Australian Residential Energy End-Use – Trends and projections to 2030

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ABSTRACT

Energy consumption in the residential sector has been decreasing in Australia since 2009, a trend not anticipated by the market nor by utilities anticipating ongoing increasing demand. A recently completed comprehensive update and re-design of the energy end-use model for Australia and New Zealand. The 2015 Australian Residential Baseline Study (RBS) examines the historical energy end use trends to 2013 and makes projections to 2030 and has utilized up to 20 years of sales data, matched with appliance attribute information (efficiency, size, etc.) of appliances, lighting and building thermal efficiency, to produce a stock and linked energy model of Australia.

The modelling found total residential energy use grow until 2009 but since then has declined and is projected to continue to decline until 2020 and will only start to increase again in the late 2020's. This decline is mainly driven by a decline in average electricity use per household, but there are also significant declines in average natural gas and wood usage per household. Analysis of this model suggests that energy efficiency factors, including the impact of energy efficiency programs and technology improvements, have contributed to the observed energy use trends over the last two decades, such as increased use of efficient lighting, refrigeration, water heating, televisions and space conditioning. Other market changes contributing to the decline in energy use include fuel switching for space heating and water heating, and water saving measures. The modelling shows the importance of up-to-date bottom-up modelling in forecasting energy market trends.

Introduction

The 2015 Australia and New Zealand Residential Baseline Study (RBS) examines the historical energy end use trends up to 2013 and makes projections from 2014 to 2030 (DIS 2015a). Two similar studies were conducted, in 1999 (AGO 1999) and 2008 (DEWHA 2008). The RBS utilizes a 'bottom up' energy end-use model of the residential energy sector, divided into major end-uses (i.e., appliances, hot water, etc.), product groups of equipment (i.e., televisions, electric water heaters, etc.), products (i.e., plasma TV, small water heater, etc.) and all major residential fuels (electricity, gas and wood). The recent 2015 update of the RBS expands on earlier studies by including additional products and utilizes a slightly different approach to the stock modelling. This 2015 study uses updated information and research derived from several projects undertaken since the 2008 study commenced (the 2008 study used data available up until 2005).

The overall top-down electricity use in the residential sector in Australia (excluding solar electric self-consumption) has declined by over 7% in 2013-14 compared to 2010-11 financial year (DIS 2015b). This is the first time in Australia's recent history that electricity use has declined over three subsequent years, and this decline was not forecast by the previous RBS

(DEWHA 2008) or by the energy market at the time (AEMO 2012). There are many factors contributing to this decline in overall electricity use, which will be discussed, but the important point is that this declining total energy use could not be foreseen by modelling based on trends based on historic data. This shows the potential importance of using bottom-up modelling as at least one of the tools used to forecast energy consumption and demand, and the need for such modelling to be regularly updated.

There have also been declines in total residential natural gas and wood consumption over the last five years (DIS 2015a), but these have been less pronounced.

The paper provides an overview of the methodology and findings of the RBS and its implications to the use of bottom-up modelling in forecasting, plus the role of regulation in improving energy efficiency.

Methodology

Methodology overview

The underlying methodology on which the residential energy end-use model and study is to be based is classified as a bottom-up engineering model (Yuning Ou 2012). It involves calculating the energy end-use consumption at the individual level and aggregating these consumptions to estimate the total locality or network consumption.

At the heart of this approach is the calculation that for each energy end use:

*Total Energy Consumed = Stock Numbers * Unit Energy Consumption (UEC).*

Determining the stock number of energy end-use equipment is undertaken by stock models which are effectively databases that keep a running tally of the number of equipment installed on a year by year basis. The stock in any year will be the sum of all past stock sales, less retirements of equipment.

The next aspect of the energy modelling is determining the value of the Unit Energy Consumption (UEC) for each end-use to be used in the residential energy end-use model. At its most basic level, UEC is determined by:

*UEC = Hours of usage * Unit Energy Input,* *or*

*UEC = Hours of usage * Unit Capacity * Unit Efficiency.*

The energy use of residential equipment can be calculated from these formulae, or from a variation of these formulae for more complex products operating in different modes or different measurement and usage metrics (such as wet appliances where UEC is a function of the usage per cycle). For products with multiple modes (e.g. products which have a standby energy consumption element), energy consumption while in operating mode must be separately calculated and added to obtain the total energy consumption in all modes. Although there are several different modes of operation found in appliances these have been condensed to the modes shown in Table 1.

Table 1: Modes of operation used in the RBS

Mode	Description
Operation 1	Main operation mode or Heating mode for space conditioning equipment.
Operation 2	Secondary operation mode or Cooling mode in space conditioning equipment
Auxiliary	Auxiliary mode used by some appliances such as energy use by fans in gas heaters

Space conditioning energy use requires special attention due to the impact of climate on usage and equipment efficiency, and the interaction of the thermal efficiency of the building shell with the usage of the equipment. There are many methods for estimating space conditioning energy use and demand. Broadly they can be divided into the measurement/metering based approaches (billing, metered data, hours of usage analysis), building thermal modelling, and engineering algorithm approach as identified by Stern (Stern 2013). In Australia there is insufficient data to use measurement/metering based approaches so the mixed engineering/building thermal modelling, using AccuRate software developed by CSIRO (AccuRate), which has previously been used to predict energy use, is used in this study. The annual variation in climate conditions has not been included in the modelled energy use; however climate variation by household location is accounted for in the RBS model.

