Human Dimensions of Residential Sector Energy Consumption

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Abstract: In a highly urbanized nation characterised by some of the lowest living density in the world, there is a need to better understand the human dimensions associated with consumption of energy. Understanding the context in which the Australians consume energy either directly or embodied in goods and services can be relevant to understanding future trajectories of energy demand in cities. This paper uses an Australian national level dataset to explore the factors determining electricity consumption. It provides the background for a more in-depth analysis of residential energy (electricity) use, particularly with regard to connections between how differences in electricity price, financial wellbeing or long term household stability (e.g. home ownership) relate to the decision-making process with regard to lowering or making energy (electricity) consumption more efficient. Results show electricity demand does not level off for higher levels of income and they seem to suggest the type of the dwelling is not as important as the retrofitting and how people make use of the living space. The data indicates that detached homes could encourage residents to increase their number of energy saving actions (ESAs) and confirms they have a higher likelihood to have insulation or solar energy sources, while living in a capital city makes it less likely to report more ESAs or to have solar power installed. Future work can also explore the relationship between different measures of electricity prices and decisions to retrofit or take energy saving actions.

1. Introduction

In a world where cities are the main locus of energy consumption and also housing more than 50% of the world population, how households consume energy and their actions directed towards reduction of energy consumption is an important factor for global sustainability (Dhakal et al., 2008; GEA, 2012; Minx et al., 2013). Energy policy research is sustained by the need for national energy security in the face of increasing fossil fuels' scarcity, increasing energy demand and the need for more efficient and less polluting energy sources. Cities at the same time can be seen as part of the problem or the solution as economies of scale and foci of innovation (Rees and Wackernagel, 1996; Droege, 2006; Grübler and Fisk, 2013).

As a particularly urbanized society, understanding Australian current residential energy consumption and its potential determinants is a crucial step in moving towards sustainable living. While coal is the largest source of electricity generation in Australia, at 64%, there has been a 7% decline in coal-fired power generation (Deparment of Industry and Science, 2014). Renewable sources were found to potentially be able to supply all energy needs in Australia and while they are still far from being the main source of energy in the domestic sector, their presence is increasing significantly (Mills, 2001). In terms of residential electricity, from 2009 when solar energy was contributing less than 1%, in 2013 the contribution was closer to 5% and the number of solar small generation units increased from below 200 thousands in 2009 to more than 1.4 million in 2015 (Deparment of Industry and Science, 2014).

The purpose of this study is to explore for an Australia-wide dataset the connections of electricity consumption and energy saving actions with (a) household demographic characteristics and (b) the dwelling structure (see footnote 3 for a list of these actions).

2. Households and the connection between energy consumption, built environment and lifestyles

2.1 Australian compact city and residential electricity use

When discussing the benefits of a compact versus spread urban form, what needs to be remembered is that the Australian city is traditionally mostly a detached dwelling based city, with separate housing accounting for about 79% of accommodation in Brisbane, 61% of Sydney and 72% of Melbourne metropolitan areas[1]. Urbanization in the sense of increasing the compactness of the living space has been promoted in a decentralized manner. In the case of Brisbane for example, the zoning in the City Plan of 2000 and then of 2014 promotes infilling in strategic areas. This system allows developers, real estate entrepreneurs to decide when the best time financially to change the landscape of an area and densify it. With low rates on bank loans in the period of 2013 – 2015, areas in Brisbane earmarked for high rise buildings are seeing a spurt of development centred around townhouses (close to semi-detached style of buildings) and apartment living.

From an urban land use planning perspective, households' residential and transport energy use is relevant in connection to the search for policies to encourage ever more energy efficient urban forms and understand what are the benefits of the 'compact city' (Jenks et al., 1996; Burton, 2000; Burton, 2003). Australian studies searching for the lowest energy or GHG emissions impact forms of residential dwelling characteristics have found diverse results and data limitations in reporting energy or electricity use have made it harder to analyse socio-demographic connections in detail. High-rise buildings are the least energy and GHG emissions efficient housing types in a study comparing electricity use at peak demand (operational energy use) of apartments to townhouses and villas (Myors et al., 2005). In Adelaide, comparing operational and 'embodied' (life-cycle) energy and emissions of detached outer suburb housing, Perkins found that inner city apartments cannot be deemed to be the most energy efficient (Perkins et al., 2009)[2]. Information was provided on income, age and other socio-economic variables of the households but, their analysis was not the main focus. Another study, relied on scenario projections to find inner suburban and inner city appartments as the most efficient in terms of embodied energy (building, furniture or appliances) and total energy in Melbourne (Fuller and Crawford, 2011). With access to a national level dataset the focus in this study is on the major patterns in the differences between detached living and other more compact forms of dwellings, leaving an in-depth discussion of the various forms of dwellings for a later study. Thus three of the hypotheses tested are:

H1 Electricity consumption for more compact forms of living (e.g. semi-detached or apartment) are lower than for detached housing.

H2 Electricity consumption for larger homes (i.e. surface area) is higher than for smaller homes.

