policies involve limiting consumption at the household level during the peak period in the evening. Consumers have been shown to be flexible in their consumption and will opt in to price-based demand response programmes (Cappers et al., 2010; Kubli et al., 2018). The price signal of the programme needs to be large enough for households to notice and for the programmes to be successful, which is potentially problematic as electricity consumption has shown to be price inelastic (Labandeira et al., 2017). Inelastic demand may be related to consumption-related habits and general inertia (Guerassimoff & Thomas, 2015; Hortaçsu et al., 2017).

An alternative is to allow respondents to opt into consumption limits in exchange for lower cost increase. Past trials in Australia investigate the effectiveness of imposing consumption limits based on energy signatures, finding that there are instances where consumption limiting is feasible for some households and firms (Australian Renewable Energy Agency [ARENA], 2020a). Broberg and Persson (2016) and Ruokamo et al. (2019) find that households would be willing to accept compensation in return for less control over their consumption. The amount of compensation required has been found to vary based on whether the electricity controlled relates to all uses versus just for heating (Daniel et al., 2018), the quantity and frequency of electricity controlled (Broberg et al., 2021; Curtis et al., 2020) and an individual's agreement with particular social norms (Gołębiowska et al., 2020). Whether the compensation varies with the type of appliance is a recent issue, with Sundt et al. (2020) finding no statistical evidence that the type of appliance-control matters. We did not find in any of these studies evidence to suggest which specific activities mattered. This begs the questions: are households willing to accept limits (or willing to pay to remove limits) on their energy consumption? Further, are households willing to forgo (or pay for) smart meters and better information in exchange for lower (higher) electricity bills?

One of the benefits of the dual WTP/WTA framework is that the model outputs can be applied to different policy scenarios; however, this does presuppose that there would be a difference between the outputs. Analysis by Willig (1976) suggests that once income effects are taken into account the estimates should be the same. However, other explanations for a persistent difference have been offered from both a neoclassical and behavioural economics perspective such as a lack of substitutes (Hanemann, 1991), commitment costs (Zhao & Kling, 2001, 2004), bounded rationality (Hoehn & Randall, 1987), mental accounting (Mishan & Quah, 2007; Thaler, 1985) and prospect theory (Barberis, 2013) to name a few. When considering electricity consumption, there have been several studies looking at the issue of the WTP to avoid outages versus the WTA compensation for increased outages (Amoah et al., 2019; Küfeoğlu & Lehtonen, 2015; Praktiknjo, 2014). The gap that we think we have identified in the literature is that there have been no studies focussing on identifying whether a disparity exists with respect to residential electricity contracts. Specifically, we question whether a WTP–WTA disparity exists for contract attributes related to infrastructure investment focussing on renewables and network stability as well as policies aligned with demand-side management.

2.2 | Australian market for residential electricity

In the decade prior to our study, residential electricity consumption in Australia grew at an average of 0.5% per annum; however, in per capita terms there was an average reduction of 1.0% per annum (Department of the Environment and Energy, 2019). Meanwhile, residential electricity prices increased by over 5% per annum on average (ACCC, 2018) due to several factors. In the same period, gas prices trended upwards, several coal fire power stations shut down (AER, 2018) and the national Renewable Energy Target (RET) increased to 20%. The RET is a legislated scheme that supports investments in renewable energy generation and is ultimately passed along to households, representing on average 6% of households' electricity bills in 2017–18 (AER, 2018). The additional wind and solar energy generation in Australia have been offsetting the increases in wholesale electricity prices (Csereklyei et al., 2019).

Under current national electricity rules, peak residential demand is to be met with minimal chance of load shedding (AEMC, 2018). The recent and imminent retirement of baseload power generators, combined with greater reliance on solar and wind energy, has raised stability issues, in part due to the intermittent nature of renewable energy generators (AEMC, 2020b). High-cost solutions exist to address reliability issues, such as the installation of different energy storage technologies. These costs, however, combine with already large network costs due to the Australian energy market serving a relatively small population by international standards, spread across a large geographical area. Thus, network and distribution costs make up a large portion of the fixed cost of operations, which are passed along to consumers and make up a significant proportion of household electricity bills (AEMC, 2021). Overall, these infrastructure investments ensure high reliability standards as set by the Australian Electricity Market Commission (AEMC, 2020a).

Past studies in Australia have found that consumers are willing to pay for improvements in service quality and supply (Hensher et al., 2014; Huh et al., 2015; Morrison & Nalder, 2009; Ozbafli & Jenkins, 2016). The primary concern for most households is that the lights turn on and appliances work when required. Further, consumers are largely unaware of the disconnect between the real-time cost in the wholesale market and the quarterly consumer bill as the regulated price is smoothed over time. One way to lower costs is to shift consumption by providing a stronger price signal such as time-of-use tariffs to encourage a consumer demand response (ACCC, 2018; Gyamfi et al., 2013). The norm for most Australian households is two-part tariffs with a fixed and variable charge (AER, 2022).