A systematic approach to the model development was used to ensure all end-uses were considered and the model was developed by focusing on products in each end use. The end-uses and their categories (where appropriate) are: water heating, space conditioning, appliances (white goods, IT and home entertainment, other equipment), cooking and lighting.

Common functions, which will supply data to or accept data in, regarding the products, are Building Stock Module (including thermal demand requirements), Energy usage aggregator, Peak demand calculator (not discussed in this paper) and user interfaces for data input/scenario testing. A schematic of the end-use model is provided in Figure 1.

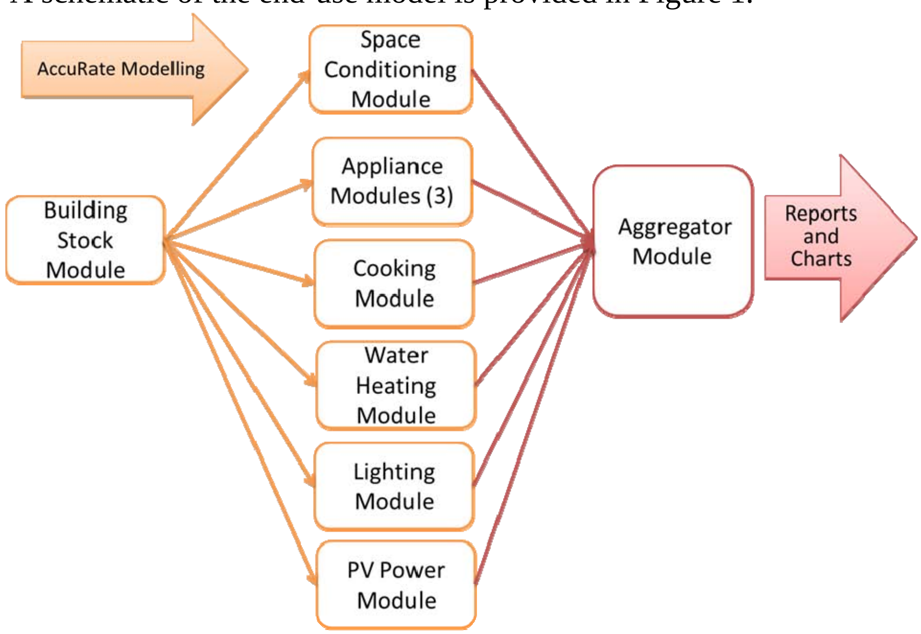

Figure 1: Schematic of energy end-use model modules and linkages (DIS 2015a)

The end-uses and categories, along with the typical equipment included in the model are shown in Table 2. The model calculates the impact of over 110 separate products segmented by all applicable fuels (electricity, natural gas, liquid petroleum gas and wood).

Table 2: End-uses and categories with typical equipment used in the RBS

End-use & category	Examples of Equipment/Products included
Space Conditioning	Air conditioning (heating and cooling), fans, resistive electric heating
Water Heating	Electric storage, solar electric, heat pump water heaters
Cooking	Cook-tops, electric oven, microwave oven
Lighting	Incandescent, halogen, LED, CFL
Appliances - White goods	Refrigerators, freezers clothes washers clothes dryers dishwashers
Appliances – IT&HE*	PCs, laptops, network equipment, printers, TVs, game consoles, set top boxes, DVD/Blu-ray, etc.
Appliances – other equipment	Pool pumps, spas, battery charging systems, other miscellaneous (cleaning appliances, irons, etc.), other misc. standby

*IT&HE = Information technology and home entertainment

The Building Stock Module main input to the other modules is data on household numbers by year, which are used for calculating average energy consumption, but it also provides information about the relative building thermal efficiency of the housing stock by year. Building thermal efficiency is used to predict decreases in space conditioning usage as the efficiency of the stock improves over time.

Research and data sources

The model inputs for the each of the products take into account the current programs that are affecting future energy use. The Minimum Efficiency Performance Standards (MEPS) and Energy Rating Label (ERL) programs that were implemented up till 2014 is found in E3 (2014, table 1). Trends in take up of energy efficiency technologies, such as LED lighting, are also considered in the forecasting of product sales and of future changes in product efficiency. Usage by households of many products is derived from Australian Bureau of Statistics (ABS) surveys, including a recent survey of 12,000 households in 2012 (ABS 2014). Household projections from the ABS have also been utilized.

The key attributes of the majority of significant equipment installed in households by year, including the average of their size and efficiency, were obtain from analysis of the sales data by model and from MEPS/ERL registration data. Sales of products were estimated from this same data or derived from penetration data, such as that obtained from ABS surveys. Research on the impact of the building thermal performance and the proportion of the building stock with improved thermal performance was also undertaken as part of this study.

Energy consumption by end use

Total energy consumption

The total residential Australian energy consumption is estimated to have increased from 357 PJ in 2000 to 397 PJ in 2009, and then declined to 381 PJ in 2013. It is forecast to continue to decline to 362 PJ in 2020 then to increase in the later part of the 2020's as shown in Figure 1.

