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Searching for public benefits in solar subsidies: A case study on the Australian government's residential photovoltaic rebate program

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ABSTRACT

The Australian Government ran a renewable energy program in the 2000s that provided rebates to householders who acquired solar Photovoltaic (PV) energy systems. Originally called the Photovoltaic Rebate Program (PVRP), it was rebranded the Solar Homes and Communities Plan (SHCP) in November 2007. This paper evaluates both the PVRP and SHCP using measures of cost-effectiveness and fairness. It finds that the program was a major driver of a more than six-fold increase in PV generation capacity in the 2000s, albeit off a low base. In 2010, solar PV's share of the Australian electricity market was still only 0.1%. The program was also environmentally ineffective and costly, reducing emissions by 0.09 $MtCO_2$-e/yr over the life of the rebated PV systems at an average cost of between AU$238 and AU$282/tCO_2-e. In addition, the data suggest there were equity issues associated with the program, with 66% of all successful applicants residing in postal areas that were rated as medium–high or high on a Socio-economic Status (SES) scale.

1. Introduction

Solar Photovoltaic (PV) energy systems convert solar radiation into electricity. They are made up of one or more modules (or solar panels), which are an interconnected assembly of photovoltaic cells. There are different types of PV systems, although most of the current generation are produced from silicon cells. Solar PV energy systems are distinct from solar hot water systems, which use solar radiation to heat water but do not generate electricity. PV energy systems are seen by many as offering a number of advantages over conventional, fossil fuel-based electricity generation. In particular, they can generate electricity with a fraction of the life-cycle greenhouse gas emissions of many other technologies. Their design characteristics also make them ideal for decentralized electricity generation.

Between January 2000 and June 2009, the Australian Government ran a program that provided rebates to householders and owners of community-use buildings who acquired PV energy systems. Originally called the Photovoltaic Rebate Program (PVRP), it was rebranded the Solar Homes and Communities Plan (SHCP) after a change in government in November 2007. Like similar programs in other countries,[1] the official objectives of the PVRP–SHCP were to promote the uptake of renewable energy, reduce greenhouse gas emissions, help in the development of the Australian PV industry and increase public awareness and acceptance of renewable energy (Australian National Audit Office (ANAO), 2004, 2010; Australian Greenhouse Office (AGO), 2005).

By the end of May 2010, the PRVP–SHCP had supported the installation of 107,752 PV systems across Australia with a combined installed capacity of 128 MW (Australian Department of Climate Change and Energy Efficiency (ADCCEE), 2010a). The vast majority (107,081) of the installed systems were for residential users. For much of the PVRP–SHCP's life, it was of a modest size, supporting the installation of around 1400 systems and 1.8 MW of peak capacity a year. However, in its final 18 months, the program experienced exponential growth. Between January 2000 and December 2007, there were 13,538 successful applications; or around 1700 a year. In the final 18 months of the program, there were over 94,000 (ADCCEE, 2010a). Ultimately, this level of public demand was unsustainable and it led to the program's demise. Facing a substantial cost overrun, the Australian Government terminated the program on 9 June 2009 (Garrett and Wong, 2009; Garrett, 2009).

While the PRVP–SHCP proved popular, questions have been raised about its cost-effectiveness in increasing the use of renewable energy, cutting greenhouse gas emissions and promoting industry development. In April 2010, ANAO published a review of the Government's climate change programs in which it calculated the marginal cost of greenhouse gas abatement under the SHCP at

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[1] For example, the United Kingdom's Major Photovoltaics Demonstration Program (which ended in 2007) and Low Carbon Building Program.

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\$447/tCO_2-e (ANAO, 2010).[2] The report also concluded that, despite the apparent success of the program, 'the total overall installed capacity of PV in Australia in 2008 was still relatively small; accounting for less than 0.2% of total installed electricity capacity' (ANAO, 2010, p. 88–89). This finding was consistent with a previous audit report, published in 2004, in which the ANAO voiced concerns about the administration and design of the PVRP and the extent to which it had reduced emissions (ANAO, 2004).

This paper provides an evaluation of the PVRP–SHCP program against the following criteria:

- the extent to which it increased the use of renewable energy;
- the emissions abatement achieved by the program and associated average marginal abatement cost;
- the extent to which the program assisted the development of the Australian PV industry and
- the fairness of the distribution of the rebates.

The paper is structured as follows. Section 2 provides a history of the PVRP–SHCP, including details of the rebates and program rules and how they evolved over time. Section 3 is broken into four subsections corresponding to the four evaluation criteria. Each subsection describes the method used to evaluate the program against the relevant criteria, presents the results and discusses the implications. Section 4 provides a conclusion on the cost-effectiveness and fairness of the program.

2. History of the PVRP–SHCP

In 1999, the Liberal-National Coalition Government negotiated a compromise deal with a minor party, the Australian Democrats, to introduce a Goods and Services Tax (GST).[3] The *Measures for a Better Environment* (MBE) package, which consisted of a collection of programs aimed at offsetting some of the adverse environmental impacts of the GST, was a key part of that deal (Howard, 1999). The PVRP was one of the MBE programs.

The Government and Australian Democrats agreed that the PVRP would provide grants to meet half the cost of household PV systems, up to a maximum of \$5500 per household, for four years (Howard, 1999). When the deal was made public in May 1999, it triggered a slump in the sales of PV systems as consumers waited for the PVRP to commence. In response, the start date of the program was brought forward to January 2000 and the rebate rate was set at \$5.50/W (\$/W) for systems of at least 450 W, up to a maximum of \$8250 per household (AGO, 2000; ANAO, 2004).

The program confronted immediate problems with oversubscription due to the demand for PVs that backed up prior to January 2000 and the higher than expected household rebate limit (ANAO, 2004). To control the excess demand, in October 2000, the Government reduced the rebate rate to \$5.00/W and lowered the household limit to \$7500 (AGO, 2001; ANAO, 2004). By early 2003, over-subscription had again become a problem, leading to further program changes. A cap was placed on total monthly approvals in February 2003, which was removed within 12 months (AGO, 2003; 2004). In addition, in May 2003, the Government announced the scheme would be extended until 1 July 2005 but the rebate rate and household limit were reduced to \$4.00/W and \$4000, respectively (Kemp and Macfarlane, 2003; Kemp, 2003; AGO, 2003). In the May 2005 budget, the Government announced it was allocating an additional \$11.4 million to the program and extending it for a further two years (Campbell, 2005; Australian Department of the Environment and Heritage (ADEH), 2005). This triggered a review of the program guidelines and, following the review, it was announced that the rebate rate would be changed again, falling in a series of 10 cent steps from \$4.00 to \$3.50/W until the program finished in June 2007 (AGO, 2006).