3 | METHODS

3.1 | Survey design

The survey used in this study was developed as part of a larger multiple-treatment DCE project, investigating various aspects of consumer affordability and preferences for alternative electricity contracts. The first part of the survey described how Australian retail electricity prices have consistently increased across the country over the last 10 years, identifying some of the reasons this has occurred, followed by some warm-up questions. Participants were then introduced to the features included in the choice tasks with supporting rationale of the contracts to be evaluated. As standard in this literature, a reminder to carefully consider their budget and to complete the tasks as if they really had to pay, that is, a cheap talk script, (Morrision & Brown, 2009). Respondents completed eight choice tasks, selecting from three different electricity contracts. Following the completion of all choice tasks, a set of sociodemographic questions were asked.

Respondents were randomly assigned to one of two treatments or versions of the survey. Each alternative in the DCE choice tasks represents a 5-year contract with costs incurred over time offering different benefits. Some of the benefits were personal: for example, real-time meters provide more information to the household. Other benefits were also societal, for example increased renewables would contribute towards eliminating the externalities associated with electricity generation from fossil fuels. The treatments share four non-cost contract features, namely changes in the amount of power sourced from renewable energy generators, limits to appliance use during the evening peak period, installation of batteries to store electricity that can be accessed by the community and providing households with more frequent updates about the cost of power to their home. Respondents saw a different status quo contract depending on the treatment. The list of features, the associated levels and status quo attribute levels for each treatment are shown in Table 1.

The policy trilemma, by definition, involves trade-offs among renewables, cost and reliability (Gunningham, 2013). Treatment 1 (WTA lower cost increase) specifies a renewable energy

TABLE 1 Description of attributes and levels in the treatments.

Attributes (contract features)	Status quo level	Non-SQ levels
Treatment 1 (WTA lower cost increase)		
Proportion of generation from renewable sources	60%	15%, 30%, 45%, 60%
Consumption restrictions	No restrictions	Two restrictions, one restriction, no restrictions
Consumption information	Real-time reminders	Quarterly, daily reminders, real-time reminders
Community storage	60 MWh	0 MWh, 20 MWh, 40 MWh, 60 MWh
Fixed cost increase per quarter for 5 years to your household	$120	$0, $10, $20, $30, $40, $50, $60, $70, $80, $90, $100, $110
Treatment 2 (WTP)		
Proportion of generation from renewable sources	15% (no change from current level)	15% (no change from current level), 30%, 45%, 60%
Consumption restrictions	Two restrictions	Two restrictions, one restriction, no restrictions
Consumption information	Quarterly	Quarterly, daily reminders, real-time reminders
Community storage	0 MWh	0 MWh, 20 MWh, 40 MWh, 60 MWh
Fixed cost increase per quarter for 5 years to your household	$0	$10, $20, $30, $40, $50, $60, $70, $80, $90, $100, $110, $120

target of 60% renewables in the status quo, no consumption limits/restrictions, real-time cost information as reminders and a fixed cost increase of $120 per month for 5 years. The non-status quo levels involve a lower level of services and a lower cost. Treatment 2 is a more traditional WTP format where the status quo has no cost increases but requires consumption restrictions. Ultimately, the two-choice experiments represent a future baseline approach and a current baseline approach.

During the survey period (May–June 2019), renewable energy generation constituted just over 15% of the national energy mix, with most electricity being generated from non-renewable energy sources, specifically coal. Research in the Australian market identified a target of 60% renewables by 2030 as feasible (Blakers et al., 2017), with a post-time-of-survey forecast, suggesting that by 2030, the proportion will be 30% (De Rosa & Castro, 2020).

Australian households' peak energy consumption on average occurs between the hours of 5 pm and 8 pm. During this time, the cost of generation at the margin is at its most expensive (AEMO, 2018). Consumption restrictions would flatten peak demand and reduce the need to access these higher priced sources. The three activities identified as having the potential to reduce residential demand included cooking, cleaning and entertainment. A list of common appliances associated with each activity was also detailed to provide context. Alternative contracts offered variations in the levels of use restrictions. Respondents' understanding of what these restrictions would mean for their electricity consumption habits was tested with questions, and respondents were also asked to rank the activities they were most and least willing to forego during the peak period.

The community storage feature highlighted that batteries would serve as a substitute load source reducing the duration of blackouts. Storage technologies also have the capacity to increase the reliability of supply as the proportion of renewable energy generation technologies increases. At the time of the survey, there were 55 energy storage projects nationally, including the large-scale (100 MW/129 MWh) Hornsdale Power Reserve project in South Australia

(Aurecon, 2018). This battery project was widely reported in the national media for its capacity to increase energy reliability for the state with 48% wind and solar, and as a result, respondents are likely to have been aware of the potential for such battery projects (Sonali, 2017). Recent research suggests that 100 kW-1 MW community battery installations in Australia are likely to be financially viable from a cost–benefit perspective (ARENA, 2020b).

