INFLUENCES ON RESIDENTIAL UPTAKE OF DISTRIBUTED GENERATION AND ENERGY EFFICIENCY[1]

Passey, R.J.[1] and MacGill, I.F.[1]
[1]Centre for Energy and Environmental Markets
University of NSW
Sydney
r.passey@unsw.edu.au

ABSTRACT

A significant proportion of approaches to drive uptake of distributed generation (DG) and energy efficiency (EE) by end-users typically rely on a combination of price signals and information. These approaches are based on the assumption that, if exposed to appropriate price signals, and with access to relevant information, end users will make rational decisions regarding energy use. As a result, DG & EE (here termed Distributed Energy, DE) will be deployed to the extent they are financially beneficial for the end-user and economically beneficial for society.

However, a growing body of research indicates that end-user behaviour, especially in the residential sector, is much more complex than this and is influenced by the broader social context (here termed BSC) in which people live – which manifests in different behaviours, habits and practices shaped by factors such as socio-economic status, ethnicity, geography, fashion and other cultural considerations. A component of the BSC that we particularly wish to focus on, because it has a strong influence on end-users' energy demand and potential interest in DE, is the infrastructure that provides energy and energy services - termed the infrastructures of provision (IoP).

To examine how these influences affect end-user decision-making and therefore take-up of DE, we have used residential photovoltaics as a case study. Our findings indicate that (i) care should be taken when using generic financial costs and values to model uptake of residential PV, and (ii) taking the IoP and BSC influences into account will require an integrated mix of policies that goes well beyond simple price signals and information.

INTRODUCTION

Conventional approaches to value and model the deployment of Distributed Energy (DE)[2] predominantly have an economic and technology focus. The various sources of financial cost and value for different DE technologies are identified, then used to estimate the financial attractiveness of these DE technologies under current and possible future market and support arrangements. This information may then be used in the development of policy to drive deployment of DE, and especially to model the extent of deployment likely to occur.

---

[1] This work was funded by the CSIRO.

[2] DE includes both distributed generation and energy efficiency

The use of this type of approach is based on the assumption that, if exposed to appropriate price signals, and with access to relevant information, end users will make rational decisions regarding energy use. As a result, DE technologies will be deployed to the extent they are both financially beneficial for the end-user and economically beneficial for society.

However, social research indicates that end-user behaviour, especially in the residential sector, is much more complex than this and is influenced by the broader social context (here termed BSC) in which people live (Shove 2004; Southerton *et al.* 2004). Thus, end-users are not homogenous but rather exhibit a variety of characteristics that influence their energy demand and potential interest in DE. This is not simply a culmination of rational preferences but also reflects a variety of different behaviours, habits and practices shaped by factors such as socio-economic status, ethnicity, geography, fashion and a range of other cultural considerations, which tend to be communal rather than individual in character.

A component of the BSC that is particularly relevant, because it has a strong influence on end-users' energy demand and potential interest in DE, is the infrastructure that provides energy and energy services ie. termed the infrastructures of provision (IoP).[3] The IoP are defined here according to a broader definition of technology (IIASA 2006), such that it includes any *hardware* involved in the delivery of energy services (from electricity generation through to end-use equipment and housing stock) as well as the associated *software* (the knowledge to appropriately apply and use the hardware) and *orgware* (the associated commercial and governance systems and institutional frameworks and capacity to deploy and integrate the hardware).

Here, we have divided the IoP influences into three components:

i) Energy supply industry-related: Those more derived from the energy supply industry - for example, the options offered to end-users (prices, information & technology) as well as DE programs which influence end-user energy behaviour (both current energy use and interest in DE).

ii) Associated physical infrastructure: Those related to the infrastructure more closely associated with the end-user - for example, the nature of the housing stock and local government building regulations and requirements.

iii) Hardware-related: Those that are more directly related to the technologies themselves - for example, the cost, availability and operating characteristics of DE hardware.

The IoP sends conflicting signals to end-users. These include the energy market arrangements, economic incentives and information used to encourage people to reduce energy use and take up appropriate DE options, as well as the range of other 'signals' that encourage opposite behaviours such as increased energy use (eg. low off-peak hot water tariffs because they encourage electric resistance storage water heaters) or energy use at particular times of the day that may increase GHG emissions (eg. low off-peak hot water tariffs because they encourage coal-fired generation).