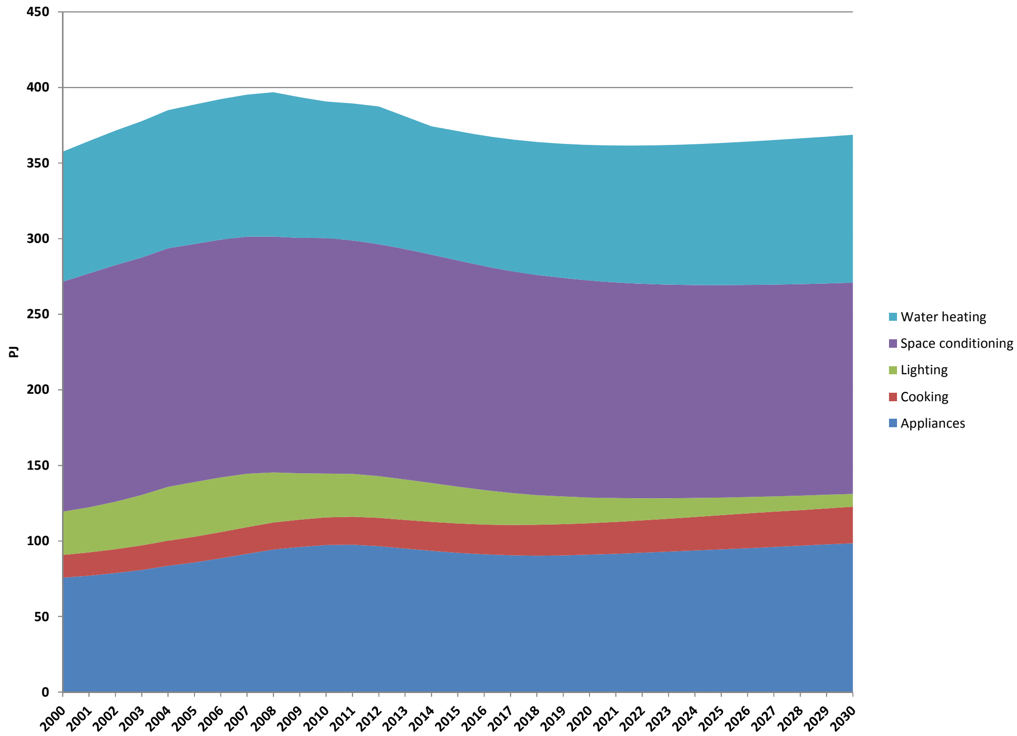

Figure 1: Estimated and forecast total residential energy consumption by end-use in Australia. Figures beyond 2013 are projections. *Source*: DIS 2015a

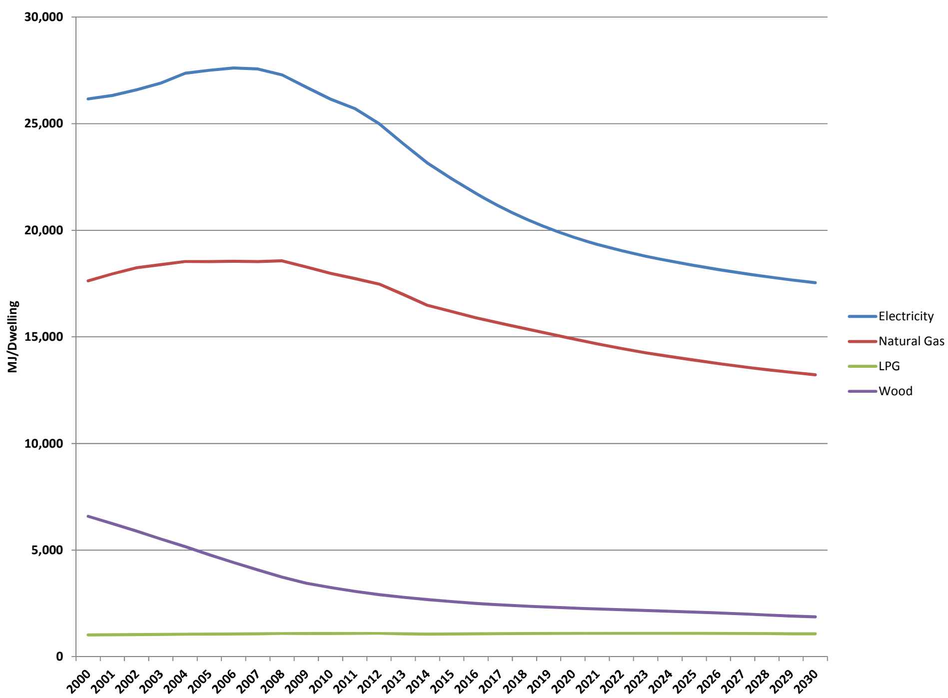

Figure 2 Estimated and forecast residential energy consumption per household by fuel in Australia. Figures beyond 2013 are projections. *Source*: DIS 2015a

Examining the underlying trends in consumption per household by fuel, as shown in Figure 3, we can see the big driver of decreasing energy use is declining electricity use, while gas use is declining but not as rapidly. Decreasing wood use is also contributing while LPG usage remains relatively stable. However, despite the ongoing decline in energy consumption per household, the increasing number of households eventually leads to an increase in total residential energy consumption from 2025 onwards.

The main end-uses that are contributing to these interesting trends are explained in the following sections.

Space conditioning

Space conditioning energy use by category displays an overall increase in energy consumption till 2004, and then a slow decline till the mid 2020's, as shown in Figure 3.

