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The implications of mandating photovoltaics on all new homes

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Abstract

The transition to near zero energy and near zero carbon homes places the policy focus firmly on the widespread application of renewable energy technologies by the mainstream building industry. This systemic change from typical business practices for house design and construction to embrace the application of photovoltaic technology is likely to come with significant risk to policy outcomes. Using evidence drawn from a reasonably large near zero energy housing estate in Australia, the use of building energy regulations to facilitate the application of photovoltaics may not deliver the expected policy outcome. Lessons learnt from Australia point to issues related to regulatory design, industry training, and compliance assessment. Addressing these issues will be essential to achieve low carbon policy intentions.

Peer-review under responsibility of KES International

Keywords: Photovoltaics, energy policy, building energy modelling, zero energy homes

1. Introduction

The application of renewable energy technologies for new housing is recognised by many governments as a key policy action to address the greenhouse gas emission impact of urban development. The concept of zero energy or zero carbon homes has become a core policy goal for many nations, primarily to be enforced through changes to building regulatory codes and standards.

Engineering modelling and numerous case studies demonstrate that passive design strategies combined with energy efficiency appliances and equipment can reduce household loads to the extent to which they can be fully provided by photovoltaics or other renewable energy technologies [1].

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But is there a likely performance outcome difference between purposefully built test buildings or building energy modelling and the reality of mass produced housing, albeit housing built to a zero energy standard? Post-occupancy studies [2, 3] have found a significant difference between the expected performance of low energy use buildings and the reality of the human constructed built form, filled with the unpredictability of actual human behaviour.

What are the policy implications from mandating photovoltaics on all new homes? How can policy makers ensure that policy intent (contribution from solar) is achieved through the mass construction of near zero energy homes covered with rooftop photovoltaics?

This study utilises monitored electricity generation data and associated surveys from a relatively large near net zero energy estate to demonstrate the likely energy outcome from larger-scale estate construction, and answers the research question: what are the policy implications from mandating photovoltaics for new homes. From this case study the research identifies problems of underperformance relating to installation faults, building design issues, and the characteristics of urban estates, and points to approaches that can help policy makers achieve the desired outcome.

2. Background

The installation of photovoltaic systems on residential buildings is firmly on the policy agenda with house energy regulatory policy in many countries moving towards zero energy or zero carbon standards [4]. For example: in the United Kingdom the target has been set at net zero carbon for new dwellings by 2016 [5]; and in Europe the EU Directive on the Energy Performance of Buildings [6] specifies that by the end of 2020 all new buildings shall be ‘nearly zero energy buildings’ [7].

Near zero energy homes are not uncommon with case studies found in many countries. For example, the International Energy Agency’s “Towards Net Zero Energy Solar Buildings” project mapped almost 300 net zero energy and energy-plus buildings worldwide [8]. And although there have been many post-occupancy studies for low carbon and near zero energy homes that utilise photovoltaics, much of this research has focussed on either single home [3, 9-12], or multi-unit designs [13, 14] developed by highly motivated design and construction teams. Little is known of the performance of near zero energy homes created en-masse under typical regulatory enforcement processes without the support of highly motivated experts.

Similarly, there have been many engineering and architectural based studies examining the potential for zero energy or zero carbon homes in many climates [15-19]. But these theoretical studies do not take into account the reality of installing photovoltaic arrays on an estate-wide variety of rooftops that may be less than optimal in orientation or pitch to maximise electricity generation, the likely impact of human installation processes, and the likelihood of landscape or adjacent built form impacts that may cause partial over-shadowing of the solar systems. This gap in the literature has policy implications, whereby engineering calculations are likely to overestimate the actual energy benefits and greenhouse gas emission savings due to the mass rollout of photovoltaic technology through building energy codes and standards.

Compliance to regulatory codes and standards is an ongoing issue for the building sector [20-22], and there is no reason to assume that compliance to energy provisions would be treated differently by the building industry. Investigations into compliance with building regulatory standards in Australia have identified problems such as the use of non-compliant products, inadequate documentation, and insufficient auditing to test compliance. For example, the Victorian Auditor-General noted that in 2010–11, although 106,788 building permits were issued by over 500 building surveyors, only 40 onsite building audits were conducted, a number too low to ensure widespread compliance with the published standards [20].