[3] Inherent in this approach is the recognition that the energy supply system is not simply responding to end-user demand, but also serves to shape it.

Note that not only are end-users influenced by the IoP and BSC, but end users also influence both the IoP and their social context, while the IoP and the social context influence each other. For example, end-users create demand for energy at particular times of the day (and so influence the required IoP), and of course make a significant contribution to their own social context. The IoP influence the social context in which energy decisions are made by, for example, delivering seemingly endless cheap energy in the absence of any immediately apparent negative impacts, thereby creating the perception that there is no need to reduce energy use. The social context influences the IoP because the IoP is developed and operated by people who live within that social context. For example, people are constantly exhorted by advertising to buy and consume more/better, endorsing increasing consumption (and therefore the need for constantly increasing supply) as exemplary rational behaviour – one consequence of which for the IoP is the focus on 'security of supply' rather than on 'security of energy services' (with the possibility of associated reduction in consumption).

A conceptual representation of the various influences on end-users is shown in Figure 1. The conventional price and information signals to end users are shown as being a subcomponent of the IoP, which in turn is shown as being a subcomponent of the BSC.

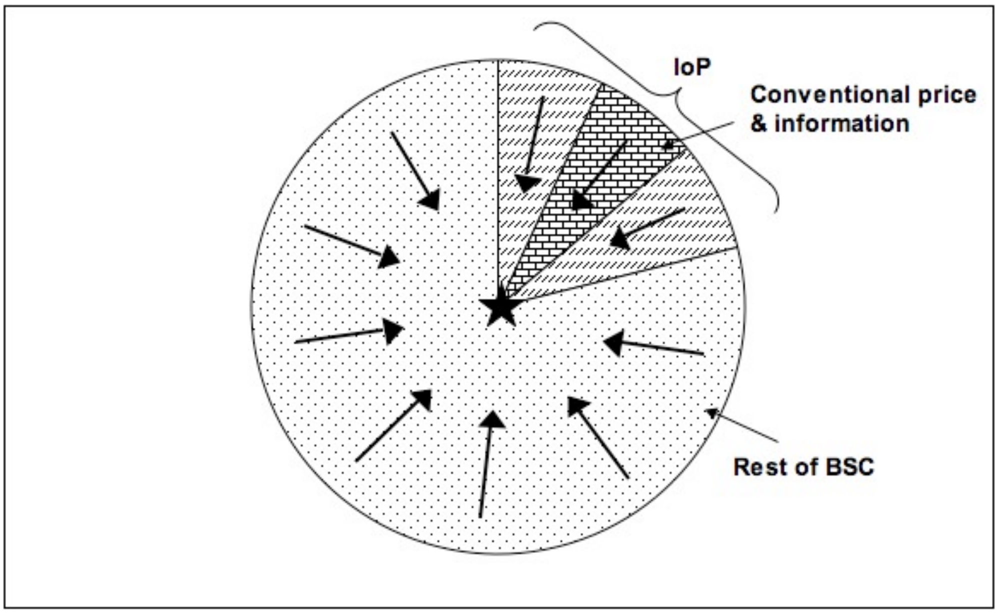

Figure 1 Conceptual representation of influences on end-users
Note that the arrows only represent the direction of influence on the end user, not the other influences from the end user to the IoP and BSC, nor those between the BSC and the IoP. The area taken up by each wedge is meant to be roughly proportional to the number of influences on the end user, not necessarily the strength of those influences.

Barriers to uptake of DE have traditionally focused on those directly related to price (eg. split incentives, access to capital, upfront costs vs long term payback and unpriced externalities) and information (eg. lack of awareness of EE potential, lack of information regarding energy use and EE options).[4] Interestingly, recent government efforts to drive energy efficiency in Australia recognise, in addition to these types of

---

[4] Note that because the IoP influences include all price signals and information derived from the infrastructure that provides energy services, they include such traditional barriers.

price and information barriers, many others that have IoP[5] and BSC[6] characteristics, although they are not identified as such (VEET, 2007; REES, 2008).

Thus, while there is a clear need for economic incentives and information to drive DE uptake, there is also a need for a better understanding of the broader IoP signals that impact on end-users, as well as how the BSC affects their decision-making. This understanding should:

i) Lead to the development of policy better able to drive effective and efficient uptake of DE; and

ii) Be useful for the development of electricity industry models, and models of individual and potentially coordinated end-user behaviour.