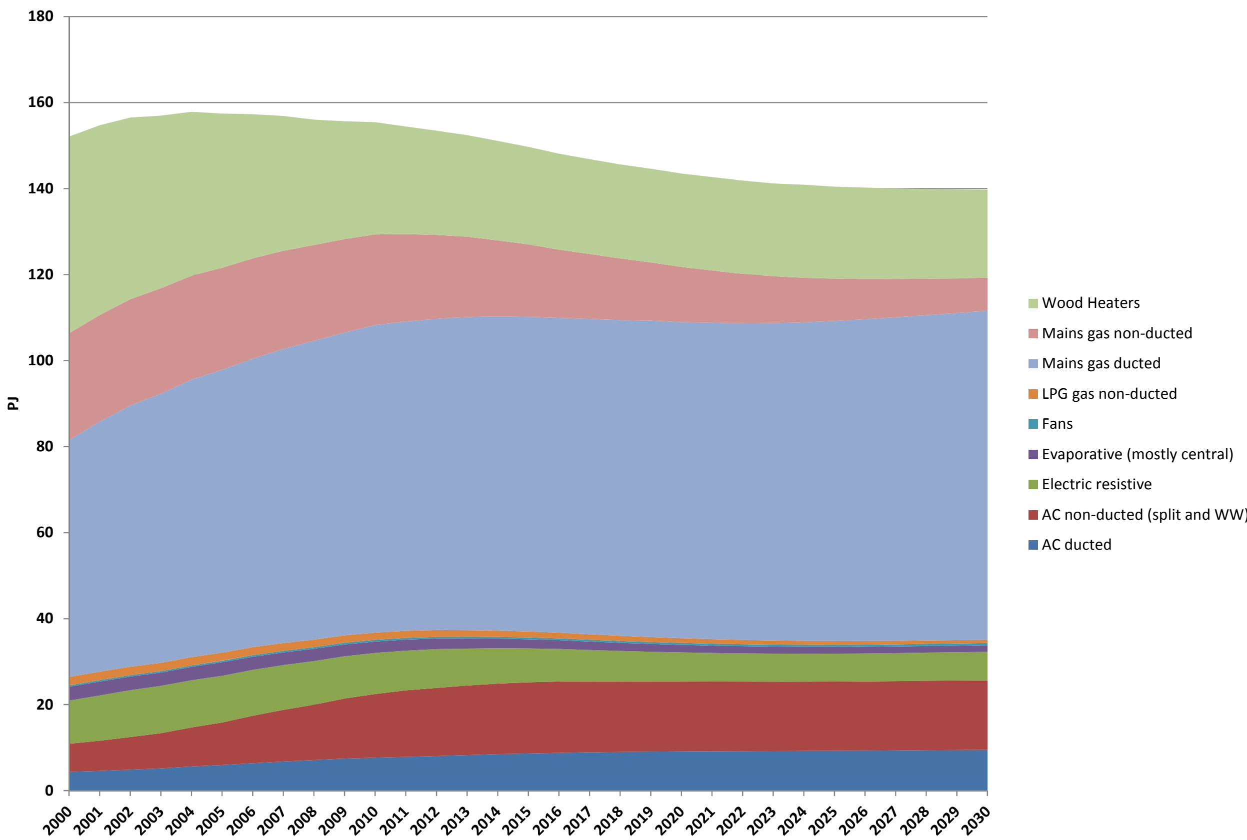

Figure 3: Estimated and forecast energy consumption of space conditioning end-use by product group in Australia. Figures beyond 2013 are projections. *Source*: DIS 2015a

Factors contributing to energy use trends. Electric air conditioning equipment has shown a rapid increase in energy consumption from 2000 to 2012, which largely reflects the increase in ownership of air conditioners in Australian homes from 0.52 to 0.94 per household. Gas ducted heaters have also increased in ownership over this period, but are reaching saturation. The resulting decline in space conditioning energy consumption was not expected, as the steady uptake in air conditioners in the decade suggested both electricity demand and consumption would keep increasing. The main reasons why space conditioning energy consumption has been decreasing since 2004 are:

- the shift from electric resistive and wood heating to use of more efficient reverse cycle air conditioners as heaters,
- an increase in the efficiency of air conditioners, from an average EER of 2.5 to 3.9 by 2013
- the impact of building thermal improvements due to the building code (in 2005 and again in 2011), and the federal governments home insulation program (EES 2011) during 2009-10 that insulated 1.2 million households (15% of total Australian households).

Lighting

Lighting demonstrates a rapid increase in energy consumption to 2006 and then is forecast to decline by over 60% to 2030, as shown in Figure 4.