Associated with compliance issue is the lack of mandatory post-construction commissioning processes for new homes, whereby although qualified persons are required to declare that the building has been constructed according to local building standards, no person is required to test and declare that the building or its energy systems are performing according to design expectations [22]. For example, a qualified electrician is required to test and declare that all electrical systems meet published electrical safety standards, they are unlikely to be required to check that the photovoltaic system is operating at the expected/designed performance level.

3. Case study

The Lochiel Park Green Village in South Australia has been chosen as the case study due to: (a) the relatively large size of the sample set; (b) the quality and detail of electricity generation data available; (c) the application of a building energy regulation to deliver the policy goal of near zero energy performance.

Lochiel Park is a suburban estate of just over 100 near zero energy homes [23]. The energy used and electricity generated at each house is being monitored and analysed to facilitate our understanding of the energy impacts of near zero energy homes. Appliance and equipment audits, and user interviews have also been conducted to extend our knowledge of the energy service expectations and experiences of contemporary digital-age lifestyles. All homes at Lochiel Park are designed to meet typical household energy services using mandated energy efficient and renewable energy technologies published in the Urban Design Guidelines [24]. The minimum requirements include:

- 7.5 NatHERS Stars thermal comfort (i.e. <58 MJ/m^2 per annum to maintain thermal comfort)
- Solar water heating, gas boosted
- 1.0kW$_p$ photovoltaic system for each 100m^2 of habitable floor area
- High efficiency air conditioning systems
- Ceiling fans in all bedrooms and living spaces
- Energy efficient lighting (i.e. compact fluorescent lamps CFLs or light emitting diodes LEDs)
- An in-home energy feedback display

The Urban Design Guidelines established a new set of rules, calling for practices outside existing institutional and professional norms, requiring the application of technologies and systems, including the integration of solar systems, uncommon within the local building industry at the time [23]. The average floor area for homes at Lochiel Park is 203.3m^2, similar to the 2008/9 South Australian average for new homes, of 199.3m^2 [25]. The local climate is temperate (Mediterranean) with mild winters and relatively hot summers reaching peaks over 35°C. Analysis on the overall performance of the homes [26], and the response of the Lochiel Park households to near zero energy housing [27] has been published by the authors. It should be noted that although the Urban Design Guidelines established a single set of rules for the design and construction of all homes in the estate, neither user behaviour nor the appliance fitout could be regulated, leading to a significant variation in total energy use [27]. The mandatory inclusion of an in-home energy feedback display helps households understand the impact of their behaviour [28].

NatHERS thermal simulation ratings are based on annual sum of the heat energy required to be added or removed to maintain thermal comfort due to building design and construction characteristics, local climate data and standardised user behaviour patterns. Note that the current building code requires all new house to be designed to achieve a rating of 6 stars, which is equivalent to 96MJ/m^2 for the Adelaide climate zone. Further detail on the NatHERS thermal comfort energy rating scheme is available at [29].

4. Results and discussion

All homes at Lochiel Park are required to have photovoltaics (PV) systems, and whilst the minimum requirement for solar photovoltaics is 1.0kW$_p$ per each 100m^2 of habitable floor area many of the households have chosen to increase their generation capacity slightly above the minimum. The average size for all systems is 2.47kW$_p$, with the smallest system capacity 1.5kW$_p$ and the largest 4.2kW$_p$. Approximately 40% of all systems use the amorphous cell type, whilst the remaining 60% use crystalline structures. The sample size of monitored homes (n) changes each year as new homes are added to the estate and the monitored data becomes available.

4.1. Solar radiation

Figure 1 shows the monthly mean daily global solar exposure collected by the Bureau of Meteorology for a 4 year study period 2011-2014. The data demonstrates a reasonably consistent seasonal pattern for solar radiation associated with a site latitude 34.9° South of the equator, with maximum solar energy during the summer period December-January and significantly lower available energy during the winter period June-July.