H3 Location in an urban area plays a role in addition to climate zone and seasonality in terms of electricity consumption.

2.2 Energy use and relationship to income and lifestyles

Drawing connections between the socio-economic circumstances of households and their operational energy consumption is not an easy topic to dissect. The relationship between income and amount of

[1] Numbers obtained by author analysis of the ABS Census 2011 data.
[2] More specifically, while inner city apartments are found to have a lower delivered total energy than outer suburban houses, they have high operational and embodied per capita energy requirements. Overall, outer suburban households had higher per capita total energy use because of higher operational transport use.

energy (electricity) use has been heavily studied and it has been found to be significant, but what is less explored is what happens at different levels of income. A number of papers find that socio-economic factors, such as income, size of household, or price of energy have a stronger association with amount of consumption rather than anything else, not necessarily considering the strength of connections with the built environment (Biesiot and Noorman, 1999; Gatersleben et al., 2002; Cao et al., 2015; IPART, 2011). Studies using methods of analysis from industrial ecology find that residential and transport (direct) energy consumption is levelling off after a certain income threshold (e.g. Lenzen et al., 2008).

Renters are in a more vulnerable position in terms of adopting energy saving measures as they rarely can bring modifications to their dwellings to make them more energy efficient, and it might be they also have less of a say in the appliances they use (Davis, 2012). More energy saving features have been found in Irish homes for owner-occupiers which are also at the higher end of the income range, but owning outright can have the highest potential energy use (O'Doherty et al., 2008). Beyond the power of decision over what retrofitting is used in the house, price appreciation of houses together with availability of credit through mortgage equity withdrawal allow households to extend their consumption: the wealth effect of housing (Parkinson et al., 2009). This can make it more likely for a household to initially make a larger investment such as retrofitting and then capitalize on its investment through lower bills and adding to their savings from the regular income. However, newer homes and more valuable homes can have more energy saving features at the same time as using more appliances (O'Doherty et al., 2008).

Some energy saving behaviour may not be motivated by price of energy and affluence, but rather by beliefs correlated with long term stability provided by home ownership. Committed environmentalists had the highest level of home ownership (83% owning their homes) for a sample of over 1200 respondents in the UK (Barr et al., 2005). Yet, pro-environmental behaviour may not lead to lower energy use (Gatersleben et al., 2002).

The paper is searching for the strongest connections at the national level between electricity consumption and *socio-economic* or *built environment* factors to guide future more in-depth exploration of these connections. It is extending previous work by exploring a larger set of variables and sample size, enabled by the publication of the Australian HECS dataset. In this paper the connection of income, electricity price, status as homeowners with the number of electricity saving behaviours is explored, in addition to other socio-economic and effects from the structure of the dwelling.

H4 Presence of energy saving retrofitting (i.e. insulation or solar power) and taking energy saving actions in a household are more likely for homeowners and financially secure households.

H5 Electricity consumption levels-off for higher quantiles (levels) of disposable income

3. Data

The Household Energy Consumption Survey has been collected by the Australian Bureau of Statistics over one year covering part of the 2011-12 and 2012-13 financial years. The scope of the survey by design is 97% of the Australian population and the sampling was designed to be reliable for results at capital state level or state level. Energy consumption data was collected for residential electricity, mains gas, bottled gas or LPG, for feed-in tariffs of solar based electricity and also for fuel used in transport. The sampling occurred in four quarters and was distributed through the year, with the data being considered to represent income patterns and seasonal patterns in temperature through the year (ABS, 2014).