Finally, smart meter technology was included as a demand-side management feature, which would allow households to access their consumption information more frequently. At the time of the survey, most households would only receive this information with their quarterly bill. Alternative technologies discussed included those which would allow current consumption information to be reviewed by households either once a day or in real time.

The cost for each contract was defined as an increase in the fixed component of the household's electricity bill, paid every quarter for 5 years. Determining the appropriate cost levels was through focus groups, interviews and a pilot study. The cost level for the status quo varied depending on how the status quo was described. In Treatment 1 (WTA lower cost increase), the status quo was described as the future default electricity contract that would be offered if current trends in energy investments continued. This contract included the maximum level of battery storage and renewables as part of the national energy mix, as well as real-time billing information and no consumption restrictions. In this treatment, respondents could opt out of this contract by selecting contracts, which were cheaper than the status quo but led to lower levels of the non-cost contract features. The framing of the status quo was tested using the methods discussed previously with no issues in comprehension noted (Figures 1 and 2).

In Treatment 2 (WTP), the status quo contract specified no increased investment in renewable energy or storage activities (as a proportion of the current energy infrastructure mix), consumption information being provided quarterly and two consumption activities being restricted for each household. It was described to respondents as the most likely situation if there were to be no increase in the fixed costs of electricity bills. This was the only zero-cost contract available in this treatment, with the other contracts involving positive costs up to a maximum of $110 a quarter.

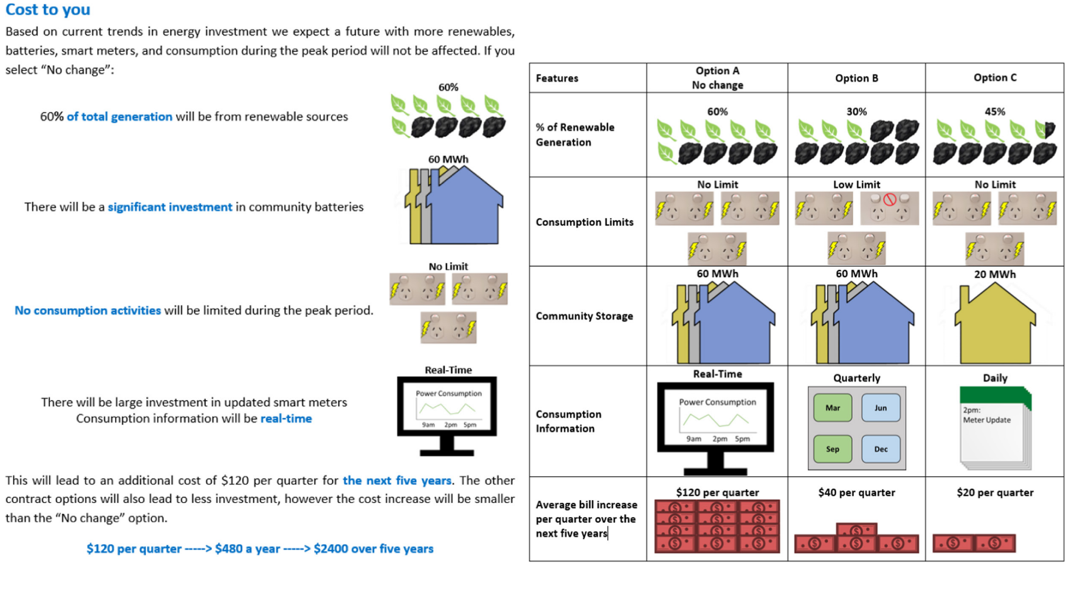

FIGURE 1 Example status quo explanation and choice task –Treatment 1 (WTA lower cost increase). [Colour figure can be viewed at wileyonlinelibrary.com]