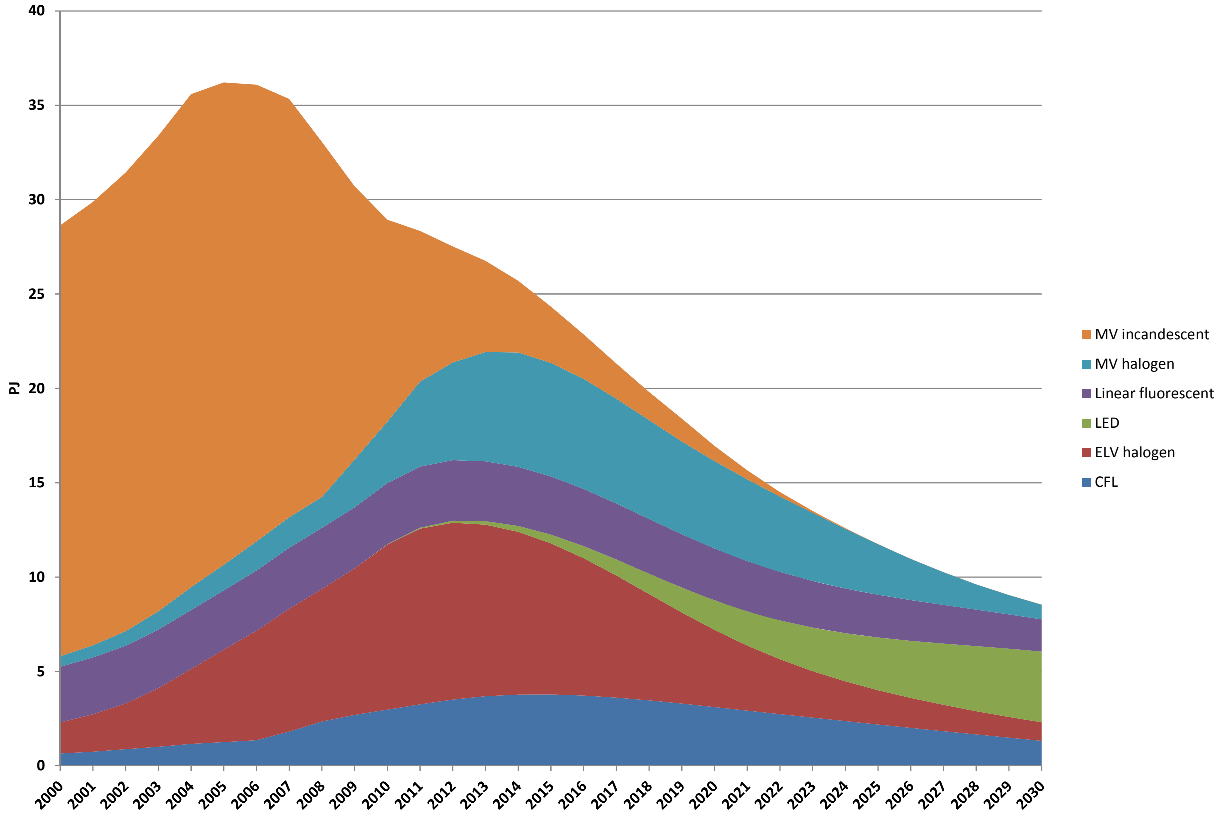

Figure 4: Estimated and forecast energy consumption of lighting end-use by product group in Australia. Figures beyond 2013 are projections. *Source*: DIS 2015a. Note: MV=mains voltage, LV =low voltage

Factors contributing to energy use trends. Lighting energy use increased in the first half of the 2000s due to the increasing number of lights per household, especially of halogen downlights. However the national phase out of incandescent lamps and the state government based white certificate programs caused an unexpected market transformation and the rapid increase in the use of more efficient CFLs over the last decade. Now, total energy consumption for lighting is forecast to continue to decline as CFLs and LEDs slowly replace halogen lamps.

Hot Water

Hot water energy consumption was increasing to 2008 and then declined by 9% to 2013. It is forecast to gradually increase till 2030 as shown in Figure 5.