A behavioural decision-making focus

To illustrate the IoP and BSC influences on end-user behaviour (in particular their energy use and potential interest in DE), we have developed three case studies of selected energy services in the residential sector and three in the commercial sector.[7] In this paper, only the residential PV case study is presented. It was chosen because it not only illustrates the IoP and BSC influences on end-user behaviour, but because the Photovoltaic Rebate Program (PVRP) data make it possible to quantitatively examine the impact of these influences.

RESIDENTIAL GRID-CONNECTED PV SYSTEM CASE STUDY

This section firstly discusses the characteristics of, and resultant sources of costs and values for, residential PV – from the perspective of electricity generators, (electricity and gas) network operators and retailers, suppliers of demand-side hardware, and end-users.[8]

The reason for identifying these sources of cost and value is to characterise how they influence the various actors' decisions regarding residential PV. These decisions result in the energy industry stakeholders offering certain types of tariffs and products etc., and attempting to influence the policy development process, which in turn influences what is made available to end users.[9] Thus, they make a significant contribution to the

---

[5] That third parties such as builders, plumbers & electricians often make key decisions that affect energy efficiency, without consideration of the long term costs and environmental impacts, and the limited availability of relatively new and emerging energy efficiency technologies and services in the marketplace.

[6] The need for rapid replacement of appliances which perform essential services (fridges, water heaters) can outweigh considerations of energy efficiency or environmental impact; existing habits and values regarding energy use may lead households to not choose energy efficient options or change behaviours, even when market information is available to them.

[7] Residential water heating, Residential space heating and cooling, Residential photovoltaics, Commercial Heating, Ventilation, Air Conditioning (HVAC), Commercial Uninterruptible Power Supplies (UPS), Commercial and Industrial Combined Heat and Power (CHP) + cooling.

[8] Note that this is a qualitative assessment – hence the reference to *sources* of cost and value rather than the *actual* costs and values. The actual costs and values will change with respect to a number of different variables such as hardware, location and time, and as explained below, are of limited value in determining the level of deployment of the various types of DG and EE hardware.

[9] For example, electricity retailers in Australia have generally opposed gross FiTs, instead favouring net export FiTs.

IoP that affects end-user energy use and uptake of different energy technologies. This type of analysis also makes it clear that from the end-users' point of view, there are many different interdependent sources of cost and value, and this complexity in itself is a barrier to driving deployment of PV (if only because it complicates the decision-making process for end-users).

The section *Impact of Infrastructures of Provision influences* discusses the most significant impacts the various IoP influences (ie. those related to all three components: Energy supply industry, Associated physical infrastructure and Hardware) have on end-users considering installing a PV system, then discusses the nature of some resultant price sensitivities for end-users, and how they may influence uptake of residential PV. The section *Impact of Broader Social Context influences* then discusses the influences of the BSC factors on residential end-users' interest in PV, while the section *PV uptake in Australia as a case study* then examines the combined impacts of the IoP (which includes the PVRP) and BSC influences.

Characteristics and resultant energy production

Grid-connected PV generally does not include any storage and so electricity can only be produced when solar insolation is available. PV output can offset conventional generation or high-cost peaking generation depending on when it occurs. To the extent that its output can be relied upon at particular times in the future, PV can defer augmentation of generation and/or network infrastructure. PV output can reduce line losses - the greater the correlation with load, the greater the reduction in losses.[10] PV exported to the grid can also influence power quality and reliability.

A particular PV system's ability to provide all these attributes, as well as their values, will be influenced by a number of factors including local and network-wide loads, the costs and availability of conventional generation, and the orientation, location, temperature, shading and maintenance of the panels and balance of system equipment (Passey et al. 2007).

PV can only export to the grid when the household load is less that the PV system's output.[11] While a PV system's average output over a year is a fairly predictable dome shape, its output on a particular day can be quite variable. Similarly, the load profile at a particular household can vary quite significantly from the network average. Since a particular system's export to the grid is a function of both these profiles (ie. PV output minus load), it is even more variable. See, for example, Figure 2, where export occurs only when the offset line goes below zero.

[10] PV's ability to provide these values is independent of whether it is exported to the grid or used on-site.

[11] In some locations (eg. Qld) a PV system exports all its output directly to the grid and so technically, the PV export profile is the same as the PV output profile. In these situations, all PV output can contribute to power quality impacts.