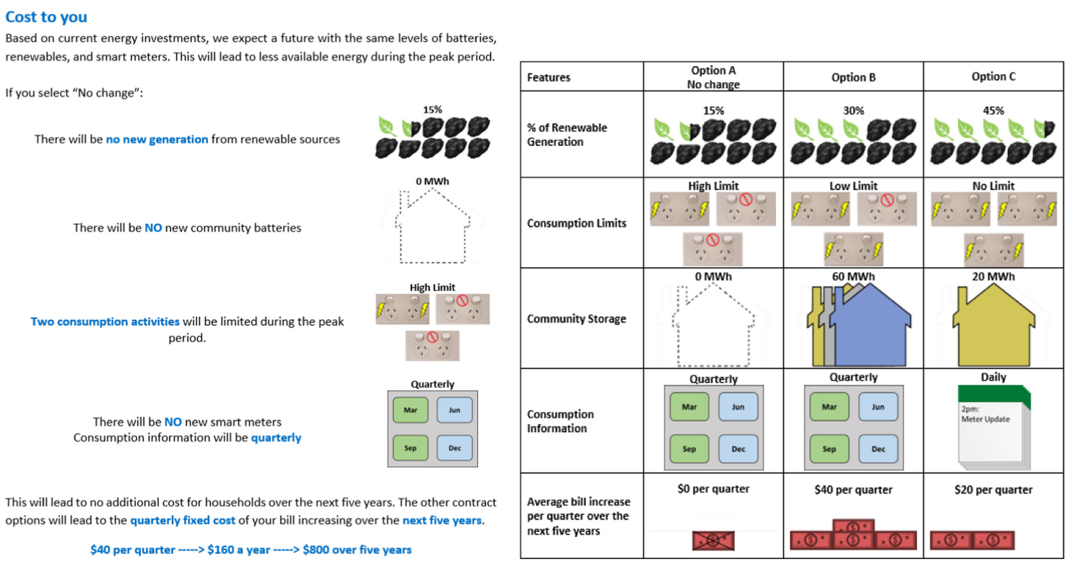

FIGURE 2 Example status quo explanation and choice task –Treatment 2 (WTP). [Colour figure can be viewed at wileyonlinelibrary.com]

3.2 | Experimental design

An efficient design was initially developed using parameter estimates obtained from the literature for renewable energy investments (Brennan & Van Rensburg, 2016; Ozbafli & Jenkins, 2016). For the other features, consumption limits, storage and consumption information, no priors were available, so the parameters were calibrated to ensure utility balance and no dominated alternatives (Bliemer & Collins, 2016; Scarpa & Rose, 2008). All designs were generated using Ngene version 1.1.1 (ChoiceMetrics, 2012). Data from a pilot survey were used to estimate a simple multinomial logit model, and the parameter estimates were used to update the priors for the final Bayesian D-efficient design. The final design included 48 choice tasks divided into six blocks with eight tasks. The final design has a simulated Bayesian D-efficient error of 0.003343 for Treatment 1 and 0.002851 for Treatment 2.

3.3 | Sampling

A stratified random sampling method was utilised for this survey in New South Wales based on gender, age and urban versus non-urban (e.g. Sydney metropolitan area versus the rest of the state). The survey was administered online by the Online Research Unit (ORU) (http://theoru.com/), one of the largest Australian panel providers. Respondents were sent a general invitation to complete the survey, as well as three follow-up reminders. Screening criteria excluded renters and required participants to live in a detached house and be responsible for paying for the household's electricity bill. The choice to exclude renters was due to the plausibility of whether the cost of smart meter installation would be incurred by the renter.

4 | ECONOMETRIC MODEL

A random utility model (RUM) is used to model household preferences for alternative electricity contracts. It is assumed in the RUM that each household selects from a discrete set in such a way that maximises utility (McFadden, 1974). For each household n facing c, choice tasks consist of j alternatives. Each of these alternatives has an associated utility level, U_{ncj}, which can be shown as:

$$U_{\text{ncj}} = \beta x_{\text{njc}} + \varepsilon_{\text{ncj}} \forall j, j = 1, 2, .., J \tag{1}$$

with βx_{njc} representing the observable component of utility, the attribute levels and associated vector of coefficients, and ε_{ncj} the unobserved error that is assumed to be i.i.d. type-1 extreme value. Given that one of the objectives of this study is to estimate the WTP for the non-cost attributes, we can instead directly estimate the utility function in preference space (Scarpa et al., 2008; Train & Weeks, 2005).

Rewriting equation (1), we can now estimate the utility function as:

$$U_{\text{njc}} = -\beta_{\text{c}} p_{\text{njc}} + \delta x_{\text{njc}} + \varepsilon_{\text{njc}} \tag{2}$$

where p_{njc} is the attribute level for cost, β_{c} is the estimated parameter for cost and δ represents the ratio of each non-cost parameter with the cost coefficient. Direct estimation in WTP space avoids the need to calculate the analytical approximation of the standard errors for parameters estimated in utility space (Daly et al., 2012). Therefore, the parameters and their associated standard errors can be used to test for statistical differences in parameters between models by comparing the confidence intervals of identical features between treatments.