In late 2006, the politics of climate change in Australia changed considerably. For much of the early 2000s, climate change attracted little interest and was confined to the edges of mainstream public debate (Macintosh, 2008). This suited the Liberal-National Government as it was opposed to significant domestic mitigation measures and refused to ratify the Kyoto Protocol (Christoff, 2005; Pearse, 2007; Macintosh, 2008; Macintosh et al., 2010). In the second half of 2006, a confluence of events, including the publication of the *Stern Review on the Economics of Climate Change* (Stern, 2007), the Australian release of Al Gore's *An Inconvenient Truth*, and a prolonged drought in southern Australia, triggered an upswing in public concern about climate change. The Opposition (Australian Labor Party) seized on this shift in public sentiment, promising to ratify the Kyoto Protocol, introduce an emissions trading scheme by 2010 and increase investment in alternative energy.

By early 2007, the popularity of the Liberal-National Government was falling. This was due to a combination of factors, one of which was the Government's record on climate policy (Macintosh, 2008; Macintosh et al., 2010). With an election due later in the year, the Government took steps to narrow the policy differences with the opposition, announcing that it would introduce an emissions trading scheme by 2012 and increase the proportion of electricity supplied by low-emission sources. In the pre-election budget released in May 2007, it also announced that the PVRP would be extended again and that the rebate rate would be doubled from \$4.00 to \$8.00/W, up to a maximum of \$8000 per household (Turnbull, 2007).

The doubling of the rebate rate fundamentally altered the financial calculus faced by PV consumers. In 2006, average PV system costs under the program were \$14/W installed (including GST), of which the rebate covered 29% and households 71% (Fig.1).[4] After the rebate was doubled, this ratio was effectively switched—the rebate covered $\frac{2}{3}$rds of average system costs and households a mere $\frac{1}{3}$rd.

The Australian Labor Party won the November 2007 federal election and, soon after taking office, made changes to the program, including rebranding it as the SHCP and limiting eligibility to PV systems that would be connected to a main-grid or very close to a main-grid (Australian Department of the Environment, Water, Heritage and the Arts (ADEWHA), 2008; ADCCEE, 2010a). By early 2008, it was apparent that the higher rebate rate and rising public interest in climate change were causing significant over-subscription in the program. The Government responded by making a series of changes in the May 2008 budget, the most significant of which was the introduction of a means test, which limited eligibility to households with an annual taxable income of less than \$100,000 (Garrett, 2008).

Despite predictions that the means test would trigger a downturn in demand and adversely affect the Australian PV industry, applications for SHCP rebates surged, rising from 11,000 in 2007–2008 to 121,376 in 2008–2009 (ANAO, 2010).[5] Faced with a substantial overrun in the costs of the SHCP, the Government

[2] All dollar amounts are in Australian dollars (AU\$).

[3] The support of the Democrats was necessary because it held the balance of power in the Senate and the Labor Party opposed the legislation.

[4] In some jurisdictions, households may have been able to access other state and local government subsidies.

[5] In the 2008–2009 federal budget the Australian Government set targets for 2008–2009 of 6000 household rebates and 400 community building grants under the SHCP (Commonwealth of Australia, 2008). These targets were exceeded by around 1500%.

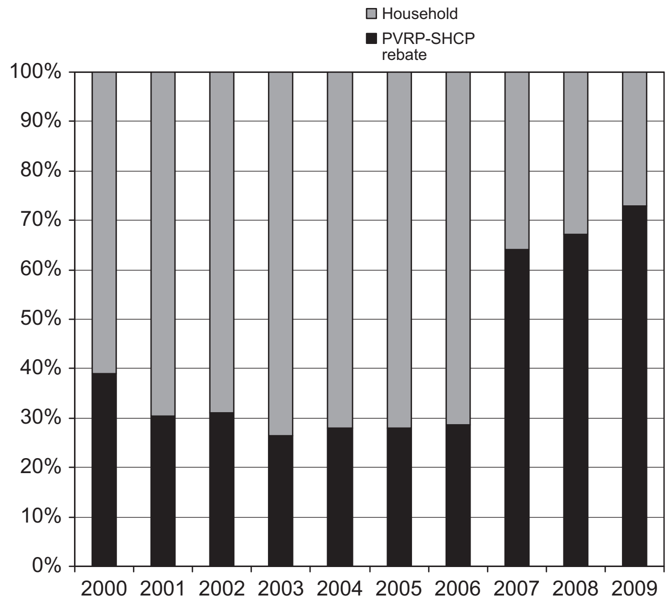

Fig. 1. Proportion of average system costs ($(nominal)/W installed capacity, including GST) covered by the PVRP rebate and households, 2000–2009 (Australian Department of Climate Change (ADCC), 2009; Australian Department of the Environment, Water, Heritage and the Arts (ADEWHA), 2010).

announced on 9 June 2009 that it would close the program, effective at midnight on that day (Garrett and Wong, 2009; Garrett, 2009). The ADEWHA received 4000 applications on 9 June 2009 (ANAO, 2010). A significant number of eligible applications were also received after that date.

The exponential growth in the PVRP–SHCP in its later years is shown in Fig. 2, which contains data on the number of successful residential PVRP–SHCP applicants and total PV watts installed under the program over the period from 2000 to May 2010.

Reported government expenditure under the PVRP–SHCP over the period from January 2000 to 30 June 2010 was $879 million (real $(2009)) (Fig. 3). However, after all eligible rebates have been processed total expenditure is expected to reach $1.1 billion (ANAO, 2010).

3. Program evaluation

To facilitate the evaluation of the PVRP–SHCP against the criteria outlined above, a freedom of information request was submitted to the ADEWHA for data on successful residential applications made under the program. In response to the request, the ADEWHA voluntarily provided a dataset containing details of 109,634 successful residential applications made and processed between January 2000 and 29 April 2010 (ADEWHA, 2010). The dataset contained the postcode of the applicant, the date the application was received, and the cost and installed capacity of the system in respect of which the rebate was provided. Names and street addresses of the applicants were withheld for privacy reasons.