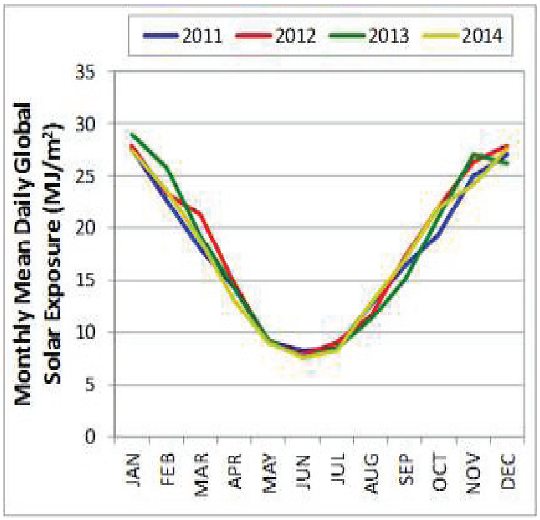

Figure 1: Global solar 2011-2014

4.2. Electricity generation

The monthly mean daily electricity generated from the photovoltaics, shown in Figure 2 (n=24), indicates a similarly consistent seasonal pattern with maximum generation during the summer months. The annual mean across the four years for this sample is 3,324kWh per household, with a standard deviation of 71.5Wh, and a coefficient of variation of 0.022. The March 2012 generation result is unusually high, a feature that is noticeable across the results from almost all households. Any degradation of the photovoltaic systems over this timeframe is masked by the size of natural annual variations.

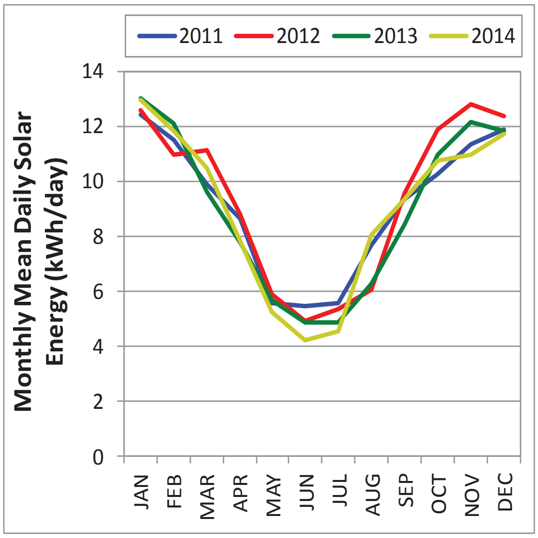

Figure 2: Average monthly PV generation 2011-2014.

The PV systems generate on average the equivalent of 43% of total annual operational energy demand and 65% of total annual electricity needs [26], although the timing of daily demand and generation results in most homes supplying excess power to the electricity grid during daylight hours and drawing back at other times. For some homes the PV system provides more than total annual electricity needs, with daily excess sold to the local network.

Examining the average monthly total delivered energy for the homes, the portion of energy supplied by the solar photovoltaic systems varies from around 80% in summer to a low of around 15% in winter [26]. Figure 3 shows the seasonal contribution for solar generation and delivered energy (electricity and gas) from the local grid.

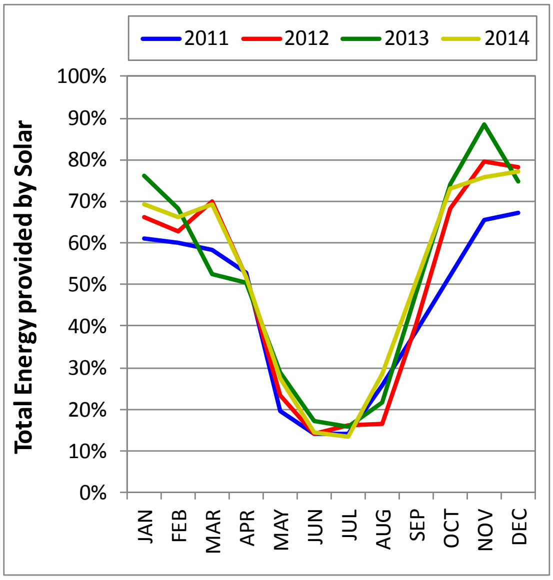

Figure 3: Solar energy portion of total monthly energy use

4.3. System efficiency

Across the case study estate (n = 43) the average size of the photovoltaic system is 2.47 kW_p, producing approximately 3,458 kWh/yr. The efficiency for individual photovoltaic systems is related to a number of factors including the type of panel, elevation (tilt angle), panel orientation, and the incidence of shading from nearby obstructions, although great care was taken during the initial development planning stage to reduce the impact of trees on rooftops?. Figure 4 shows the performance range for a sample of monitored homes for a 12 month period.