One of the consequences of using the error term specified is that the estimated parameters are fixed, and preferences are therefore assumed to be homogeneous. This assumption can be relaxed by specifying a mixed multinomial logit model (MMNL) such that:

$$\delta_{\text{nk}} = \beta^{m} + \beta^{\text{s}} \tau_{\text{nk}} \tag{3}$$

where δ_{nk} is a population-level estimate composed of β^{m} a vector of mean WTP–WTA for each attribute. The final component $\beta^{\text{s}} \tau_{\text{nk}}$ is used to estimate random taste variation, with the zero-mean error term τ_{nk} in part determining the shape of the distribution for each parameter. For every non-cost parameter, a normal distribution is specified, and for the cost attribute, a lognormal distribution. Full correlation was estimated between all random parameters, with their associated standard errors calculated using the delta method.[1] All models estimated included an alternative-specific constant for the status quo (ASC status quo) and the third alternative (ASC Option C). Sociodemographic variables included in the status quo alternative include gender, age and education. Gender is a dummy variable equal to one for female, age is continuous, and education was also coded as several dummy variables representing the highest level of education attained. The base level is high school education, with each variable representing diploma (e.g. trade education), undergraduate and postgraduate. An error component has also been included, which is shared among the non-status quo alternatives. This parameter has been included to control for substitution patterns, for example alternatives that are experimentally generated and those that are experienced such as the status quo (Scarpa et al., 2007). The error term τ_{nk} is simulated as integrating over tau leads to no closed-form solution for the MMNL. Therefore, the log-likelihood function is solved using maximum simulated likelihood, with the solution to Equation (2) being shown as:

$$\text{LL}(\beta') = \sum_{n=1}^{N} \ln \left[\frac{1}{R} \sum_{r=1}^{R} \prod_{j=1}^{J} \prod_{c=1}^{C} \left(P_{\text{njc}}^{r} \right)^{y_{\text{njc}}} \right] \tag{4}$$

[1]The associated correlation matrix can be provided by the authors upon request.

with y_{njc} representing the actual choices made and r the number of draws used for simulation. The draws were sampled using Modified Latin Hypercube Sampling (Hess et al., 2006) with draws increasing incrementally to 5000 ensuring the stability of parameter estimates. The final models were estimated using Python Biogeme (Bierlaire, 2016) with supporting code from Rose and Zhang (2017).

5 | RESULTS

Descriptive statistics of the sample, relative to the state, based on the latest 2016 census are presented in Table 2. For age and gender, we find there is no statistically significant difference between the sample and census proportions in New South Wales ($\alpha = 5\%$). Minor variations were noted due to difficulties with meeting quota targets for some of the categories, specifically young women. In total, 302 respondents were obtained for Treatment 1 and 300 for Treatment 2. In both treatments, households were most willing to reduce/change when they cleaned and least willing to reduce/change cooking, with entertainment being the intermediate activity. These questions were asked prior to the choice tasks.

The choice frequencies for each treatment are shown in Table 3. Across both treatments, most of the choices made were for the non-status quo alternatives. For Treatment 2 (WTP), over a third of respondents chose the zero-cost status quo, even though this alternative involved two consumption restrictions being imposed on the household. A test of the difference in proportions between treatments suggests that the status quo was chosen less for Treatment 1 (WTA lower cost increase) and the difference is statistically significant ($t = 15.44$, $p < 0.001$). This may be, in part, due to the status quo being the highest cost alternative, including no consumption restrictions with all non-cost features being set at their maximum level. Approximately 26% and 57% of all choices, respectively, made in each treatment involved an alternative, which imposed two consumption restrictions on the households.

TABLE 2 Descriptive statistics.

	Rest of New South Wales				Greater Sydney			
	Men		Women		Men		Women	
Age	Sample	Census	Sample	Census	Sample	Census	Sample	Census
18–29	2.33%	2.66%	1.83%	2.66%	6.64%	6.98%	5.81%	6.81%
30–44	4.32%	3.82%	4.48%	3.99%	10.47%	9.80%	10.30%	9.80%
45–59	3.82%	4.49%	4.49%	4.65%	8.31%	7.81%	8.64%	8.14%
60+	6.31%	5.81%	5.98%	6.31%	7.97%	7.64%	8.31%	8.64%

	Treatment 1	Treatment 2
Activity Most Willing to go Without		
Cleaning	81.33%	84.44%
Cooking	8.67%	7.28%
Entertainment	10.00%	8.28%
Activity Least Willing to go Without		
Cleaning	7.00%	5.30%
Cooking	54.33%	57.62%
Entertainment	38.67%	37.09%

TABLE 3 Proportion of alternatives selected.