Table 1. Variables and descriptive statistics for the whole dataset

Variable	Description	Mean (SD)	% of total
Dependent Variable			
Electricity	Weekly electricity used (kWh)	126.54 (115.88)	
Independent variables			
Price			
Price	Average electricity price per kWh (expenditure/demand)	0.27 (0.54)	
Household characteristics			
Equivalised income	Equivalised household weekly disposable income	903.05 (670.62)	
Household size	Number of people in the household (ordinal 1 – 6)	2.44 (1.29)	
Dependent children	Number of dependent children (ordinal 0-5)	0.49 (0.90)	
Elderly household	Household is composed of people over 65 years (dummy 0 -1)		20.36
Saving weekly	Part of the weekly budget goes to savings. Base case: breaking even or going over the budget (dummy 0-1)		41.37
Renter	Dwelling tenure type. Base case other forms of tenure (dummy 0 -1)		39.7
Energy saving actions[3]	Number of energy saving actions (ordinal 0-8): each possible action is given an equal weight of 1	5.11 (1.74)	
Dwelling characteristics			
Detached dwelling	Dwelling type: separate		81.15
Dwelling size	Number of bedrooms (ordinal 1-6)	3.09 (0.89)	
Dwelling age: >20 yrs	Age of dwelling >20 years (dummy 0 – 1)		65.56
Dwelling age: unknown	Age of dwelling is unknown (dummy 0 – 1)		1.60
No hot water	No hot water system installed in the home (dummy 0 – 1)		0.72
Two or more hot water systems	Two or more hot water systems are installed in the home (dummy 0 – 1)		2.94
Insulated dwelling	Dwelling has insulation (dummy 0 - 1)		73.69
Insulation unknown	Insulation status unknown (dummy 0 – 1)		
Solar	Solar hot water or PV present (dummy 0 – 1)		17.57
Geographic location			
Capital city	Resides in a capital city (dummy 0-1)		46.65
New South Wales	*Resides in New South Wales (base case)*		*17.13*
Victoria	Resides in Victoria (dummy 0 – 1)		17.07
Queensland	Resides in Queensland (dummy 0 – 1)		14.18
South Australia	Resides in South Australia (dummy 0 – 1)		16.90
Western Australia	Resides in Western Australia (dummy 0 – 1)		15.05
Tasmania	Resides in Tasmania (dummy 0 – 1)		10.58
Northern Territory	Resides in Northern Territory (dummy 0 – 1)		3.41
ACT	Resides in ACT (dummy 0 – 1)		5.67
Seasonality and climate			
Zone 1	Climate zone 1: high humid summer (dummy 0 – 1)		4.75
Zone 2	Climate zone 2: warm humid summer (dummy 0 – 1)		12.52
Zone 3 / 4	Climate zone 3 / 4: hot dry summer (dummy 0 – 1)		7.10
Zone 5	Climate zone 5: warm temperate (dummy 0 – 1)		31.96
Zone 6	*Climate zone 6: mild temperate (base case)*		
Zone 7 / 8	Climate zone 7 / 8: temperate / alpine (dummy 0 – 1)		18.78
September	*Data collection season: September quarter (base case)*		23.98
December	Data collection: December quarter (dummy 0 – 1)		32.63
March	Data collection: March quarter(dummy 0 – 1)		19.00
June	Data collection: June quarter (dummy 0 – 1)		24.39

[3] Refers to: using a low-flow shower head; using energy efficient light bulbs for the majority of lights (such as CFLs); taking short showers; using cold water for all or most clothes washes; drying clothes on a washing line for all or most washes; switching appliances off at the wall; switching off chargers for rechargeable appliances when not in use; and using draft-proofing seals on doors and windows.

4. Method

The analysis in the paper focuses on the electricity use and factors shaping it, and, on the energy saving behaviours of households. Cao and colleagues find Australian total residential energy use is determined by income, energy price, location in terms of climate region or perhaps state-based differences in policy, number of people in the household and a number of dwelling characteristics (dwelling size, age or number of hot water systems) (Cao et al., 2015). Another regression based analysis of Sydney's residents electricity consumption finds that living in a detached house, the number of bedrooms, of occupants and income level were positively associated with electricity consumption (IPART, 2011). This paper employs a similar approach and the same data as Cao and colleagues (2015), but it is focused on analysing electricity consumption rather than total energy and on the circumstances surrounding electricity saving measures, focusing on connections to urban form.

The first empirical model is a electricity consumption (in kWh) as a function of income, price of electricity, a series of m household composition factors hhc_{j_h} for each household h, a series of p dwelling characteristics dwc_{j_h} for each household h , a series of dummy variable factors D_{j_h} for each household h representing location, climate zone and seasonality and the error term ε_h.

$$\ln E = \alpha_0 + \alpha_1 \ln inc + \alpha_2 \ln price + \sum_{j=1}^{m} \alpha_{3j} hhc_{j_h} + \sum_{j=1}^{p} \alpha_{4j} dwc_{j_h} + \sum_{j=1}^{n-1} \alpha_{5i} D_{j_h} + \varepsilon_h \quad (1)$$

To study the energy saving behaviour, having insulation, solar power or taking energy saving actions an empirical a probit estimation model is used (Finney, 1947). This model is based on the cumulative normal probability distribution function, which unlike the logit assumes normal distribution of errors: $\Pr(Y = 1 \mid X) = \Phi(X'\beta)$, where X is a vector of regressors, Φ is the standard normal cumulative distribution function (cdf) and the β vector of coefficients are estimated as maximum likelihood. The linear predictor $\eta_i = x_i'\beta$, with x_i are a series of covariates, is obtained by inversing the cdf of the probability π_i of a positive outcome: $\eta_i = \Phi^{-1}(\pi_i)$. The equations of the probit or ordered model for studying the factors associated with reporting presence or absence of insulation, of solar power or with taking energy saving actions (ESAs) are:

$$\ln SOL = \beta_0 + \beta_1 \ln inc + \beta_2 \ln price + \sum_{j=1}^{m} \beta_{3j} hhc_{j_h} + \sum_{j=1}^{p} \beta_{4j} dwc_{j_h} + \sum_{j=1}^{n-1} \beta_{5i} D_{j_h} + \varepsilon_h \quad (2)$$

$$\ln INS = \gamma_0 + \gamma_1 \ln inc + \gamma_2 \ln price + \sum_{j=1}^{m} \gamma_{3j} hhc_{j_h} + \sum_{j=1}^{p} \gamma_{4j} dwc_{j_h} + \sum_{j=1}^{n-1} \gamma_{5i} D_{j_h} + \varepsilon_h \quad (3)$$

$$\ln ESAs = \tau_0 + \tau_1 \ln inc + \tau_2 \ln price + \sum_{j=1}^{m} \tau_{3j} hhc_{j_h} + \sum_{j=1}^{p} \tau_{4j} dwc_{j_h} + \sum_{j=1}^{n-1} \tau_{5i} D_{j_h} + \varepsilon_h \quad (4)$$