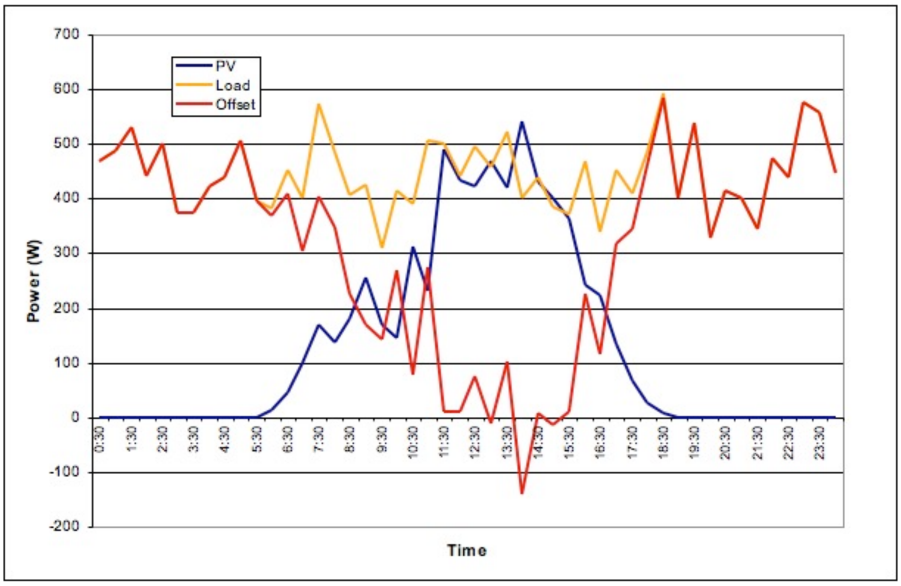

Figure 2 Single residential 1kW PV - output, load and offset load
Newington household, 2nd Dec 2004, (derived from data associated with Watt et al. 2006)

Sources of cost and value for stakeholders

Electricity industry

The various sources of cost and value for PV include the following: [12]

Baseload generators: could be negatively affected by PV at significant levels of deployment (because of possible movement down the dispatch stack to a lower dispatch price, or reduced projections for demand growth).

Peaking generators: could be negatively affected by PV (at significant levels of deployment) to the extent that it correlates with times of network-wide peak demand (because of reduced sales and possible movement down the dispatch stack to a lower dispatch price, or reduced projections for demand growth).

Distributed Network Service Providers (DNSPs): could possibly be negatively affected by PV to the extent that it affects the power quality and integrity of their network. They could be negatively affected by reduced transmission, although this depends on whether financial compensatory measures are in place. They may be positively affected (at significant levels of deployment) to the extent that PV can defer network augmentation and improve power quality. The impact on DNSPs revenue also depends on the extent to which the connection costs charged to customers cover or exceed the deep and/or shallow connection costs incurred by the DNSP.

Retailers: the net impact of PV will be determined by the difference in the cost the retailer pays for the electricity the PV system produces and the cost the retailer pays for electricity produced by conventional generation, including all passed on charges (such

[12] The degree to which a particular generator, DNSP or retailer is affected will be determined by a range of factors including its contracts and hedging in place, and the degree to which costs can be passed on. These impacts are discussed here simply to highlight the fact that, at relatively high levels of penetration, different hardware options can influence a utility's cashflow in different ways.

as TUOS and DUOS charges)[13] and assistance with compliance with government targets such as MRET. If a FiT applies, it may be paid for through some form of levy on either DNSPs or the retailer, and in both cases this cost would most likely be passed on to end-users.

Natural gas industry

The installation of PV is unlikely to have any significant impact on the natural gas industry because PV-derived electricity is unlikely to be a preferred choice to displace gas-fired heating (water, space or cooking). In fact, conversion from electricity to gas would decrease on-site electricity use and so increase the amount of PV-derived electricity available for sale.

End-users

Hardware purchase costs

The hardware purchase costs for a PV system include the panels and any required mounting as well as Balance of System (BOS) components – such as the inverter and wiring. According to PVRP data, these are currently averaging around $13,000 per kW before any government assistance is included (PVRP 2006). Installation of systems in remote areas are likely higher, with anecdotal evidence suggesting $14,000 to $15,000 per kW.

Connection to the grid can incur additional costs payable to both the DNSP and the retailer. These can range from around $100 to over $1,000 depending on their connection requirements, and whether the connection is single phase or three phase.