Whilst the average generation performance for the systems is 1.40kWh per peak watt installed ($R^2 = 0.6482$), it is noticeable that some systems are greatly underperforming due to system faults, poor orientation, over-shadowing or other installation problems, examples of fault detection and output power improvements are discussed by Whaley et al. [27]. The reality of a large scale roll out of rooftop photovoltaics is that orientation, elevation, and the incidence of shading will often vary away from optimal performance. And although the potential for this type of photovoltaic technology at this latitude is arguably higher at around 1.53kWh per peak watt installed, the policy outcome as designed is likely to be closer to an average of 1.39kWh per peak watt installed.

The Urban Design Guidelines set a system minimum capacity requirement for the photovoltaic system of 1.0kW_p for each 100m^2 of habitable floor area, without prescribing orientation or tilt angle requirements. The alternative of an installed system performance standard which sets a minimum expected electricity generation output after considering panel orientation and tilt, rather than a minimum system capacity requirement, may have resulted in a more predictable and reliable electricity generation outcome.

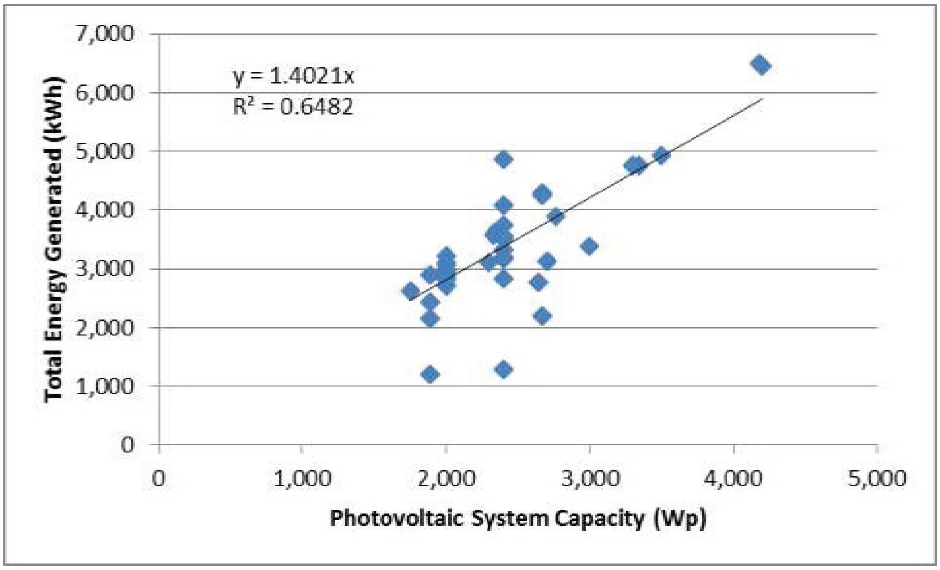

Figure 4: Annual energy generation versus photovoltaic system capacity for homes in Lochiel Park

4.4. Installation problems

The evidence from Lochiel Park shows that a small number of photovoltaic systems were incorrectly installed, with some systems having a number of solar panels not contributing to electricity generation through the DC/AC inverter. Figure 5, which shows the electricity generation from Households K and Z for the study period, highlighting the relative underperformance during 2012, and an approximate increase in gross electricity generation during 2013 due to the rectification of a system faults [30]. A simple commissioning process post-construction is likely to have identified this type of fault, and led to system rectification prior to building regulatory compliance sign-off.