The dataset was split into two for the purpose of the analysis: one for the equity issues and another for the electricity generation, abatement and cost issues. Both datasets were then cleaned to remove or correct erroneous or incomplete data entries. After the cleaning process, the equity and generation/abatement/cost datasets contained details of 107,656 and 106,494 successful applicants, respectively.

3.1. *Increase use of renewable energy*

3.1.1. *Method*

Three measures were used to evaluate the extent to which the residential component of the PVRP–SHCP increased the use of renewable energy:

- the aggregate generation capacity of the solar PV systems in respect of which a residential rebate was granted (rebated PV systems);
- the estimated annual electricity generation from rebated PV systems and
- the generation capacity and annual generation of rebated PV systems as a proportion of total Australian electricity generation capacity and output.

The generation capacity and output of the rebated PV systems were calculated using the generation/abatement/cost dataset. To do this, three underlying assumptions were adopted. First, it was assumed that all rebated PV systems were installed in the year in which the rebate application was made. Second, the lifetime of all rebated PV systems was assumed to be 30 years, consistent with the International Energy Agency's (IEA) *Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity* (Alsema et al., 2009). This is a reasonably generous assumption as the lifetime of residential PV systems can be significantly less than 30 years (Pacca et al., 2007; Alsema et al., 2009; Sherwani et al., 2010). Third, to account for module degradation, it was assumed that the efficiency of the rebated PV systems declines in a linear manner to be 80% of the initial efficiency at the end of the 30 year lifetime (Alsema et al., 2009).

The generation capacity of the rebated PV systems was calculated by summing the rated capacity of each system recorded in the dataset. The annual output of each system was calculated by multiplying its capacity in the relevant year by a zone rating (or output factor). In accordance with the third assumption above, the capacity of the rebated PV systems was assumed to fall by 20% over their lifetime. Zone ratings for PV systems installed in Australia were obtained from the Australian Office of the Renewable Energy Regulator (ORER) (ORER, 2010). The ORER zone ratings provide an estimate of the likely average annual output of a small PV system (≤ 100 kW) located in one of four zones in Australia over a period of up to 15 years. These ratings are typically used to determine the number of renewable energy credits that small generators, including household solar PV systems, are entitled to under the Renewable Energy Target (a tradeable certificate scheme designed to promote the uptake of renewable energy). The ratings take into account the latitude of the zones (and associated levels of solar radiation) and the operational characteristics of sampled systems in the zones, including orientation, tilt and shading. They also assume that, on average, systems operate at $\sim$5% below rated capacity due to module degradation experienced over the renewable energy credit deeming period (i.e. 1, 5 or 15 years).[6] To prevent double counting of the effects of module degradation, the ORER zone ratings were increased by 5% for the purposes of this analysis.

To estimate the output of the rebated PV systems in a particular year, applicant postcodes were matched to the relevant modified ORER zone rating. The identified zone rating was then multiplied by the capacity of the applicant's system in the relevant year to provide an estimate of annual electricity generation. The results were aggregated and compared to total Australian electricity generation capacity and output, the data for which

[6] Julian Mateer (ORER, pers. comms., 25 October and 13 December 2010).

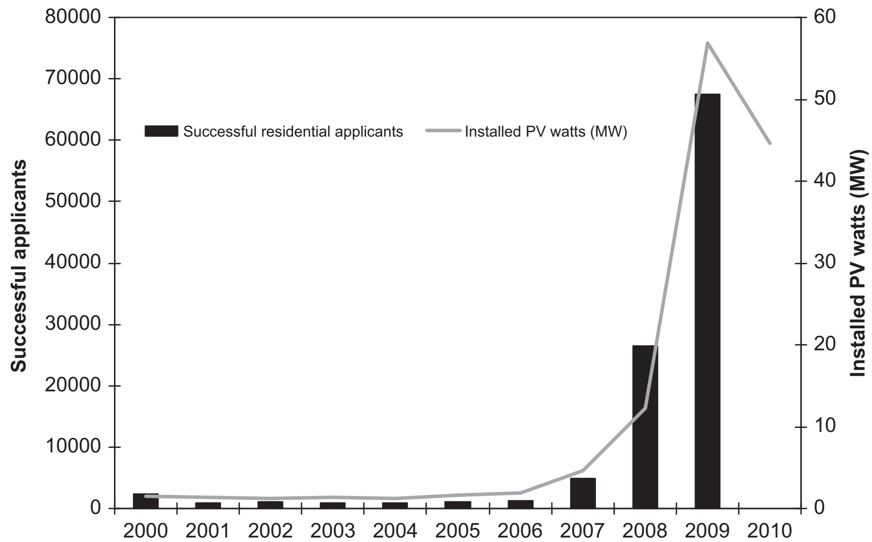

Fig. 2. Successful residential applicants (by year of application) and total installed watts (MW) under the PVRP–SHCP, 2000–2010 (ADEWHA, 2010; ADCCEE, 2010a). This includes watts installed under the community building component of the program, which comprised 0.6% of systems installed under the PVRP–SHCP to the end of May 2010 (ADCCEE, 2010a).

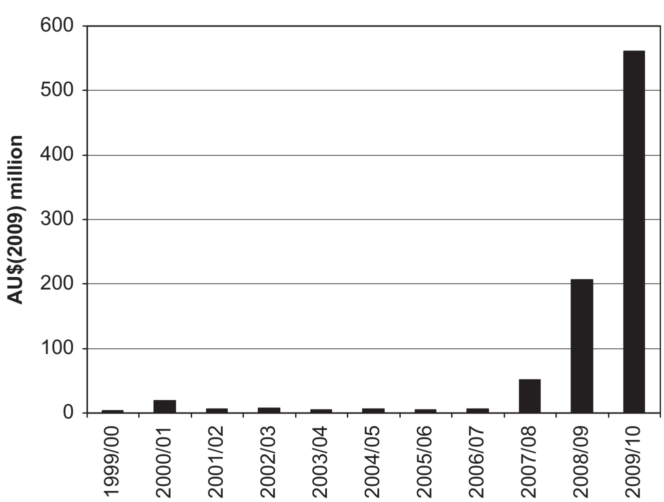

Fig. 3. Reported Australian Government expenditure under the PVRP–SHCP ($(2009)), 1999/2000–2009/2010 (Hill, 2001; Kemp, 2002; 2003; 2004; ADEH, 2005; 2006; Australian Department of the Environment and Water Resources (ADEWR), 2007; ANAO, 2004; 2010; Commonwealth of Australia, 2010a; 2010b).

were obtained from the Australian Bureau of Agricultural and Resource Economics (ABARE) (Dickson et al., 2001; Cuevas-Cubria and Riwoe, 2006; Donaldson, 2007; Cuevas-Cubria et al., 2010; Syed et al., 2010).