There are a number of special deals offered both by retailers as well as by independent installers where a 1kW system can be as low as $895.[14] In addition to government rebates, these very cheap offers seem to rely on bulk purchase to keep down costs. Connection costs, such as an extra meter, would be additional.

Reduced energy costs

Most states currently use net metering where energy produced by a PV system then used on-site is effectively paid the retail tariff, and energy exported into the grid is generally paid the retail tariff minus GST. The retail tariff is generally a flat tariff but may be a Time of Use (ToU) tariff, in which case, depending on its structure, a system owner may be paid a higher rate during times of PV output.

South Australia, Queensland and Victoria have announced feed-in tariffs (FiTs) based on net export to the grid, while the ACT and Western Australia have announced gross generation FiTs, and the Commonwealth has expressed a desire for a nationally consistent FiT. As shown in Figure 2, it is very difficult to predict the level of net export because this is affected by the variability of both the PV output and the load. Analysis based on the Newington Olympic Village indicates that an average house with a 1kW system (the maximum size that receives the full PVRP, and the likely maximum size for Solar Cities installations) would have very low levels of net export and so is unlikely to generate much income (PVPS/CEEM 2007). Of course, houses that have low energy

[13] Transmission Use Of System and Distribution Use Of System

[14] For example, see http://www.beyondbuildingenergy.com/solarneighbourhoods.php

use throughout the day should have higher levels of export, and a net export approach may encourage energy efficiency – although this is likely to emphasise just shifting demand to later times in the day.

Environmental and other attributes

In addition to the FiT approaches outlined above, residential grid-connected systems are eligible for the PVRP (currently $8/W up to a maximum of 1kW, subject to a means test). They can also create RECs[15] which may be used to offset some of the hardware purchase price or may be sold to the electricity retailer. They can also create GreenPower Rights (GPRs) if the retailer wishes to sell the generated electricity as GreenPower, however these are in the process of being phased out. PV can also provide value by helping compliance with schemes such as BASIX.

Impact of Infrastructures of Provision influences

The most significant IoP-related influences on residential grid-connected PV systems, in addition to any direct government policies (eg. PVRP, BASIX etc.), are currently;

Energy supply industry-related:

i. the nature of the tariffs applied to electricity used on-site and exported eg. flat rate, ToU, types of FiT,
ii. the costs of connection as well as the administrative difficulties in getting connected,

Associated physical infrastructure:

iii. whether the householder owns the premises,
iv. solar access, both at the time of installation and in the future, and
v. State and local government building regulations and requirements.

Hardware-related:

vi. high capital cost of PV systems,
vii. availability of systems and personnel to install them.

Resultant price sensitivities for residential PV

The key price sensitivity for householders will be the payback time of the PV system and associated costs, presumably based on predicted energy costs.

Warranties on PV systems are generally around 20 years, although some systems are now entering the market with warranties as low as 10 years. Warranties on inverters are generally around 10 years. Householders may expect the system to pay itself off in that time, including all connection costs and a possible replacement inverter.

As can be seen from the above, the actual payback time will be directly influenced by a number of variables (points i, ii, iii and vii) and so there is no single ‘price sensitivity’ that can be applied across the board, ie.

- Original situation

[15] Here RECs are taken to include the VRECs and NRECs associated with the Victorian and NSW RE target proposals – which may not be implemented if MRET is expanded.

  - o whether the homeowner was on a particular type of tariff prior to system installation,
  - o demand profile prior to system installation, and.

- New situation
  - o the cost of the system including connection costs,
  - o whether a replacement inverter is needed,
  - o whether the homeowner is on a particular type of tariff after system installation,
  - o demand profile after system installation, and
  - o the availability of rebates etc.

Thus, the sum of the various costs and values is most likely to produce a bell-shaped distribution curve of payback times across the population. For a particular end-user the curve could be quite different, and could change with time as their personal circumstances and finances change.

Impact of Broader Social Context influences

The various BSC influences can have a further impact on end-users' energy use and interest in residential PV. While the PVRP was around $4/W, a 1kW system was unlikely to pay itself off during its lifetime, especially if discounting was applied. Systems over 1kW would take even longer to pay back because the PVRP only applied to the first 1kW. However, despite this lack of financial viability, over the last 15 years, the rate of installation of grid-connected PV has steadily increased each year, with over 15,000 kW installed by end 2007 (Watt 2008). This has been for a number of reasons that can be classified as BSC ie.