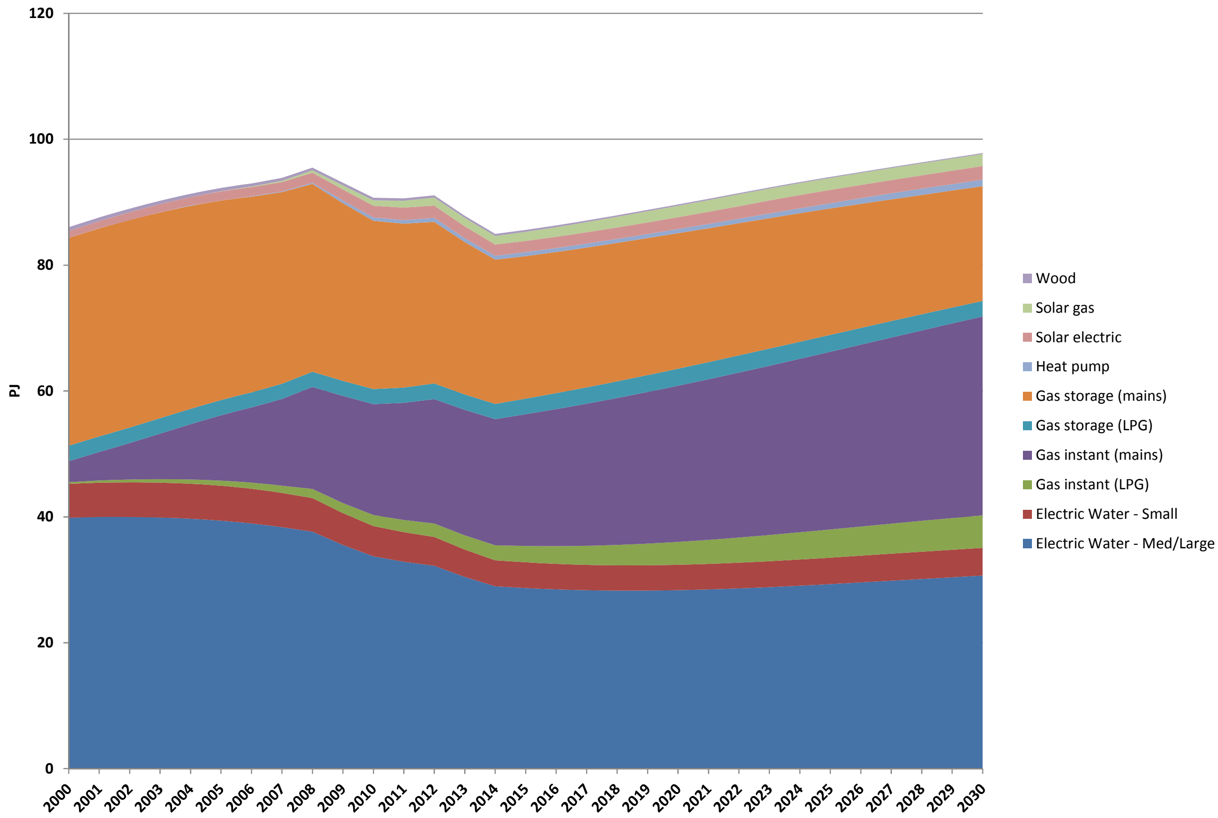

Figure 5: Estimated and forecast energy consumption of water heating end-use by product group in Australia. Figures beyond 2013 are projections. *Source*: DIS 2015a

Factors contributing to energy use trends. The main factor contributing to the reduction in energy use in hot water, in the second half of the 2000s for gas usage has been the switching by consumers to the more efficient instantaneous gas from storage gas water heaters. The main factors affecting electricity consumption have been consumers moving to solar and heat pump water heaters from electric storage water heaters, encouraged by incentives from state and federal governments and regulations that required new homes to install solar and heat pump water heaters. Average ownership of electric water heaters declined from 0.62 in 2000 to 0.46 in 2013. In addition, behavioural changes due to an extended drought and rapid take up of water efficient showers have also contributed to significant reductions in energy use per water heater. Research conducted for the RBS, utilising electricity distributor data on off-peak and controlled load water heaters, has found that the a decline in hot water use from water efficiency measures and changes in behaviour has contributed to approx. 10% of the reduction in total hot water electricity consumption in Australia.

The energy use by electric water heaters is now forecast to increase slightly, as the fuel switching rate declines and no other MEPS or water efficiency measures are planned to be implemented. The financial and regulatory incentives for solar and heat pump water heaters have also been significantly reduced, resulting in sales of these heaters reducing to pre-2007 levels.

Appliances – White goods

White goods electricity use by category shows a slow increase in energy consumption to 2010, then stabilises and is forecast to increase again from 2018 to 2030, as shown in Figure 6.

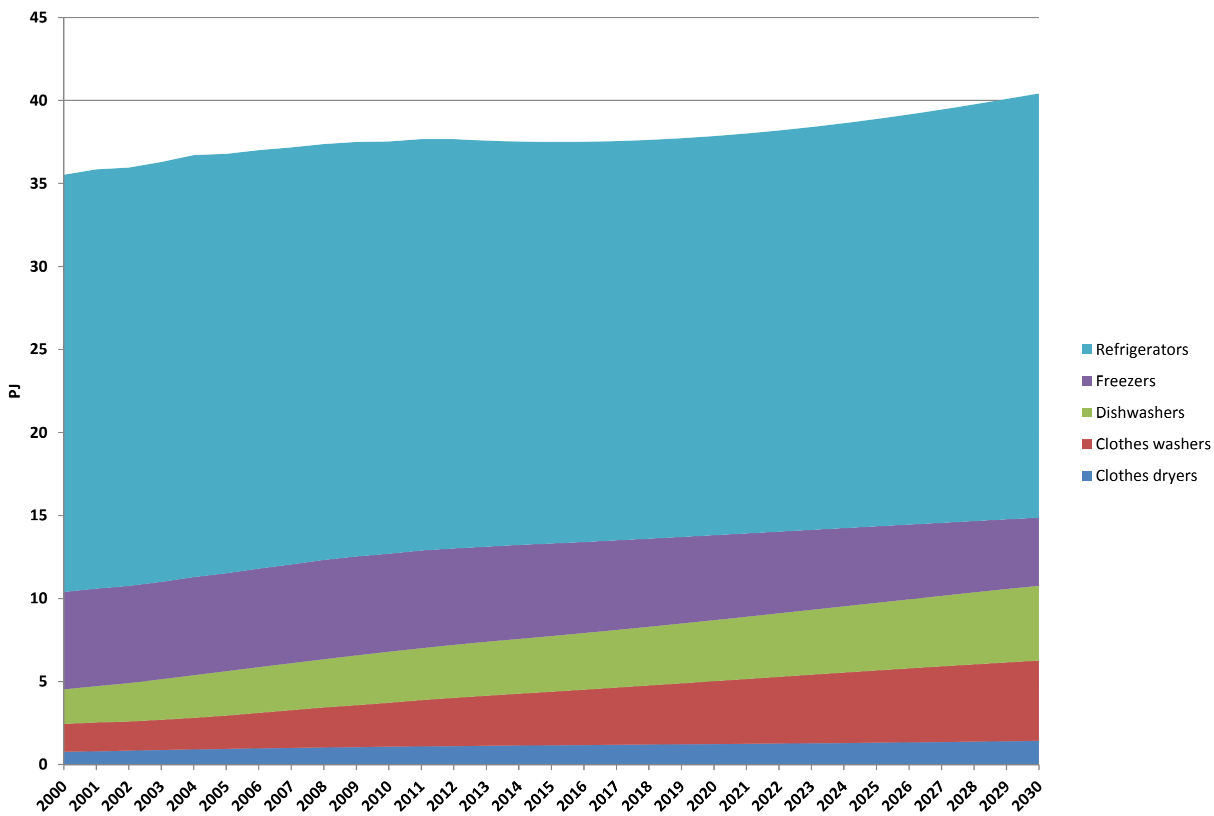

Figure 6: Estimated and forecast energy consumption of white goods end-use by product group in Australia. Figures beyond 2013 are projections. *Source*: DIS 2015a