3.1.2. Results

The total installed capacity of the rebated PV systems is 126 MW and the estimated combined output from these systems in 2010 is 171 GWh. This constitutes approximately 0.25% of Australia's total generation capacity in 2010 (51 GW) and 0.07% of projected 2010 generation (256 TWh) (Cuevas-Cubria et al., 2010; Syed et al., 2010).

Between 2000 and 2009, cumulative installed PV generation capacity in Australia rose from 29 to 184 MW (IEA, 2009; 2010). Rebated PV systems represent ~80% of this increase. Over the same period, Australia's total generation capacity rose from 41 to 50 GW, resulting in PV's share of capacity increasing from 0.07% to 0.37% (Cuevas-Cubria et al., 2010; Syed et al., 2010). Similarly, total electricity generation was 207 TWh in 1999–2000 and is projected to be 256 TWh in 2009–2010 (Dickson et al., 2001; Cuevas-Cubria and Riwoe, 2006; Donaldson, 2007; Cuevas-Cubria et al., 2010; Syed et al., 2010). PV's share of this increased from 0.02% in 2000 to 0.1% in 2009 (IEA, 2009; 2010; ADEWHA, 2010).

The PVRP–SHCP appears to have been a major driver of the increase in solar PV capacity and generation in the 2000s. Rebated PV systems account for the bulk of the observed increase and it is reasonable to surmise that most householders would not have invested in these systems in the absence of the rebate. While the PVRP–SHCP was a driver of the observed trends, other factors were also influential. In particular, between 1 July 2008 and 1 August 2010, solar PV feed-in tariffs were introduced in six Australian jurisdictions (Australian Capital Territory (ACT), New South Wales (NSW), Queensland (Qld), South Australia (SA), Victoria (Vic) and Western Australia (WA)), providing an additional subsidy for PV generators in these areas. The introduction of the state and territory feed-in tariffs, and the expectation of their introduction, is likely to have contributed to the sharp rise in the uptake of PV systems in the latter part of the 2000s. Declining PV system costs, which are discussed in greater detail in Section 3.3, are also likely to have been a factor.

3.2. Abatement and average social marginal abatement cost

3.2.1. Method

The emission reductions produced by the residential component of the PVRP–SHCP and associated average social marginal abatement cost were calculated using a Life-Cycle Analysis (LCA) method, similar to that adopted by Oliver and Jackson (2000). Under this approach, the abatement produced by an abatement technology is calculated by subtracting the full life-cycle emissions of the technology from the life-cycle emissions associated with a reference technology (i.e. a counterfactual baseline that represents the emissions that would have occurred had the abatement technology not been deployed). The marginal abatement cost is then calculated by subtracting the cost of the reference technology from the cost of the abatement technology, and dividing this by the abatement.

In the current context, the abatement technology is the rebated PV systems. The reference technology is the electricity supply from the grid that the rebated PV systems displace. The life-cycle emissions associated with the rebated PV systems were calculated using a PV emission factor estimate of 50 g CO_2/kWh, derived from Sherwani et al. (2010). The emissions associated with the displaced electricity supply were calculated using jurisdiction specific full fuel cycle emission factors, which take into account direct emissions from generation, emissions associated with the extraction, production and transport of fuels used by generators, and emissions attributable to electricity lost in the transmission and distribution networks. For the period, 2000–2008, the emissions factors published by the Australian Department of Climate Change were used (ADCC, 2009). For the remaining years, projections were made that took into account the likely changes in the electricity sector that will arise from Australia's current greenhouse gas mitigation targets (5% reduction off 2000 levels by 2020 and a 60% reduction by 2050).

The social cost of the rebated PV systems was calculated using the system cost data in the generation/abatement/cost dataset, adjusted to remove GST (which was treated as a transfer). The social cost of the grid-sourced electricity was calculated using estimates of the long-run variable cost of supplying the displaced electricity to residential users in the relevant Australian jurisdictions (i.e. the marginal resource cost, which excludes fixed costs, GST and other relevant taxes and transfers). The projections of the long-run variable cost of grid-sourced electricity assumed the introduction of a carbon price in 2015 and treated the carbon price (i.e. the tax or permit price) as a transfer. Low- and high-range marginal abatement cost estimates were calculated to account for uncertainties associated with the avoided costs of the displaced electricity.[7]

3.2.2. Results

The total emissions abatement generated by the residential component of the PVRP–SHCP is estimated at 3.62 $MtCO_2$-e over the lifetime of all rebated PV systems. The aggregate is 0.6% of Australia's net emissions (Kyoto accounting) in 2008 (576 $MtCO_2$-e). Over the life of the rebated PV systems (i.e. 39 years), the average annual abatement is estimated at 0.09 $MtCO_2$-e/yr, which represents 0.016% of Australia's 2008 emissions. This is well within the margin of error for the measurement of emissions from Australia's electricity sector (204 $MtCO_2$-e $\pm 5\%$) (ADCCEE, 2010b).

The average social marginal abatement cost of the rebated PV systems is estimated at between \$238 and \$282/tCO_2-e. This incorporates the cost of all rebated PV systems, which was almost \$1.4 billion (\$(2009), excluding GST), and the avoided costs associated with the displaced electricity supply. This estimate is significantly below the ANAO's program-wide estimate of \$447/tCO_2-e. The reason for the disparity in the estimates is unclear because the ANAO did not publish information on its method. However, sensitivity analysis conducted using the generation/abatement/cost dataset suggests the ANAO estimate may have been calculated using a modified private marginal abatement cost method, which did not account for the avoided electricity supply costs.