- People like having the electricity meter spin backwards
- People like the feeling of 'independence'
- Because of altruism and simple ideological support
- Because ownership can be seen as a sign of wealth

Conversely, many people are unlikely to install a PV system, even when they are financially viable ie.

- Because of ideological opposition
- Because of aesthetic values
- People tend to discount longer-term benefits more than is realistic
- Because they just don't 'get around to it'

In addition, the IoP influences that are less related to price impacts and more related to physical infrastructure, local regulations and personnel (points iv, v, vi and viii above), will also have an impact on an end-user's interest in PV as well as its feasibility.

As a result, the bell-shaped distribution curve of payback time referred to in the previous section cannot be assumed to be equivalent to a curve representing end-users' interest in residential PV. A hypothetical 'interest in residential PV' curve would have an entirely different shape which would be different for different end-users and would also almost certainly change over time as their personal circumstances changed.

PV UPTAKE IN AUSTRALIA AS A CASE STUDY

The installation rate of PV systems that receive the PVRP provides an interesting real-life example where both the uptake of a particular DG technology, as well as its cost to the owner, have been tracked over time (based on PVRP data). This allows the correlation between rate of technology uptake and costs to be compared, with variations from a direct correlation presumably due to other IoP, as well as BSC, influences.

The value of the PVRP started at $5.50/W in Jan 2000, was reduced to $5/W in Oct 2000, then reduced to $4/W in May 2003, then increased to $8/W in July 2007. The total cost of system installation has also changed over that time. Figure 3 compares the watts installed each month with the final system cost paid by the system owner after the PVRP rebate, from the scheme's commencement in Jan 2000, through to June 2006.

In some cases, there does appear to be a correlation with price – for example in 2001 to early 2002 as installations drop and the price increases. Then in 2002 as the price drops, installations increase. In May 2003, installations drop as the rebate drops to $4/W. However, from then on, there are times when the installations halves or doubles with little change in price. In addition, the changes in installations in 2001 and 2002 seem to reflect more than the relatively small changes in price. Interestingly, the 50% drop in installations from May 2003 doesn't appear to coincide with a significant increase in the final cost seen by the system owner, but instead, may correspond more to a psychological response to the rebate decrease.

As can be seen in Figure 4, increasing the PVRP rebate to $8/W in July 2007 had a marked impact on interest – increasing it by 3 or 4 fold as the final price to the system owner dropped to around $5/W. At this price the system should pay itself off well within its lifetime (assuming no discounting) and in 20 years (assuming a 7% discount rate). It is likely that a further increase in the PVRP would result in a further increase in interest, while a decrease would have the opposite effect. Thus, rather than a particular price trigger point for sudden and significant uptake of residential PV, there is likely to be a graduated ongoing price responsiveness i.e. as the price decreases, there is an increase in interest. However, this correlation may not be linear. The current rate of uptake driven by the $8/W PVRP may only be in specific segments of the population, and so could be of limited duration. At some point it is likely that even with free systems, not everyone would install them. This could be for a variety of reasons as outlined above including; not being an owner/occupier (IoP), not having solar access (IoP), and being ideologically opposed to PV, despite the financial benefits (BSC). Note that such widespread deployment of PV is also likely to be opposed by network operators because of real and perceived interference with their networks (IoP).