Correlations between the main variables were analysed, but reports are not fully presented here due to lack of space. There is no sign of strong collinearity to lead us to dropping any of the variables. Largest significant correlation observed was between climate zone 2 and location in Queensland, at 0.8302, but base regression model collinearity check shows the correlation does not introduce high collinearity in the model.

Table 2. Significant correlations between major variables (significance level: * for p<0.01)**

	Weekly electricity used
Average electricity price	-0.0836***
Equivalised income	0.1238***

5. Results

5.1. Household energy saving behaviour and socio-demographic variables

Hypotheses 1, 2 and 3 are tested through the a multiple linear regression model with results reported in table 3. Multicollinearity is not an issue in the model as variance inflation factors (VIF) are all lower than 10. In the regression the dependent variable was log-transformed. Seasonality factors were added to each models to test their influence, but as the focus is not on these factors they were not reported in the results tables to save space. Descriptive information on the variables used in the multiple linear regression is in Appendix I.

Table 3. OLS regression (with robust standard errors) of the electricity consumption against the socio-demographic variables. In brackets: robust standard errors.

Independent variable	Ln (electricity) [kWh] *(robust s.e.)*	Independent variable	Ln (electricity) [kWh] *(robust s.e.)*
Ln (price)	-0.5748***		
	(0.0267)	Capital city	-0.0701***
Ln (equivalised income)	0.1157***		*(0.0140)*
	(0.0123)	Victoria	-0.1748***
Household size	0.1970***		*(0.0239)*
	(0.0083)	Queensland	-0.1473***
Dependent children	-0.0713***		*(0.0368)*
	(0.0107)	South Australia	0.0157
Elderly household	-0.0932***		*(0.0221)*
	(0.0179)	Western Australia	-0.1851***
Saving weekly	-0.0830***		*(0.0233)*
	(0.0129)	Tasmania	0.2265***
Renter	-0.0259		*(0.0437)*
	(0.0171)	Northern Territory	0.0569
Detached dwelling	0.0864***		*(0.0624)*
	(0.0198)	ACT	-0.1629***
Dwelling size	0.1279***		*(0.0480)*
	(0.0092)	Zone1	0.2674***
Dwelling age: >20 yrs	0.0264**		*(0.0577)*
	(0.0134)	Zone2	0.0793**
Two or more hot water systems	0.2091***		*(0.0368)*
	(0.0406)	Zone3 / 4	0.1593***
Insulated dwelling	0.0509***		*(0.0299)*
	(0.0196)	Zone5	0.0375*
Insulation: unknown	-0.0188		*(0.0215)*
	(0.0256)	Zone 7 / 8	0.0672
Solar	-0.1743***		*(0.0420)*
	(0.0192)	December	0.0429***
Energy saving actions	-0.0329***		*(0.0156)*
	(0.0038)	March	0.1094***
			(0.0180)
constant	2.2887***	June	0.1784***
	(0.0986)		*(0.0179)*
Observations	7463		
Adjusted R^2	0.4427		
Mean VIF	2.20		
p	0.0000		

*Note: standard errors in parentheses, significance levels: * for p< 0.10, ** for p<0.05, *** for p<0.01*

In table 3, both electricity use (as KWh) and income are presented as natural logarithm values, meaning the coefficient of income represent elasticity: for a one increase in income there is an expected 0.1157% increase in electricity consumption. For a one percent increase in price, an expected 0.5748% decrease in electricity consumption is expected. The large number of observations available contributes, to relationships being significant at the one percent level. For the rest of the independent variables coefficients which are not log transformed, the coefficients are transformed through the exponential function to reach a meaningful interpretation: a one unit increase in the number of people in a household, leads to exp(0.1970)-1=0.2177 or 21.77% increase in direct energy consumption. However, provided the number of people in the household is constant, if the family is composed of more children or elderly people, then this is associated with 6.85% and 8.88% respectively less electricity use. From the same table it can be seen that having a larger number bedrooms (higher surface area in the home) and more hot water systems are factors highly associated with more electricity consumption. Also, older dwellings and those with insulation seem to be inhabited by families with higher electricity bills. On the other hand, families which have installed solar PV or hot water, consume about 16% less KWh and those that additionally take energy saving actions, consume a further 3% less electricity. Weekly kWh use is lower also if the dwellers manage to save money weekly (i.e. general savings, not necessarily due to lower bills), but renting was not found to be a significant factor.