As Fig. 4 shows, the average marginal abatement cost of the rebated PV systems declined significantly between 2000 and 2009, falling by over 40%. The estimated marginal abatement cost of the systems installed in 2000 was between \$415 and \$450/tCO_2-e. By comparison, the abatement cost of the 2009 rebated systems was between \$211 and \$256/tCO_2-e. The observed decline in abatement costs was a product of a reduction in system costs. Information and analysis on the trends in system costs is provided in Section 3.3 below.

[7] Additional information on the methods used to estimate the abatement and marginal abatement costs associated with the rebated PV systems is provided in Appendix A.

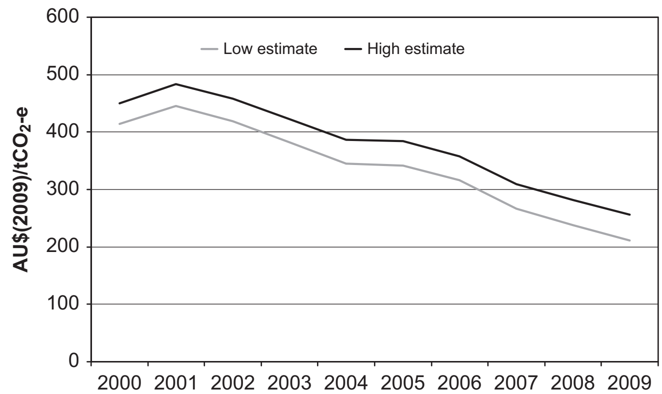

Fig. 4. Average social marginal abatement cost associated with rebated PV systems (\$(2009)/tCO_2-e), low- and high-range estimates, by year of assumed installment, 2000–2009 (ADCC, 2009; ADEWHA, 2010).

The marginal abatement costs varied significantly between jurisdictions, reflecting differences in solar resources and the emissions intensity of displaced electricity supply. The highest abatement costs were recorded in Tasmania, with a program-wide estimate of between \$1536 and \$1779/tCO_2-e. This reflects Tasmania's geographical position (it is Australia's southern most state) and the associated lower levels of solar radiation and the fact that a large proportion of Tasmania's electricity is sourced from hydro-electric generators. The lowest program-wide abatement costs were found in Victoria (\$209 to \$244/tCO_2-e). This is mainly attributable to Victoria's dependence on brown coal electricity generation, which has resulted in it having the highest emissions intensity of electricity generation in the nation (ADCC, 2009).

Fig. 5 shows the spread of the low-range average marginal abatement cost estimates for NSW, ACT, VIC, QLD, SA and WA. Tasmania was omitted because of its extremely high abatement cost estimates and the Northern Territory was omitted due to the small sample size ($n=177$).

3.3. Development of the Australian PV industry

3.3.1. Method

The evaluation of the industry development benefits of the residential component of the PVRP–SHCP is complicated by the existence of multiple factors that may have affected the Australian PV sector over the 2000s. These include the federal Renewable Energy Target, state/territory renewable energy subsidies and feed-in tariffs, proposals for the introduction of a carbon price, federal and state/territory solar PV research, development and demonstration programs, fluctuations in the value of the Australian dollar and competition from foreign manufacturers. Separating out the influence of the PVRP–SHCP from these factors is complex and requires counterfactual assessments to be made.

The approach taken in this paper was to use a simple inductive approach where the effectiveness of the PVRP–SHCP as an industry-assistance measure was judged on the basis of three criteria:

- to what extent did the program promote activity in the PV sector;
- did the activity generated by the program produce domestic industry development benefits and
- is the program-induced growth in the sector likely to be sustainable?

No attempt was made to differentiate between the impacts of the residential and community building components of the program.

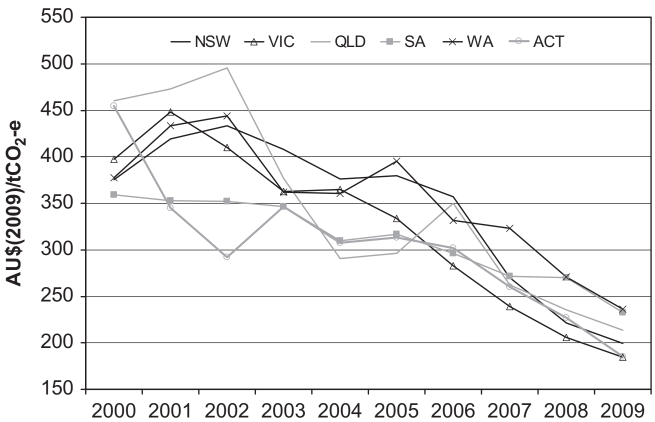

Fig. 5. Average social marginal abatement cost associated with rebated PV systems ($(2009)/t$CO_2$-e) in NSW, ACT, VIC, QLD, SA and WA, low-range estimates only, by year of assumed installment, 2000–2009 (ADCC, 2009; ADEWHA, 2010).

To evaluate the program's effect on business activity, annual government expenditure was compared to the estimated market value of the systems that were installed under the program. Data on annual program expenditure were obtained from Australian Government budget papers and ANAO reports (2004; 2010). The market value of the installed systems was estimated by multiplying the average annual system cost ($(2009)/W) derived from the generation/abatement/cost dataset by the actual annual installed PV capacity under the program, which was obtained from the ADCCEE (ADCCEE, 2010a).

Four measures were used to provide insights on the extent to which the activity generated by the PVRP–SHCP produced domestic industry development benefits:

- the value of solar PV business in Australia;
- the value of PV imports and exports;
- the number of solar PV manufacturers, and total cell and module production (in MW), in Australia and
- the value of the economic benefit to domestic PV businesses from the PVRP–SHCP.

Data on these issues were obtained from the IEA's Co-operative Program on Photovoltaic Power Systems (Watt, 2003; 2004; 2005; 2006; 2007; 2008; 2009; Watt and Wyder, 2010), the ADCCEE (ADCCEE, 2010a) and the generation/abatement/cost dataset.

The long-term prospects of the solar PV industry rest on the ability of PV electricity to compete with other forms of generation. Given this, the effectiveness of the PVRP–SHCP in promoting sustainable industry development can be measured on the basis of whether it significantly reduced the cost of solar PV electricity. To do this, system cost data were drawn from the generation/abatement/cost dataset. Additional data on system costs, including trends in module and non-module costs, both in Australia and in other comparative developed countries, were obtained from the IEA's Co-operative Program on Photovoltaic Power Systems (IEA, 2009; 2010). These data provided a basis from which to make tentative conclusions on the likely impact of the PVRP–SHCP on system cost trends.