Factors contributing to energy use trends. Energy use by white goods has been impacted by a number of factors, some causing decreases in energy and others increasing energy use. Refrigerators and freezers have been subject to MEPS (1999 and 2005) and ERL (since 1986, with updated scales in 2000 and 2010). The average energy efficiency of new refrigerators has improved by over 35% from 1996 to 2005, which has had a significant impact on the total refrigerator energy use, although ownership has increased to almost 1.4 refrigerators per household by 2010. The combined impact of these two factors means that energy use by refrigerators has increased by 7% from 2000 to 2010. Further MEPS are planned; however details are not yet published.

The other major factor contributing to the increase in energy use by white goods is the shift from top loading to front loading clothes washers, which uses more energy as they generally heat water to a minimum temperature to enhance washing performance while lowering total water use.

The current MEPS will progressively improve the efficiency of the white good stock, as older inefficient appliances are replaced, but this will have a decreasing impact over time. Consequently the projected increase in the number of households will eventually lead to an increase in the total energy use by white goods, which is forecast to occur over the period 2020 to 2030.

Appliances – IT&HE

The total energy use of Information Technology & Home Entertainment (IT&HE) increased by almost 100% from 2000 to 2010. It then started to rapidly decline, which was not expected by the market at the time, and now is forecast to continue to decline to 2020 before slowly increasing to 2030, as shown in Figure 7.

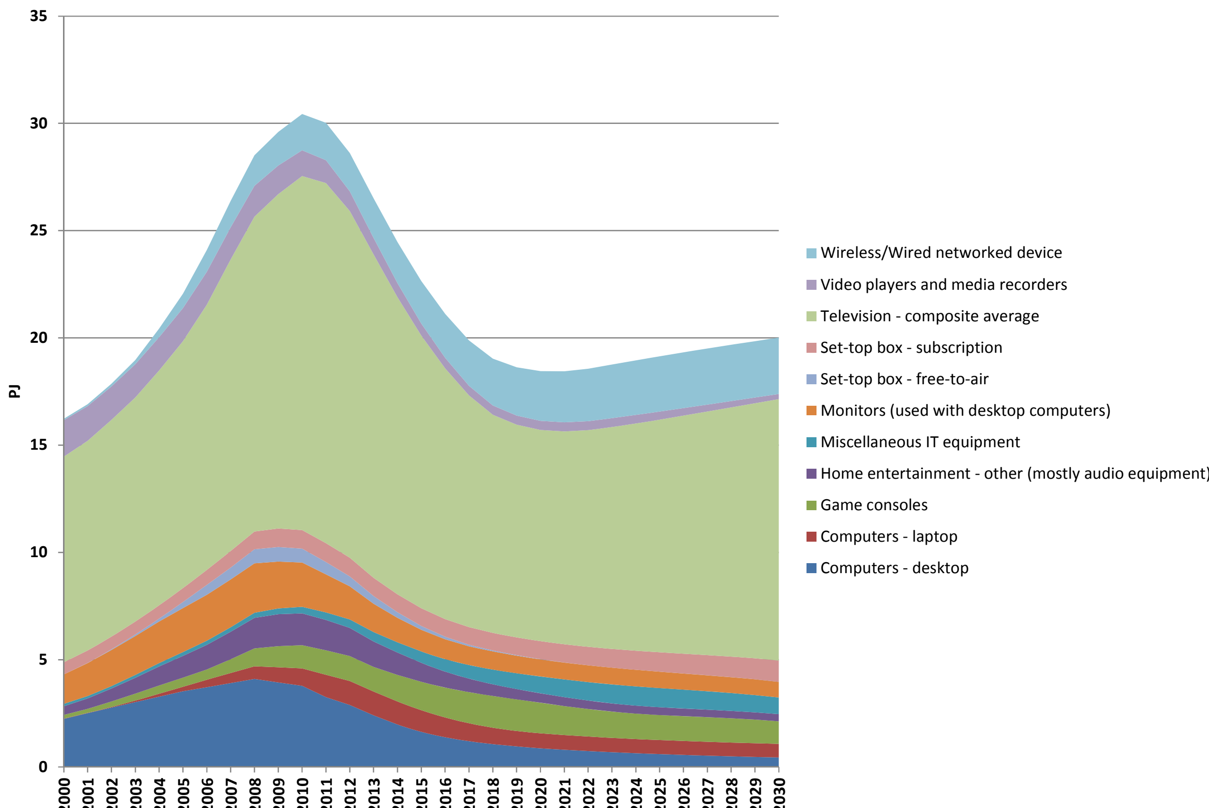

Figure 7: Estimated and forecast energy consumption of IT&HE end-use by product group in Australia. Figures beyond 2013 are projections. *Source*: DIS 2015a