As far as location is concerned, being in a capital city is associated with lower weekly electricity use figures as opposed to living in the rest of the state. Living in some states seems to lead to significantly lower weekly electricity bills than the base case New South Wales (NSW): namely by about 13-17% in Victoria, Queensland, Western Australia or the Australian Capital Territory. The opposite is true for being in Tasmania, at around 25% more, while South Australia and Northern Territory homes tend to have just slightly higher bills than NSW. In terms of the climate, hot humid or dry summer areas (zones 1, 2, 3-4) attract significantly more electricity use than the base case of mild temperate climate. Seasonality data appears significant in the basic regression model, but is not explored in detail here, rather left to a future paper.

Coefficients in table 4 for the probit and in table 5 for the ordered probit models represent marginal effects. An example of the interpretation is the level of probability to have or not have solar power for a one-unit change, or, discrete change (in the case of dichotomous variables) in the independent variable. Table 4 shows that presence of insulation in the building does not seem to be connected to the price of electricity or level of income. The probability of solar hot water (SHW) or solar electricity (SPV) being in use in a dwelling is associated with a significantly lower price paid for electricity overall. A t-test showed the mean electricity price paid by those household with solar power is significantly lower mean at 0.19 $/kWh versus 0.29$/kWh. Homes with insulation or solar power are less likely to be older than 20 years by 9.76% and 4.51% respectively and are more likely to be detached by 7.5% and 13%. Also, homes in the capital cities of Australia have a significantly lower chance of reporting use of solar power, 4.76%, than those in other states. In terms of the household composition, solar energy sources are more likely to be present in larger households, but not those with more dependent children. Households with insulation or solar power will be less likely to be renters by approximately 10% and 18%. Also, the households which have SHW or SPV installed are also more likely to be able to make weekly savings.

From table 5 it can be seen that from 5 to 6 ESAs there is a pivot point in the effect of most variables where the direction of the effect switches. Households taking 5 ESAs are slightly more likely to be smaller, have more children, be a renter and live in a semi-detached unit or an apartment. Renters are 3.34% less likely to undertake all eight saving actions and people living in detached homes are about 1.2% percent more likely to do this. Living in a capital city also leads to lower chance, by 1.93% of undertaking all eight ESAs. Hot and dry summers in zone ¾, highly humid weather in zone 1 or warm temperate weather in zone 5 seem to be less conducive to undertaking all 8 ESAs than the base case, zone 5 – mild temperate.

Table 4. Probit regression of insulation and solar power against the socio-demographic variables. The table reports average marginal effects and unconditional robust standard errors in brackets.

	Insulation *(unconditional s.e.)*	Solar hot water or solar electricity *(unconditional s.e.)*
Ln (price)	0.0075	-0.4957***
	(0.0055)	*(0.0815)*
Ln (equivalised income)	0.0108	0.0050
	(0.0068)	*(0.0069)*
Household size	0.0078	0.0214***
	(0.0050)	*(0.0054)*
Dependent children	-0.0033	-0.0251***
	(0.0065)	*(0.0069)*
Elderly household	0.0129	-0.0040
	(0.0096)	*(0.0116)*
Saving weekly	0.0019	0.0220**
	(0.0078)	*(0.0087)*
Renter	-0.1032***	-0.1814***
	(0.0090)	*(0.0137)*
Detached dwelling	0.0750***	0.1299***
	(0.0109)	*(0.0170)*
Dwelling size	0.0233***	0.0221***
	(0.0055)	*(0.0061)*
Dwelling age: >20 yrs	-0.0976***	-0.0451***
	(0.0089)	*(0.0088)*
Two or more hot water systems	0.0004	0.0398*
	(0.0220)	*(0.0218)*
Capital city	-0.0131	-0.0476***
	(0.0087)	*(0.0098)*
Victoria	0.1100***	-0.0091
	(0.0142)	*(0.0168)*
Queensland	-0.0105	-0.0495**
	(0.0179)	*(0.0250)*
South Australia	0.1136***	0.0922***
	(0.0135)	*(0.0144)*
Western Australia	0.0333***	0.1120***
	(0.0127)	*(0.0153)*
Tasmania	0.0282	-0.0170
	(0.0325)	*(0.0361)*
Northern Territory	-0.0438	0.2017***
	(0.0282)	*(0.0363)*
ACT	0.0518	-0.0107
	(0.0342)	*(0.0376)*
Zone1	-0.1087***	0.1016***
	(0.0247)	*(0.0336)*
Zone2	-0.0227	0.1062***
	(0.0183)	*(0.0250)*
Zone 3 / 4	-0.0060	0.0156
	(0.0171)	*(0.0201)*
Zone5	0.0060	0.0113
	(0.0129)	*(0.0142)*
Zone 7 / 8	0.0572*	-0.0596*
	(0.0317)	(0.0344)
Observations	6914	7777
Chi2	861.13	817.25
p	0.000	0.000
Pseudo R^2	0.1874	0.1757

*Note: standard errors in parentheses, significance levels: * for p< 0.10, ** for p<0.05, *** for p<0.01*

Table 5. Ordered probit regression results for taking five or more energy saving actions against socio-demographic variables. The table reports average marginal effects and unconditional robust standard errors in brackets.