3.3.2. Results

Between January 2000 and 30 June 2010, the PVRP–SHCP supported the installation of residential and community solar PV systems worth $1.6 billion ($(2009), including GST) (ADCCEE, 2010a; ADEWHA, 2010). Federal Government expenditure on the program over the equivalent period was $879 million,[8] suggesting that every dollar invested under the PVRP–SHCP triggered $0.79 of investment in solar PV systems from other sources (i.e. private investment plus subsidies provided under other government programs) (Fig. 6).

The stimulus provided by the PVRP–SHCP helped bring about a significant increase in the size of the Australian PV sector. Between 2002 and 2009, the value of PV business in Australia rose from $188 to $505 million ($(2009)) (Fig. 7). However, a significant proportion of the economic benefit associated with the growth in the industry accrued to foreign PV manufacturers. This is evident in the import/export data, which shows that between 2002 and 2009, the value of PV imports rose from $17 to $295 million (Fig. 8). The growth in imports reflects the fact that a large proportion of the domestic PV market in the 2000s was reliant on imported PV modules. Due to this reliance, the value of domestically produced modules sold under the PVRP–SHCP to 30 June 2010 was probably around $290 million ($(2009), excluding GST). The value of domestic non-module business generated by the program was probably in the order of $330 to $490 million, bringing the total PVRP–SHCP related benefit to the domestic PV industry to between $620 and $780 million ($(2009), excluding GST) over the period 1 from January 2000 to 30 June 2010.[9]

As Fig. 8 shows, the value of Australian PV exports rose from $75 million in 2002 to a high of $161 in 2004, before heading on a downward trajectory that saw them reach zero in 2009. The trends in exports reflect the fortunes of BP Solar, who for most of the life of the PVRP–SHCP, was Australia's dominant commercial PV cell and module manufacturer.[10] During the mid-2000s, BP Solar produced around 35–42 MW of PV cells and 8–12 MW of PV modules at a plant in Sydney. The cells were manufactured from imported wafers and most (~80%) were exported. Similarly, around 50% of BP Solar's modules were exported. In March 2009, BP Solar closed its Australian operations. The former BP plant was subsequently acquired by SilexSolar Pty. Ltd. (a wholly owned subsidiary of Silex Systems Ltd.) and reopened in November 2009. Manufacturing and sales of cells and modules recommenced in early 2010 and, later in the year, SilexSolar Pty. Ltd. announced that it was increasing its module production capacity from 13 to 20 MW in 2011, and was hoping to increase cell production toward the 50 MW capacity of the plant (Silex Systems Ltd., 2009; 2010).

Over the life of the program, system costs ($(2009)/W installed, excluding GST) of rebated PV systems fell by 44%, with the sharpest decreases occurring in 2007 (13%), 2008 (9%) and 2009 (9%). These trends are shown in Fig. 8, which provides the system costs across the residential program (excluding GST), divided into six categories on the basis of the size of the installed system (250–750, 751–1250, 1251–1750, 1751–2250, >2250W and all systems). These trends are similar to those recorded by the IEA, which found that typical system prices for grid-connected

[8] Hill (2001), Kemp (2002; 2003; 2004), ADEH (2005; 2006), ADEWR (2007) and ANAO (2004; 2010).

[9] The estimated value of the benefit to domestic PV businesses was based on three assumptions. First, module costs represented 55% of the average cost of systems that were subsidized under the program in 2000, and that this proportion increased linearly to 65% in 2010. Second, 70% of the modules installed under the program were imported. Third, imports comprised 10-40% of average non-module costs. The module-related assumptions were based on data from the generation/abatement/cost dataset and the IEA's Co-operative Program on Photovoltaic Power Systems (Watt, 2003; 2004; 2005; 2006; 2007; 2008; 2009; Watt and Wyder, 2010). No reliable data were available on the import component of average non-module costs. Accordingly, a 'best guest' estimate range of 10–40% was adopted.

[10] Solar Systems Pty. Ltd. manufactured a small number of concentrating PV systems in Australia during the 2000s but was declared bankrupt in 2009 (William Ring, pers comms, 20 September 2010). The company was acquired by Silex Systems Ltd. in early 2010. In addition, Origin Energy Ltd. operated a pilot plant in Adelaide, South Australia, during the 2000s.

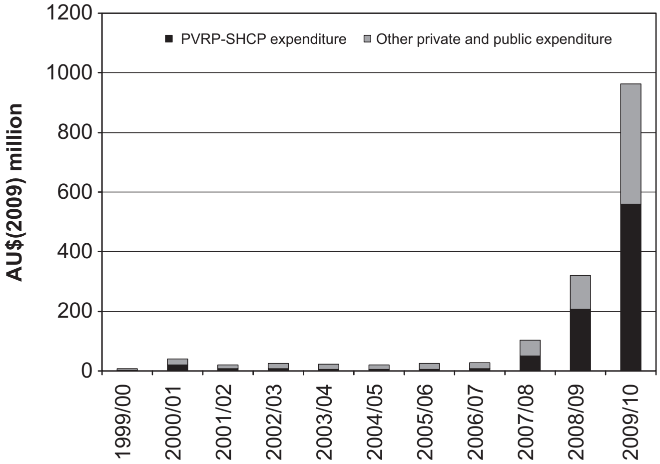

Fig. 6. Expenditure on subsidized PV systems under the PVRP–SHCP ($(2009)), by *source*, January 2000–2030 June 2010 (Hill, 2001; Kemp, 2002; 2003; 2004; ADEH, 2005; 2006; ADEWR, 2007; ANAO, 2004; 2010; Commonwealth of Australia, 2010a; 2010b).