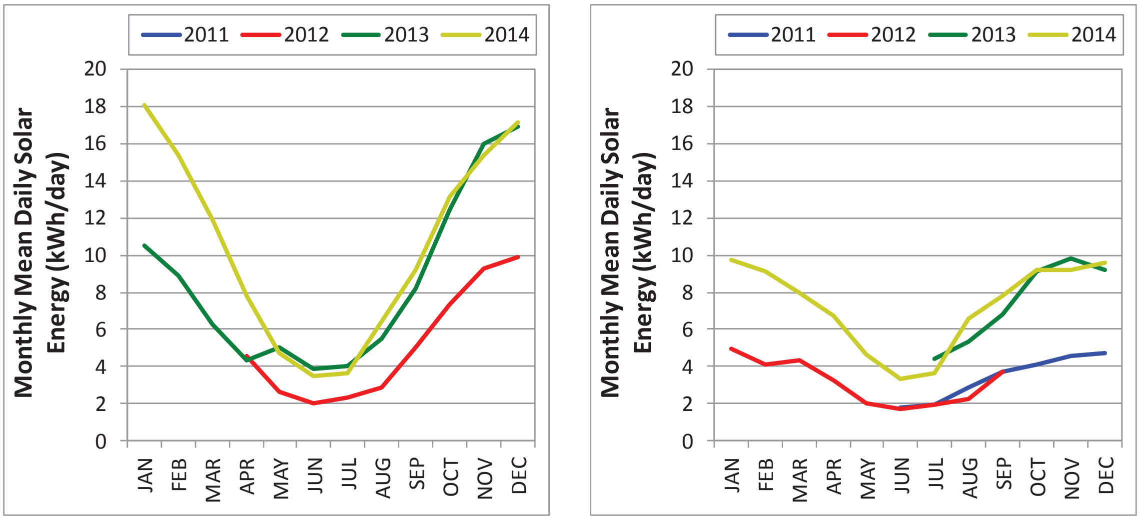

Figure 5. Monthly solar generation Household (left) K, and (right) Z

4.5. Peak demand management

The integration of photovoltaics into mainstream housing reduces both total annual delivered energy use and the rate of delivered energy demand at different times. For example, the electrical energy used during extreme climatic events such as a summer heatwave reflects higher demand for thermal comfort energy use (air conditioner usage) and without on-site electricity generation may place stress on the local electrical grid [31]. Figure 6 shows that for a 2 day heat wave event energy use increases gradually from the overnight low to a peak in the early evening. During the daylight hours solar generation offsets much of the electricity used, but on sunset without solar generation the net electricity demand spikes to a peak at around 18:30pm, before gradually reducing as thermal comfort energy demand decreases with the lowering of outdoor air temperatures through the night. Due to on-site photovoltaic generation, the timing of the peak draw on the local electricity supply network by Lochiel Park homes is delayed by several hours, easing stress on the local grid.

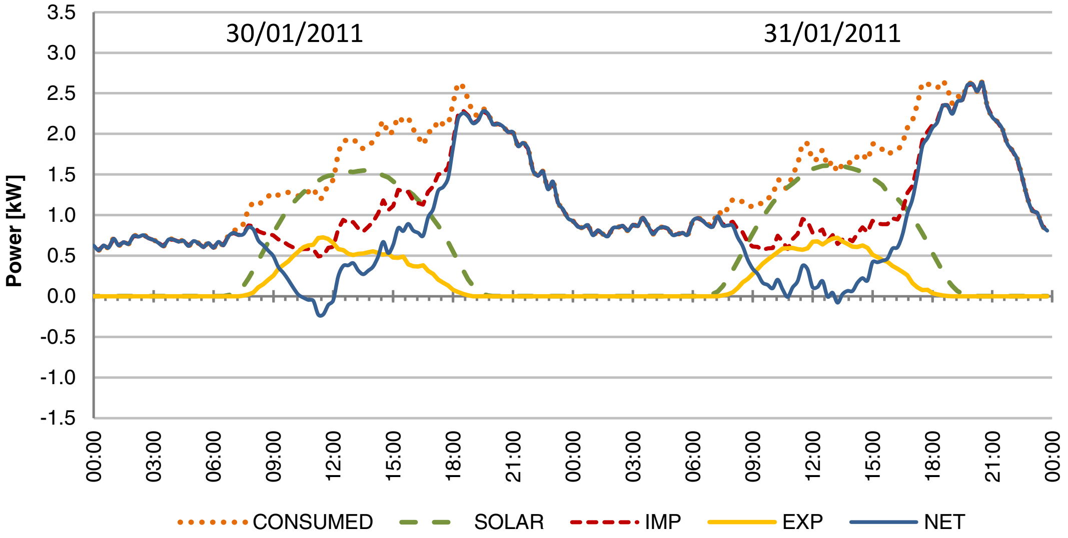

Figure 6: Average consumed, solar, imported, exported, & net electrical power profile for a two-day period
Reproduced from [31]