	5 energy saving actions (ESA)	Model 2: 6 ESA	Model 3: 7 ESA	Model 4: 8 ESA
Ln (price)	0.0006	-0.0012	-0.0024	-0.0021
	(0.0005)	*(0.0010)*	*(0.0021)*	*(0.0018)*
Ln (equivalised income)	0.0069***	-0.0138***	-0.0279***	-0.0243***
	(0.0009)	*(0.0016)*	*(0.0032)*	*(0.0029)*
Household size	-0.0012*	0.0025*	0.0050*	0.0043*
	(0.0006)	*(0.0013)*	*(0.0026)*	*(0.0023)*
Dependent children	0.0029***	-0.0058***	-0.0117***	-0.0102***
	(0.0008)	*(0.0016)*	*(0.0033)*	*(0.0029)*
Elderly household	-0.0009	0.0018	0.0036	0.0031
	(0.0013)	*(0.0026)*	*(0.0052)*	*(0.0045)*
Saving weekly	0.0001	-0.0002	-0.0003	-0.0003
	(0.0010)	*(0.0020)*	*(0.0041)*	*(0.0035)*
Renter	0.0094***	-0.0190***	-0.0384***	-0.0334***
	(0.0014)	*(0.0025)*	*(0.0050)*	*(0.0044)*
Detached dwelling	-0.0034**	0.0068**	0.0136**	0.0118**
	(0.0016)	*(0.0031)*	*(0.0063)*	*(0.0055)*
Dwelling size	-0.0008	0.0015	0.0031	0.0027
	(0.0007)	*(0.0014)*	*(0.0028)*	*(0.0024)*
Dwelling age: >20 yrs	0.0015	-0.0030	-0.0060	-0.0052
	(0.0010)	*(0.0021)*	*(0.0042)*	*(0.0036)*
Two or more hot water systems	0.0001	-0.0003	-0.0006	-0.0005
	(0.0026)	*(0.0052)*	*(0.0105)*	*(0.0091)*
Capital city	0.0054***	-0.0110***	-0.0222***	-0.0193***
	(0.0012)	*(0.0023)*	*(0.0045)*	*(0.0040)*
Victoria	0.0030	-0.0060	-0.0120	-0.0104
	(0.0019)	*(0.0038)*	*(0.0076)*	*(0.0066)*
Queensland	-0.0025	0.0051	0.0103	0.0089
	(0.0028)	*(0.0056)*	*(0.0113)*	*(0.0097)*
South Australia	-0.0009	0.0019	0.0038	0.0033
	(0.0017)	*(0.0034)*	*(0.0068)*	*(0.0059)*
Western Australia	0.0072***	-0.0145***	-0.0292***	-0.0254***
	(0.0018)	*(0.0036)*	*(0.0072)*	*(0.0063)*
Tasmania	0.0075**	-0.0152**	-0.0307**	-0.0267**
	(0.0037)	*(0.0073)*	*(0.0148)*	*(0.0129)*
Northern Territory	0.0042	-0.0085	-0.0172	-0.0149
	(0.0044)	*(0.0089)*	*(0.0180)*	*(0.0157)*
ACT	0.0043	-0.0086	-0.0174	-0.0151
	(0.0037)	*(0.0075)*	*(0.0152)*	*(0.0132)*
Zone1	0.0122***	-0.0247***	-0.0498***	-0.0432***
	(0.0041)	*(0.0081)*	*(0.0163)*	*(0.0141)*
Zone2	-0.0035	0.0071	0.0143	0.0124
	(0.0028)	*(0.0057)*	*(0.0114)*	*(0.0099)*
Zone 3 / 4	0.0077***	-0.0155***	-0.0313***	-0.0272***
	(0.0023)	*(0.0046)*	*(0.0092)*	*(0.0080)*
Zone5	-0.0056***	0.0112***	0.0227***	0.0197***
	(0.0017)	*(0.0034)*	*(0.0068)*	*(0.0059)*
Zone 7 / 8	-0.0017	0.0034	0.0068	0.0059
	(0.0035)	*(0.0070)*	*(0.0141)*	*(0.0123)*
Observations	7822	7822	7822	7822
Chi2	456.28			
p	0.000			
Pseudo R^2	0.0148			

*Note: standard errors in parentheses, significance levels: * for p< 0.10, ** for p<0.05, *** for p<0.01*

5.1 Household affluence and electricity consumption

As opposed to the multiple linear regression which averages out results across the whole population, the quantile regression results can show the effect of explanatory variables on different quantiles of the electricity consumption distribution. Figure 1 is showing that as available equivalised disposable income is higher the consumption of electricity appears to increase as well. What can be seen is an increasing importance of income with increasing quantiles of household electricity use.