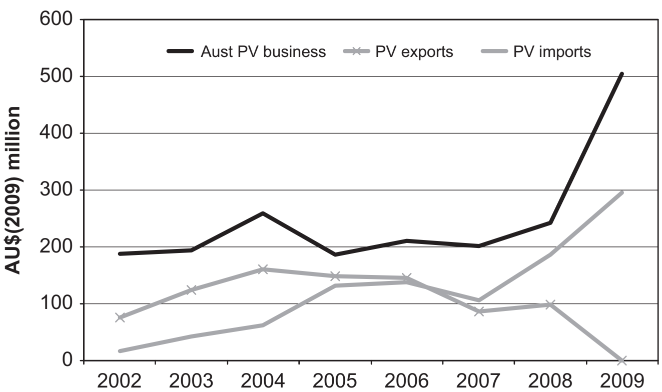

Fig. 7. Value of Australian PV business, PV imports and exports ($(2009)), 2002–2009 (Watt, 2003; 2004; 2005; 2006; 2007; 2008; 2009; Watt and Wyder, 2010).

systems of up to 5 kW in Australia fell by 36% between 2000 and 2009; from $14 to $9/W ($(2009), excluding GST) (Watt and Wyder, 2010). Despite the decline in costs, at the close of the PVRP–SHCP, solar PV energy systems were still not competitive (on a purely financial basis) with other forms of residential electricity supply and, in the absence of ongoing government support, are likely to remain so in the short- to medium-term (Cuevas-Cubria et al., 2010; Syed et al., 2010).

The trends in quarterly PV installations under the PVRP–SHCP (watts installed) and average quarterly rebated PV system costs (excluding GST) between January 2000 and June 2009 are moderately correlated, with a product–moment correlation coefficient of -0.56 (r), which is statistically significant at the 0.05 level. Controlling for the influence of foreign exchange rate variations, using both AU$/US$ and the Australian Trade Weighted Index (TWI) (Reserve Bank of Australia, 2010), provides partial correlation coefficients between installed capacity and system costs of -0.70 and -0.67, respectively. The nature of this correlation, and the fact that the PVRP–SHCP was one of the major drivers of PV industry activity in the 2000s, suggest that the program was a causal factor in the decline in system costs. However, its role should not be overstated. Several other government programs are likely to have had a material influence on the Australian PV market in the 2000s, particularly the Renewable Energy Target and state/territory feed-in tariffs. Further, similar downward trends in system costs were experienced in a number of other developed countries, including the United States, Italy, Japan, Denmark and Sweden.[11] Given the Australian market's dependence on imported components, international prices and foreign exchange rates are likely to have had a major influence on domestic system costs.[12] Yet the PVRP–SHCP is still likely to have contributed to the decline, particularly in the latter years of the program, by promoting competition in the domestic market (Watt and Wyder, 2010).

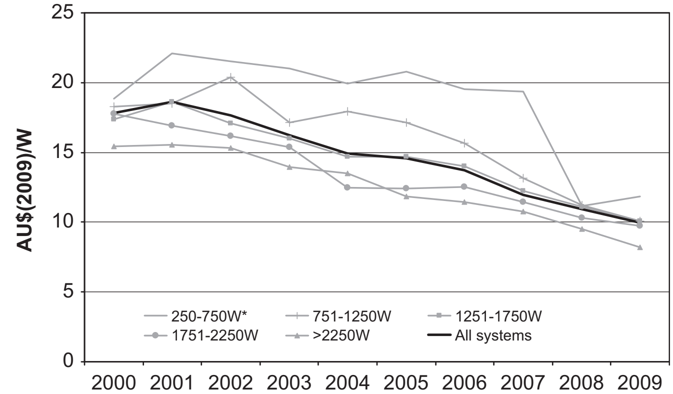

Fig. 8. Rebated system costs ($(2009)/W installed capacity, excluding GST), by year of assumed installment and size of installed system (ADCC, 2009; ADEWHA, 2010). The sample sizes for the 250–750 W category were very small in 2008 ($n=11$) and 2009 ($n=6$), raising doubts about the validity of the results in this category for these years.

Although the PVRP–SHCP is likely to have been a factor in the drop in system costs, the data indicate that any price-related benefits of the program could have been achieved at a lower cost. Three quarters of the observed decrease in average system costs occurred over the period 2000–2007, before the explosion in the size of the program. Total government expenditure on the program at the end of 2007 was less than $100 million ($(2009)). Terminating the program at this point, or putting in place effective measures to limit its size, would have greatly reduced the budgetary impact of the program and is unlikely to have substantially altered the trajectory of PV system costs. The experience with the PVRP–SHCP illustrates that the failure to adequately control the size of renewable energy support measures can have serious implications for their cost-effectiveness.

From the data that are available, a number of conclusions can be drawn on the PVRP–SHCP's impact on the domestic PV industry. First, by providing $879 million in consumer subsidies, the program contributed to $1.6 billion of expenditure on PV systems. Second, the PV sector as a whole was relatively stable through the 2000s but experienced a sharp rise in 2008 and 2009, a significant proportion of which is almost certainly due to the expansion of the PVRP–SHCP in these years. The impact of the program is reflected not only in the increase in PV business but also the rise in the number of accredited installers, which rose from 210 in 2006 to 1200 in 2009 (ANAO, 2010).[13] Third, while the PVRP–SHCP did trigger growth in the PV industry, it did not translate into sustained growth in cell and

[11] Wiser et al. (2009a; 2009b), National Renewable Energy Laboratory (2009), Castello et al. (2010), Yamamoto and Ikki (2010), Ahm (2010) and Hultqvist (2010).

[12] The product–moment correlation coefficients between average quarterly exchange rates and average quarterly rebated PV system costs are -0.82 (AU$/US$) and -0.77 (TWI). Controlling for the impacts of the program (annual W installed) provides partial correlation coefficients of -0.86 (AU$/US$) and -0.84 (TWI).

[13] See also Clean Energy Council (2009).

module production. Cell and module production in Australia grew modestly from a low base during the 2000s but dropped dramatically in 2009 when BP Solar closed its Sydney plant. Silex Systems Ltd. is poised to increase Australian cell, module and concentrator production over the coming years; however, this is unrelated to the PVRP–SHCP. Fourth, a significant proportion of the economic benefit associated with the PVRP–SHCP accrued to foreign PV manufacturers and distributors. Fifth, while the PVRP–SHCP is likely to have contributed to a decline in PV system costs, the extent of this contribution is uncertain, the price-related benefits of the program could have been achieved at a lower cost and solar PV generation costs were still significantly above grid parity at the close of the program.