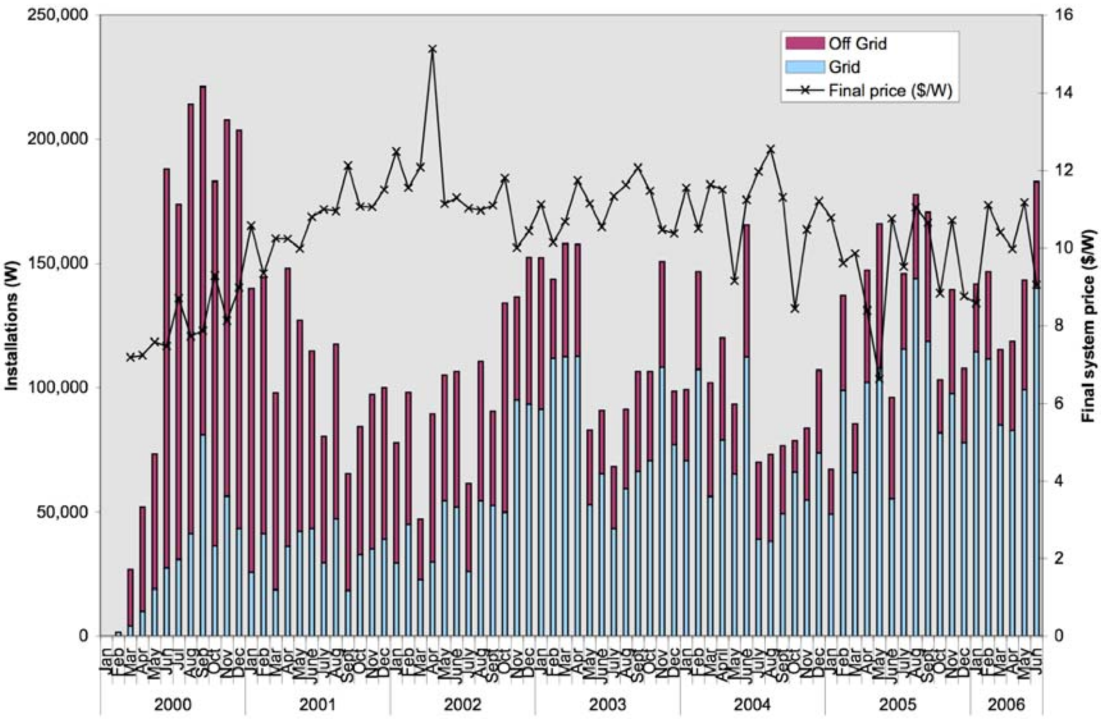

Figure 3 Watts installed by month, and cost paid by system owner, Jan 2000 to June 2006, for systems receiving the PVRP, from PVRP (2006)

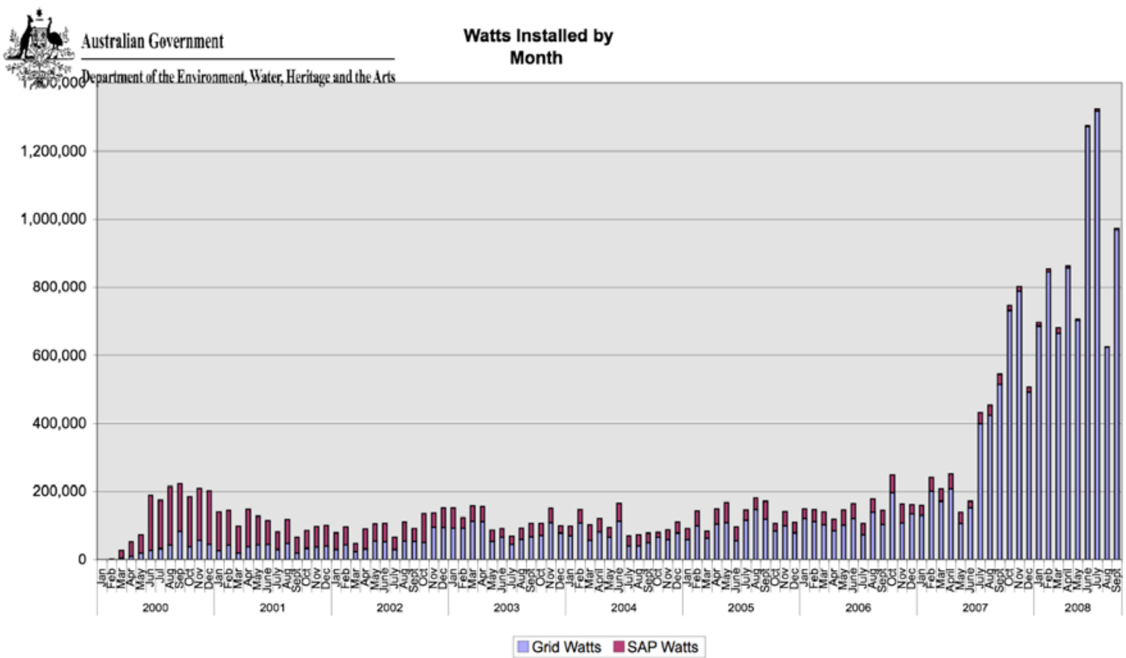

Figure 4 Watts installed by month, Jan 2000 to Sept 2008, for systems receiving the PVRP, from AGO (2008)

DISCUSSION

There appears to be significant value in evaluating end-user interest in PV with a behavioural or decision-making focus, not only with a technical and/or economic focus. The relevant decisions made by end-users are not necessarily rational (especially with regard to maximising economic outcomes), are strongly influenced by the infrastructures that provide energy services (IoP), and are also affected by the social context in which they are made (BSC). The financial outcomes of a PV installation are therefore only one influence on the decision to install or not.