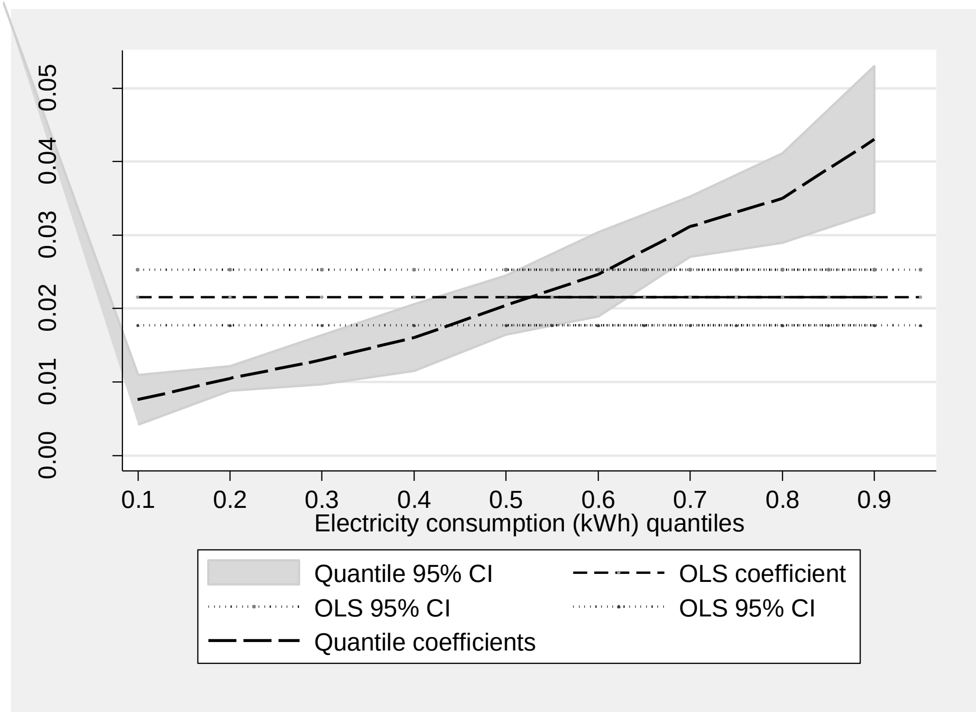

Figure 1. Variation in electricity consumption according to decile (dependent variable on the horizontal) according to income quantiles (1000 bootstrap replications). Quantile regression error bars correspond to bootrapped 95% confidence intervals.

6. Discussion, conclusions and future work

For H1, the amount of electricity consumption was found to be significantly and positively associated with detached dwellings rather than semi-detached homes or apartments. However, the connection of the dwelling type with the amount of electricity consumption is weaker than the connection with the dwelling size, household size, and the number of hot water systems and the presence of solar power. Aside from validating hypothesis H2, the relationship found here between electricity consumption and the size of the dwelling or number of people living in it are factors that could be of greater importance for how much electricity is consumed in a house rather than dwelling type per se. In a nutshell, these results seem to suggest the type of the dwelling is not as important as the retrofitting and how people make use of the living space. This validates some previous findings, but also finds different magnitude or type of associations which will need further exploration. For example Cao an colleagues (2015) find positive significant associations between number of people in the house, number of children, or dwellers being older with total energy consumed, but in this paper the last two factors were negatively associated with electricity use.

For H3, it can be seen the capital city effect, keeping all other factors constant is actually significant at the lowest error level of one percent and conducive to lower electricity consumption at home. The climate zone dummy variables indicate a benefit from living in a mild temperate climate region (zone 6, the base case), as all other regions have positive associations. This is different from (Cao et al., 2015) who found that zone 2, areas with warm humid summers and mild winters, tend to have lower electricity use than all other regions. This result may be due to differences in sample size (higher in this study) or how variables were defined. A future study could try to enquire into distinct effect of city living and aspects of urban form (residential density) on electricity consumption through the medium of energy savings behaviours using a system of seemingly unrelated regressions (SUR).

For H4, results are considered in terms of the income, weekly saving ability and ownership status. Results seem to not show a significant association of presence of insulation or solar power with income, but showed a significant association with the ability to save weekly in the case of solar power and a clear strong association of renters having lower chances to live in insulated homes with solar power. As the income measure is weekly disposable income, this shows that long-term financial stability rather than short term income could be involved in decisions such as household renovations which eventually lead to energy savings. With presence of insulation not connected to almost any household socio-economic variables, except the renting status, suggests that insulation installation may be part of the construction codes and regulation and particularly so for certain locations. The positive association in the basic multiple linear regression of insulation with electricity consumption points to a potential rebound effect in consumption occurring.

More income detracts from the likelihood to undertake eight energy saving actions (ESAs, see note 3 for the types), but whether households manage to save weekly does not seem to matter. As table 3 shows, more income is associated with more electricity consumption as well, this finding seems to verify those of Poortinga and colleagues (2003) who found technological solutions are preferable to behavioural changes for people in higher income brackets. Being a renter seems to be a strong indicator that not only the home will not have insulation or solar power, but also there is a significantly lower chance to take eight ESAs. While taking ESAs would lower the electricity bills, looking at the correlations, renters are also negatively associated with being able to save weekly, but they tend to live in dwellings less than 20 years old. Results seem to corroborate the findings of Barr and colleagues, as homeowners are more likely to take a higher number of actions to save on electricity (Barr et al., 2005). Overall there seems to be a renter effect which leads to lower overall kWh used, but also less efforts to save electricity. It is worth noting that electricity saving actions have a 5 to 6 times weaker relation with the amount of electricity consumed than presence of solar hot water or solar PVs. In a future paper, this motivation or causality of energy saving behaviours should be explored in more depth together with the opportunities for savings on the electricity bill that homeownership indirectly affords to homeowners.