Factors contributing to energy use trends. The main factor contributing to the rapid increase in IT&HE energy use to 2011 was from the increase in TV ownership (from 1.7 in 200 to 2.2 in 2011) and purchase of larger flat screen TVs. At the same time, energy use of new TVs increased by over 50% from 2000 to 2008. However, due to the technological improvements in the efficiency of new TVs and the introduction of MEPS and labelling in Australia in 2009, the energy use per new TV has now declined to levels below those of the old screen technology used in the last century. Ownership of TVs has also declined to less than 2 per household in 2014 and is forecast to decline further with the change to portable devices for viewing of video by consumers. The forecast increase in energy consumption by TVs from 2020 is due to the increase in average size and number of higher energy consuming TVs, such as ultra-high definition.

Another factor reducing energy use is the increased use of laptop/notebook PCs and tablets which has led to the decline in total energy use by desktop PCs in households. Network devices (which are always connected and using power) are forecast to further increase their share of total IT&HE energy consumption as their numbers increase.

Conclusions

Residential energy use in Australia increased during the 2000s but then unexpectedly declined in recent years since 2008. The modelling reported in this paper explains the major factors contributing to the changes in electricity energy use in the residential sector and explores the impacts of these trends on forecast electricity use. There have been dramatic declines in the last five years in the electricity consumption in some end-uses, such as hot water, IT&HE and lighting, and even some decline in space conditioning energy use. With continued changes in types of equipment installed in households, and the improvements in efficiency being realised in the stock of equipment, total energy use is now declining and forecast to continue to decline till 2020, despite household numbers continuing to grow. Only after 2025, assuming no further regulatory or market changes occur to further increase appliance efficiency beyond assumed autonomous efficiency improvement, is total residential energy consumption expected to increase.

This change in energy consumption since 2008 was not forecast as forecasts based on historic trends could not anticipate the rapid changes in appliance efficiency, regulations and household appliance usage which have caused this change. The use of a bottom up detailed modelling approach has enabled the factors contributing to these changes in energy use to be understood and for forecasting to be improved. The rapid changes though also point to the need to regularly update such modelling if the resulting forecasts are to remain reliable.

The decline in total residential energy use seen in the last few years have been caused to a significant extent by the efficiency measures introduced by governments during the period 1999 to 2012. The largest regulatory impacts have been from MEPS for heat losses of electric storage hot water heaters, MEPS for lighting, and MEPS and Labelling for TVs, refrigerators/freezer and air conditioners. Significant impacts have also occurred due to state and federal government programs that encouraged the installation of efficient showers, solar/heat pump water heaters and efficient lighting.

Interestingly, these regulatory improvements have not focused on gas appliances and there has been no significant improvement in new gas appliance efficiency over the last 15 years. The potential for further energy savings via improving gas appliance efficiency may therefore exist.

References

AEMO (Australian Energy Market Operator) 2012, National Electricity Forecasting Report, Australia, Australian Energy Market Operator 2012, www.aemo.gov.au

ABS (Australian Bureau of Statistics) 2014, *Household Energy Consumption Survey (HECS)*, published as 4670.0 Household Energy Consumption Survey, 2012, Australia, Australian Bureau of Statistics. www.abs.gov.au

AccuRate software available from Hearne Software, www.hearne.software/Software/AccuRate-Sustainability/Editions

AGO (Australian Greenhouse Office) 1999, *Australian Residential Building Sector Greenhouse Gas Emissions 1990–2010*, Canberra, Australia, 1999, Australian Greenhouse Office , prepared by Energy Efficient Strategies. www.energyrating.gov.au

DEWHA (Department of the Environment, Water, Heritage and the Arts) 2008, *Energy Use in the Australian Residential Sector 1986–2020*, Canberra, Australia 2008, Department of the Environment, Water, Heritage and the Arts, prepared by Energy Efficient Strategies www.energyrating.gov.au

DIS (Department of Industry and Science) 2015a, *Residential Energy Baseline Study: Australia*, Department of the Industry and Science, Canberra, Australia, August 2015, Prepared by EnergyConsult. www.energyrating.gov.au

DIS (Department of Industry and Science) 2015b, *Australian Energy Statistics*, Canberra, August 2015, Department of Industry and Science. www.industry.gov.au

E3 (Equipment Energy Efficiency) 2014, *Impacts of the E3 program: Projected energy, cost and emission savings*, Commonwealth of Australia (Department of Industry) March 2014. www.energyrating.gov.au

EES (Energy Efficient Strategies) 2011, *The Value of Ceiling Insulation - Impacts Of Retrofitting Ceiling Insulation To Residential Dwellings In Australia*, Energy Efficient Strategies for the Insulation Council of Australian and New Zealand, 2011. www.icanz.org.au

Stern 2013, *Chapter 10: Peak Demand and Time-Differentiated Energy Savings Cross-Cutting Protocols*, The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures, US National Renewable Energy Laboratory, Frank Stern, Navigant Consulting, Subcontract Report NREL/SR-7A30-53827, April 2013.

Yuning Ou 2012, *Proposing a Bottom-up End-use Energy Model for Chinese Residential Sector at City-Level*, November 2012. Presented at PLEA2012 - 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture Lima, Perú 7-9 November 2012