Alternative selected:	Treatment 1 (WTA lower cost increase)	Treatment 2 (WTP)
Option A (Status Quo)	16.4%	36.0%
Option B	45.4%	34.3%
Option C	38.2%	29.7%

The second column of Table 4 reports the mixed logit model results of the WTA lower cost increase treatment. All the mean parameters, except for the daily reminders feature, have signs in line with economic theory and are statistically significant. The daily reminder is negative and statistically significant, implying that respondents would pay to remove this feature from the fixed cost of their contract. The alternative-specific constant for the status quo alternative is negative, suggesting that there is unobserved heterogeneity that leads respondents to select away from the status quo contract. The standard deviations show that there is preference heterogeneity within the sampled population (Hensher et al., 2015). A significant error component suggests that respondents evaluate the trade-offs between the non-status quo alternatives differently, relative to the status quo. The status quo age interaction term is positive, suggesting that older respondents are more likely to select the status quo. Gender is also significant, suggesting that women are relatively less likely to select the status quo. Finally, all the education parameters are significant, suggesting that those who have greater than a high school education are more likely to select the status quo alternative.

The third column of Table 4 reports the WTP treatment. Except for the daily reminder, all the estimated coefficients have the expected sign and are statistically significant. The ASC for the status quo is the same sign as for Treatment 1, but it is relatively smaller. This result is not surprising given the higher choice frequency for this treatment reported in Table 3. In terms of the standard deviation parameters, all are statistically significant. The error component is also significant for Treatment 2. The coefficients for the sociodemographic factors suggest that older and female respondents are more likely to select the status quo and only those respondents with a diploma are more likely. Finally, compared with respondents with high school education, respondents who attained an undergraduate or postgraduate level of education were less likely to select the status quo; however, only the former level is significant. In terms of model diagnostics, there are minor differences in terms of the final log-likelihood for each treatment. The AIC and BIC coefficients suggest that the WTP model is a slightly better fit.

Table 5 reports the results of tests for differences between the WTP and WTA lower cost increase parameter distributions. The null hypothesis of equality of mean preferences is rejected for the renewables and no restrictions contract features. This result implies that respondents need to be compensated more for reductions in the proportion of renewables, relative to the WTP equivalent. For the no restrictions feature, respondents would require more compensation to go from no activities to two activities restricted during the evening peak period. This is in contrast to the WTP treatment where the respondent would be paying to remove two restrictions being imposed by default.

6 | DISCUSSION AND POLICY IMPLICATIONS

We present two different scenarios in the form of treatments in an effort to unravel the complexities and trade-offs inherent in the energy policy trilemma. In Treatment 1, households were presented with a nontrivial 'rebate' (our WTA lower cost increases) in the form of a stream

TABLE 4 MMNL estimated in WTA lower cost increase/WTP – space by treatment.

Variable	MMNL – treatment 1 (WTA lower cost increase) Coef. (Robust SE)	MMNL – treatment 2 (WTP) Coef. (Robust SE)
Mean Parameters		
Daily reminders	−1.938** (0.887)	−0.048 (1.379)
Real-time reminders	9.407*** (0.941)	4.909*** (1.384)
One consumption restriction	5.189*** (0.654)	6.814*** (0.769)
No consumption restrictions	28.390*** (0.779)	14.576*** (0.337)
Renewable generation	0.676*** (0.018)	0.385*** (0.030)
Storage	0.229*** (0.017)	0.196*** (0.011)
Household cost ($/year)	−2.925*** (0.201)	−2.184*** (0.363)
ASC (status quo)	−150.225*** (3.681)	−31.072*** (1.734)
ASC (Option C)	−7.677*** (0.585)	−2.750*** (0.492)
Standard deviation parameters		
Daily reminders	8.717*** (0.189)	3.961*** (0.570)
Real-time reminders	11.729*** (0.363)	11.030*** (0.466)
One consumption restriction	19.175*** (0.278)	13.243*** (0.724)
No consumption restrictions	35.811*** (0.936)	15.276*** (0.413)
Renewable generation	1.146*** (0.011)	0.569*** (0.023)
Storage	0.621*** (0.007)	0.366*** (0.008)
Household cost ($/year)	2.358*** (0.363)	2.082*** (0.511)
Error component	120.950*** (1.472)	51.257*** (0.471)
Status quo interactions		
Age	0.204*** (0.028)	−0.041** (0.018)
Gender	−19.295*** (1.208)	7.023*** (0.681)
Diploma	56.749*** (0.991)	5.961*** (0.836)
Undergraduate	39.161*** (1.209)	−9.273*** (0.547)
Postgraduate	74.370*** (1.714)	−2.248** (0.915)
Diagnostics		
No. of observations	2416	2400
Log-likelihood	1792.140	1799.090
AIC	3670.280	3684.184
BIC	3829.971	3843.447
McFadden Pseudo R^2	0.320	0.318

Note: *** 1% significance ** 5% significance * 10% significance.

of lower future fixed cost increases in exchange for varying lower targets in renewables, reliability, information and less freedom in appliance usage and household activities. In Treatment 2, households were presented with a status quo contract, which involved no additional fixed costs and two consumption restrictions imposed versus contracts leading to increases in service provision but with a stream of higher costs.