These results show that homes with solar power capacity tend to pay significantly less for electricity, but not those with insulation. In fact insulation seems to be associated with higher amounts of electricity being used which can point to a rebound happening. Since high electricity prices combined with feed-in tariffs could have been the original motivator to install solar power, this result could be explained by electricity prices being reduced for generating dwellings, which have alternative options for supplying their own electricity and may be in a position to negotiate better energy prices[4]. Future research could analyse households' motivation to install solar hot water or PV.

Results disagree with the last hypothesis, H5, as the result of the quantile regression shows that while the households on the lower end of the income distribution have to use electricity despite their income level, at the higher level of the income distribution there seems to be a propensity to consume

[4] Rises in electricity prices of 49%, increase in the number of installations of renewable technologies, mild weather and energy efficiency legislation were observed during 2010 – 2012 (ABS) Australian Bureau of Statistics (2014). 4670.0 - Household Energy Consumption Survey, Australia: Summary of Results, 2012: Business Survey of Residential Electricity Distribution (BSRED), Experimental Estimates. Canberra, (ABS) Australian Bureau of Statistics,. 2014.

connected more strongly to the amount of income available for this type of expenditure. This result isn't in agreement with findings from ecological economics studies such as (Lenzen et al., 2008).

This paper is a national level exploration into the factors determining electricity consumption in Australia according to a recent large scale energy survey. The data analysed here represents general correlations and the survey questions had limited information with regard to the motivation (i.e. causation). Overall there needs to be an acknowledgement of the limitations of this study, particularly with regard to understanding motivation of installation of insulation, renewable energy technology and taking energy saving actions. Quantitative analysis of time-series data and qualitative surveys would shed more light on understanding causality. Also, qualitative data to explore motivations of renters in taking energy saving actions or of home owners in installing insulation or solar power. This work provided the background for a more in-depth analysis of particular aspects to do with residential electricity use, particularly with regard to connections between how differences in electricity price, financial wellbeing or long term household stability relate to the decision-making process with regard to lowering or making energy (electricity) consumption more efficient. The data indicated that separate housing living could be allowing residents to take more modifications for energy efficiency rather than semi-detached or apartment buildings, but more in-depth analysis is needed for other types of dwellings. Results also showed that direct energy demands such as electricity do not appear to level off for higher levels of income. More work is needed to understand connections between the effect of location, urban structure and socio-economic factors on the consumption of electricity, particularly to understand the particular effect of living in a city. Future work can also explore the relationship between different measures of electricity prices and decisions to retrofit or take energy saving actions.

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Appendix I

Table 6. Summary statistics of the variables for the OLS regression model (Observations = 7463)

Variable	Mean	Std.Dev.	Min	Max
Electricity	127.9464	116.3992	2	3710
Price	0.282027	0.544466	0.004184	24.33333
Equivalised income	927.7775	658.5987	2	12295.74
Household size	2.43575	1.263201	1	6
Dependent children	0.453571	0.872436	0	4
Elderly household	0.228326	0.419782	0	1
Saving weekly	0.435482	0.495853	0	1
Renter	0.251106	0.433678	0	1
Detached dwelling	0.815758	0.387708	0	1
Dwelling size	3.118049	0.88368	1	6
Dwelling age: >20 yrs	0.655099	0.475368	0	1
Dwelling age: unknown	0.013131	0.113845	0	1
No hot water system	0.005762	0.075692	0	1
Two or more hot water systems	0.028541	0.166523	0	1
Insulated dwelling	0.763366	0.425044	0	1
Insulation status unknown	0.119791	0.324739	0	1
Solar	0.163071	0.369455	0	1
Energy saving actions	5.203939	1.681071	0	8
Capital city dweller	0.483586	0.499764	0	1
Victoria	0.180222	0.384398	0	1
Queensland	0.142436	0.34952	0	1
South Australia	0.154898	0.361831	0	1
Western Australia	0.136138	0.342958	0	1
Tasmania	0.102104	0.302805	0	1
Northern Territory	0.030685	0.172474	0	1
ACT	0.066997	0.250034	0	1
Zone1	0.044218	0.205593	0	1
Zone 2	0.124213	0.329846	0	1
Zone 3 / 4	0.059092	0.235812	0	1
Zone 5	0.260887	0.439148	0	1
Zone 7 / 8	0.19456	0.395888	0	1
December	0.322123	0.467321	0	1
March	0.193086	0.394746	0	1
June	0.23918	0.426611	0	1