The length of the extreme climatic event influences the amplitude of the peak electricity demand. Figure 7 shows that during a summer heatwave of four consecutive days (n = 27), the average net draw on the electricity grid increases, possibly as the buildings struggle to shed excess heat and more cooling energy is required to maintain thermally comfortable conditions. This can be seen by the gradual increase in overnight energy demand, probably due to increased use of ceiling fans, air conditioning and a higher frequency of refrigeration cycling.

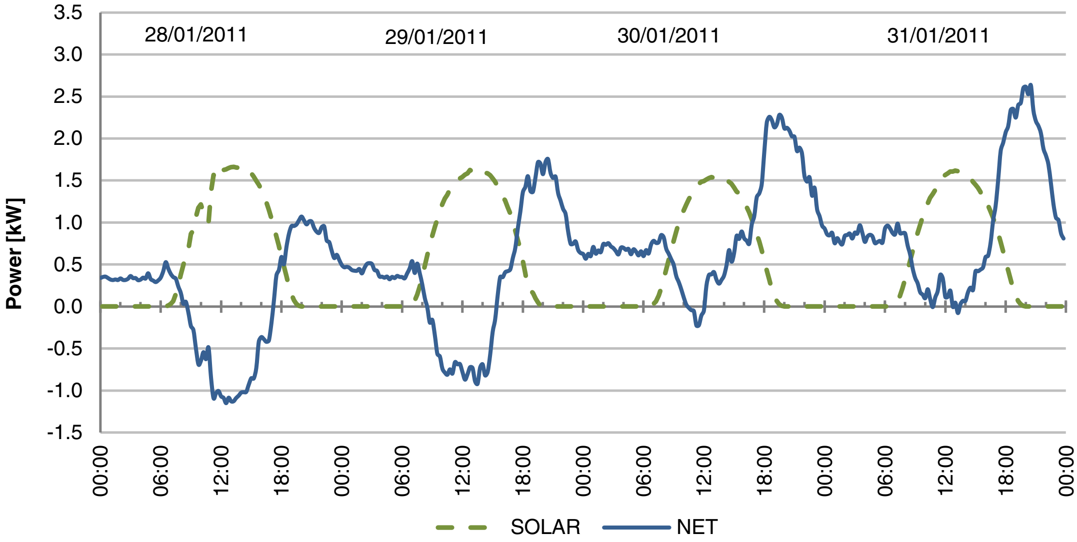

Figure 7: Average solar and net electricity power profile for the hottest four-day period of 2011
Reproduced from [31]

5. Conclusion and policy implications

Photovoltaics are expected to be commonly integrated into mainstream housing as a key industry response for the transition to near zero energy and near zero carbon building standards. And while we may expect less than optimal performance from the retrofitting of solar technologies onto existing rooflines, with new build there is an expectation of higher performance outcomes.

The results from a near zero energy estate demonstrates that there may be a range of issues that result in less than optimal performance, in particular problems associated with installation faults, less than optimal orientation and tilt angles, and over-shadowing from existing trees and built structures.

From a policy perspective there are a number of actions that can address these problems. Evidence from the case study indicates that a performance outcome-based standard rather than a system capacity-based approach could lead to a more predictable and consistent electricity generation and carbon reduction outcome. Mandatory commissioning may be a useful tool to facilitate correct installation, and further training and guidance may help improve the skill of building design practitioners to optimise building design to maximize the effectiveness of solar technologies.

The transition to near zero energy homes is likely to have significant additional benefits, with the evidence from the case study demonstrating the potential for peak energy demand benefits due to the application of PV, which could reduce the need for electricity network infrastructure investment. In the context of climate change and the resultant increase in extreme climatic events, the wide-scale application of PV may provide substantial network benefits.

The lessons learnt from case study estates such as Lochiel Park provide strong guidance for policy makers involved in the delivery of near zero energy and near zero carbon building standards, and further research trialing industry training and compliance commissioning processes will help policy makers identify successful strategies for the large-scale roll-out for photovoltaic systems by the building sector.

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