The estimated coefficient for renewables was statistically significant and the expected sign. This result is consistent with past WTP studies reporting a consistent positive preference for more renewable energy generation (see, e.g., Ma et al., 2015). The premium

TABLE 5 Estimated mean marginal WTA lower cost increase/WTP and 95% confidence intervals.

Attribute (feature)	WTA lower cost increase treatment	WTP treatment	Parameter difference?
Renewable Generation: 10% decrease (increase)	$6.76 [$6.42, $7.11]	$3.85 [$3.26, $4.45]	Yes
Storage: 10 MWh decrease (increase)	$2.29 [$1.97, $2.62]	$1.96 [$1.75, $2.16]	No
Restrictions Imposed: One restriction	$5.19 [$3.91, $6.47]	$6.81 [$5.31, $8.32]	No
No restrictions	$28.39 [$26.86, $29.92]	$14.58 [$13.92, $15.24]	Yes
Daily reminders	-$1.94 [−$3.68, −$0.20]	Not significant	Yes
Real-time reminders	$9.41 [7.56, $11.25]	$4.91 [$2.20, $7.63]	No

Australian households are willing to pay on top of the average household electricity bill that is relatively small compared with other studies; for example, German households are willing to pay a premium of up to 16% (Kaenzig et al., 2013). Our results suggest a small additional premium noting the existing contribution Australian households already make towards renewable energy investments (on average approximately $122 or 9% of their annual bill in 2020/21 (AEMC, 2020b)). This amount is comparable to the average premium reported in Soon and Ahmad (2015) of $85.92 USD ($118.41 AUD).[2] It may also be that since renewables are already perceived to be leading to reduced costs, there may not be any perceived benefit to providing additional funding as part of their current electricity bill. AEMO has noted that more battery storage and virtual power plants (interconnected energy resources) will be required as more renewables are installed (AEMO, 2020b). Therefore, from a policy perspective more may need to be done in the way of information provision to change consumer preferences going forward to prefer more renewable generation. It may be that as electricity bills start to fall, as suggested in the most recent AEMC price trend report (AEMC, 2021), consumers may start to perceive the financial benefits of more renewable generation, encouraging a gradual change in preferences.

The result for the storage feature is consistent with past studies analysing preferences for energy reliability. One of the benefits related to battery storage is the potential flexibility in the management and operation of power systems to reduce the likelihood of a blackout event. Previous studies have shown that the premium paid varies according to the duration of blackouts avoided (Abdullah & Mariel, 2010; Amador et al., 2013; Goett et al., 2000; Pepermans, 2011). It has also been shown that WTP is related to the time of day and season (Carlsson & Martinsson, 2008). Historically, the NSW grid has been very reliable; however, nationally there have been rare instances of storm damage and localised load shedding during sustained heat waves. This may explain why the WTA–WTP for this feature is small, relative to the other features. From a policy perspective, this result also shows that there is public support for battery technology at the community level. Beyond the capacity to reduce the duration of blackouts, battery storage is increasingly being studied as a means to support renewable energy generation technologies (Cebulla et al., 2018; Hartner & Permoser, 2018; Nelson et al., 2018; Soini et al., 2020).

Consumption limits have the highest WTA lower cost increase estimates relative to other features in Treatment 1. Households in Treatment 2 similarly have a higher WTP to remove restrictions relative to the other features in the treatment. Households required a larger rebate

[2]Converted using the USD:AUD closing spot price rate as of 31 December 2021.

in the form of lower cost increases when compared to the WTP to remove consumption restrictions. A recent study by Srivastava et al. (2020) also measures the compensation required to enrol in similar demand management programmes, using Belgian households. Their case study focusses on multiple features associated with a specific demand-side management programme, such as varying time lengths and different appliances being restricted. In our study, the focus is different as we vary the number of activities that are restricted during the peak period. Regardless of this difference, there is a similarity in the size of the results, with their main result suggesting that households require 41€ ($64.14 AUD[3]) per year to participate in a daily demand-side management programme. This amount lies between the two estimates we obtained when considering the two consumption limit-level estimates (converted to annual measures) of $73.12 and $41.68 in our study. Despite differences in the size of estimates, our study supports the idea that households are willing to participate in demand-side management policies if they are compensated appropriately.