Note that in the model used here, the IoP includes all the technologies (which includes orgware, software and hardware components) that provide energy services – ranging from electricity generators through to end-use equipment and even housing stock. The IoP's influence occurs through a number of avenues including the mix of energy-related information and price signals delivered to end-users, any associated policies, the personnel needed to install the system, as well as the relevant physical infrastructure such as the house on which the system is to be installed. These manifest in particular costs and values for end-users and can also affect the feasibility and ease of installation. The BSC influences are harder to define but essentially contribute to each individual's personal preferences, which in turn affect their responses to the IoP influences, and resultant level of interest in PV. They also affect the nature of the IoP and vice versa.

Thus, the two broad conclusions that can be drawn from this research are:

(i) Care should be taken when using generic financial costs and values to model uptake of residential DE. While there may be an average cost-responsiveness, this is of unknown duration, for an unknown cost range and could change over time as circumstances change.

(ii) Policy used to drive uptake of DE needs to be developed with the IoP and BSC influences in mind, not only rely on selected information and price signals to promote rational responses in what is assumed to be a perfectly functioning energy market. This is not to say that information and price signals are unimportant. Rather, because of the complexity of the IoP and BSC contexts in which decision-makers operate, and the resulting variety of influences on them, a number of coherent policies within an integrated energy policy framework are likely to be required to drive effective and efficient deployment of DE.

REFERENCES

AGO (2008) *Watts installed by Month* spreadsheet available from http://www.environment.gov.au/settlements/renewable/pv/index.html

IIASA (2006) *What is Technology?* from http://www.iiasa.ac.at/Research/TNT/WEB/Page10120/page10120.html?sb=5

Passey, R., Watt, M., Outhred, H., Spooner, T. and Snow, M. (2007) *Study of Grid-connect Photovoltaic Systems – Benefits, Opportunities, Barriers and Strategies*, for The Office of Energy, Western Australian Government.

PVPS/CEEM (2007) *Submission to the Government of South Australia: Discussion Paper on South Australia's Feed-in Mechanism for Residential Small-Scale*

Photovoltaic Installations, February 2007, by the Australian PVPS Consortium and CEEM UNSW.

PVRP (2006) PVRP statistics provided by the AGO for the 2006 PVRP Review.

REES (2008) *South Australian Energy Efficiency Scheme Consultation Paper, February 2008*, Department for Transport, Energy and Infrastructure, South Australian Government.

Shove, E. (2004) Efficiency and Consumption: Technology and practice, *Energy & Environment*, 15, p1053-1065.

Southerton, D., Chappells, H. and Van Vliet, B. (2004), *Sustainable Consumption – The Implications of Changing Infrastructures of Provision*, Edward Elgar Publishing, Cheltenham.

VEET (2007) *Victorian Energy Efficiency Target Scheme: Issues Paper*, Department of Sustainability and Environment and the Department of Primary Industries, Victorian Government.

Watt. M. (2008) *National Survey Report of PV Power Applications: Australia 2007*, for the IEA Co-operative Programme on Photovoltaic Systems.

Watt. M., Passey, R., Barker, F. and Rivier, J. (2006) *Newington Village: An analysis of photovoltaic output, residential load and PV's ability to reduce peak demand*, a report for the NSW Department of Planning.

BRIEF BIOGRAPHY OF PRESENTER

Dr Robert Passey is a Senior Research Associate with CEEM. He also works as an occasional consultant for selected clients, and as a casual academic for the Centre for Photovoltaic Engineering (UNSW) in the areas of Renewable Energy and Climate Change Policy, Building Integrated Photovoltaics, Life Cycle Analysis, and Energy Efficiency. Robert specialises in energy policy research and analysis, spanning a broad mixture of renewable energy technologies, energy efficiency, climate change, and carbon capture and storage. Specific interests include market mechanisms to reduce greenhouse emissions and increase penetration of low emission technologies.