While there have been projects to test the feasibility of demand-side management programmes (ARENA, 2020a), these trials are characterised by a high degree of self-selection. Our sample may be more representative of wider community preferences in so far as our respondents received a general invitation to answer a survey (limitations of online panels notwithstanding). Studies have shown that for these programmes, the opt-in rates were significantly lower relative to those trials where customers could opt out (e.g. Parrish et al., 2019). Indirectly, the findings of this study support the idea that respondents prefer to opt out of demand-side management programmes and require compensation to participate. It could also indicate that households may not be aware of ways that they could reduce their demand. This contract feature could be beneficial for utilities, depending on whether the revenue generated (increased revenue foregone) from removing (imposing) consumption limits would offset the projected costs (saved) of reducing peak demand.[4]

For the second demand-side management policy, the installation of smart meters, households value smart meters that provide real-time feedback. The non-significant result for daily reminders is consistent with previous studies that suggest real-time provision of information is relatively more useful for managing consumption compared with daily consumption summaries (Gans et al., 2013; Gleerup et al., 2010). Therefore, the negative WTA lower cost increase results for the daily reminders could be interpreted as households perceiving the daily reminder as being potentially annoying.

Previous studies have shown that one of the key drivers of consumers adopting smart energy technologies is the perception that it will lead to lower bills (Rausser et al., 2018; Wilson et al., 2017). In our study, we note the potential influence of the Victorian experience (e.g. neighbouring state). The rollout of smart meters in Victoria was promoted as a means of reducing industry costs related to ensuring a reliable supply of energy. Eventually, these cost savings were expected to lower prices for consumers, but according to the Victorian Auditor General (2015), this rollout had no effect on prices, and consumer benefits were not realised. Given the low WTP for smart meters, a more effective policy would be to target installation to households that are energy-aware and actively focussed on reducing their electricity bills, rather than a widespread installation of smart meters.

The previous discussion highlights that households are willing to pay more for a greener and more reliable energy system as well as some support for demand-side management. Interestingly, looking at the status quo interactions it appears that those who are older, female and have more education are likely to support the existing transition, either by being more

[3]Euro to AUD conversion rate calculated based on the EUR:AUD closing spot price 31 December 2021.

[4]This comparison is assumed for a vertically integrated utility, where both the costs of generation and selling electricity are incurred.

likely to select the status quo contract in the WTA treatment or less likely to select the status quo in the WTP treatment. Compared across both treatments, the status quo interactions are almost perfectly mirrored, the exception being the binary variable on a diploma level of education. Previous studies have identified that education often leads to an increase in the propensity to switch electricity contract switching literature (He and Reiner 2017; Hortaçsu et al., 2017; Schleich et al., 2019); however, this result more so relates to identifying better contracts more aligned with household preferences (or at least finding a better deal). As for the other interactions, there is ambiguity with respect to what is the anticipated result, for example gender is often considered a control variable and age has been found to have mixed effects on contract switching rates (Daglish, 2016; Hortaçsu et al., 2017; Shin & Managi, 2017).

The disparity between the WTA lower cost increase and the WTP results is not surprising in the context of the wider environmental SP literature. The description of the status quo allows the methods and results to be used in settings with different infrastructure investment or demand-side management policies. Depending on the investment being considered and tolerance for error, the estimates can be transferred, or the DCE set-up utilised to explore preferences in other settings. For example, there are situations where access to short-term fossil fuel generators is being evaluated, such as the Japanese Government opting to shift its nuclear/fossil fuel/renewable energy targets post-Fukushima (Chapman & Itaoka, 2018). The recent impacts of COVID-19 forced governments to redirect resources towards managing increased political and economic instability, potentially delaying the transition to a low-carbon electricity sector (Hoang et al., 2021). WTA may be useful and appropriate if thecost–benefit analysis for the storage features focusses on reductions in the reliability of the network. The WTP treatment could be an appropriate measure to use if the focus is on estimating the benefits from a more reliable grid in a developing country context.

7 | CONCLUSION

The overall goal of this study was to explore whether Australian households were willing to continue supporting the transition towards a greener, yet still reliable electricity market. The results suggest that households are willing to engage in active demand-side management, including utilising information from smart meters and paying more in exchange for utilising electricity during the peak evening period. This last activity is important from a policy perspective since if implemented it could reduce the gap between what is paid for and the marginal cost to supply electricity. This study also suggests that a WTP–WTA disparity exists when considering electricity contract features, expanding upon an ever-growing list of goods where this disparity has been documented.

Finally, future studies could address some of the limitations of this study. The generalisability of the results is limited in that the sampling only included homeowners in New South Wales. It may be the case that households in other states and territories, as well as other types of households (e.g. renters and apartment dwellers), share the same preferences. We make no such claim in this study; however, this may be a subject for future studies. Significant preference heterogeneity was noted for all features, especially in the results related to removing restrictions, which could be investigated. This may have led to a two-stage decision-making process where certain restriction levels were excluded and then the other features evaluated. Finally, we also note that the feasibility of covering a 60% renewable investment level with the max price of \$6400 paid by households over 5 years is untested. The upper levels of the attributes were based on household preferences, not on engineering studies. Despite these limitations, we believe that the results reported in this study support the idea that the average Australian household is still willing to fund additional renewable investment without compromising the reliability of the network, as well as participate in demand-side management policies.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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