3.4. Fairness of the distribution of rebates

3.4.1. Method

To determine whether there were equity issues associated with the distribution of rebates, the Australian Bureau of Statistics' (ABS) Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) was used to analyze the socio-economic profile of the areas in which the successful applicants reside (ABS, 2006a). The IRSAD provides a measure of the economic and social resources in an area and is calculated using Australian census data, in this case from 2006 (ABS, 2006b; Adhikari, 2006). The index provides a score and percentile ranking for each 'ABS postal area' based on the characteristics of the households and individuals who reside in the area.[14] The higher the score and percentile rank, the higher the relative socio-economic advantage and lower relative disadvantage (and *vice versa*) of an area's households and residents.

Using the IRSAD, a socio-economic percentile ranking amongst all Australian postal areas was assigned to each successful applicant on the basis of their postcode. The number and proportion of successful applicants from postal areas with low (1st quartile), medium-low (2nd quartile), medium-high (3rd quartile) and high (4th quartile) Socio-economic Status (SES) ratings was then calculated. The proportion of applicants in each SES quartile by postal area was used as a general measure of the fairness of the distribution of rebates across the Australian population.

The flaw in this method is that it does not capture the actual socio-economic profile of the successful applicants; only that of the postal area in which they live. The IRSAD score of applicants could be significantly higher or lower than the score of their postal area. Another issue associated with the chosen method is that it is based on a general SES index rather than a narrower measure of economic resources. Some may argue that the fairness of the distribution of rebates should be measured solely on the basis of whether the recipients had above or below average income or wealth. While equity judgments are subjective, an approach based exclusively on access to economic resources was rejected because it does not account for the other factors that were likely to influence the distribution of rebates, particularly the human capital and social resources of households.

The underlying equity test that was adopted was whether the rebates were unjustifiably skewed toward one group in society over another. The economic resources of households are clearly relevant to this issue because, over the life of the program, the upfront costs of acquiring a residential solar PV system, even with the rebate, were generally significant (> \$3000 for a 1 kW system) (\$(2009)) ADEWHA, 2010).[15] These upfront costs may have excluded many low to medium income households from the program. In addition to economic resources, human capital and social resources are relevant because of their capacity to influence households' awareness of the program and the transaction costs they face in purchasing PV systems and accessing the rebates.[16] For example, in the case of the PVRP–SHCP, most of the information about the program was provided online, meaning households were less likely to be aware of the rebate if they did not have access to the internet.[17] Similarly, households with higher levels of education and in higher skilled occupations were more likely to find it easier to access information on residential solar PV systems, to evaluate the long-term cost savings associated with subsidized PV systems and to obtain relevant information from members of their social networks.

Given the likely importance of social and educational capacities in accessing the rebate, it was considered inappropriate to confine the equity analysis to a measure of economic resources. The IRSAD, as the best available general SES measure, was believed to be more suitable because it captured both the economic and social resources of the applicants' postal areas.

3.4.2. Results

The proportion of successful PVRP–SHCP applicants from postal areas with low (1st quartile), medium-low (2nd quartile), medium-high (3rd quartile) and high (4th quartile) SES ratings, by year of application, is shown in Table 1. Fig. 9 shows the distribution for the PVRP and Fig. 10 shows the equivalent results for the SHCP.

The results show that the rebates under the PVRP–SHCP were skewed toward postal areas with medium-high to high SES ratings; 66% of all successful applicants were from these postal areas. In the early years of the PVRP, the distribution was more equitable, with a greater proportion of applicants coming from postal areas with low and medium-low SES ratings. However, as the program matured and the number of successful applicants increased, the proportion of successful applicants from these lower SES postal areas declined. In the final 18 months of the program, when the SHCP was in operation, only 11% of successful applicants came from low SES postal areas.

The results suggest that the distribution of rebates under the PVRP–SHCP was inequitable in the sense that most recipients came from medium-high to high SES rated areas. It is important to note that, because of privacy restrictions, data were not able to be obtained on the SES profile of successful applicants or the distribution of rebates within postal areas. Further research on these issues could shed additional light on the equity implications of the program.

4. Conclusion

The residential component of the PVRP–SHCP performed modestly against the chosen measures. The program was a major driver of a more than six-fold increase in PV generation capacity and output in the 2000s. However, the increase was off a low base and PV's share of the Australian electricity market in 2010 is still only 0.1%. The program was environmentally ineffective and

[14] The 'ABS postal areas' are not an exact match of the official *Australia Post* postcodes, which are more widely used in the community and are recorded in the PVRP–SHCP dataset. However, they were created to match the official postcodes as closely as possible and are widely seen as a suitably close approximation.

[15] In the final stages of the program, some retailers were offering residential solar PV systems at very low prices, making household economic resources less of a barrier to the uptake of the systems.

[16] A number of studies have found that the main factors explaining the low uptake of government benefits in eligible populations are lack of awareness and transaction costs (Currie, 2004; Bunt et al., 2006; Baker, 2010).

[17] The IRSAD includes information on internet access.

costly. It will reduce emissions by 0.09 $MtCO_2$-e/yr over the life of the rebated PV systems (0.016% of Australia's 2008 emissions) at an average abatement cost of between $238 and $282/$tCO_2$-e. The program also appears to have had a relatively minor impact as an industry assistance measure, with much of the associated benefit flowing to foreign manufacturers and most of the domestic benefit being focused outside of the high value-added manufacturing areas. Finally, the data suggest there were equity issues associated with the program, with 66% of all successful applicants residing in medium-high and high SES rated postal areas.

An issue that was not analyzed in this paper is whether the PRVP–SHCP succeeded in its objective of increasing public awareness and acceptance of renewable energy. Given the number of PV systems that were subsidized under the program, and the broad area over which they were installed, it is reasonable to presume that the PVRP–SHCP had some impact on community attitudes. However, total government expenditure on the program is expected to be $1.1 billion ($(2009)) when it is finally wound up. This is more than the Australian Government's annual allocation to the Australian Broadcasting Corporation, which in 2009–2010 was $915 million (Commonwealth of Australia, 2010c). If a primary object of the PVRP–SHCP was to promote awareness, these benefits may have been obtained at a lower cost by employing other strategies, including standard social marketing techniques.

Many of the deficiencies of the PRVP–SHCP arose in its final two years. Up until mid-2007, the Australian Government was able to contain the program by repeatedly adjusting the rebate rates and household limits. This is likely to have caused uncertainty in the PV industry and stifled investment but it successfully controlled the costs and inequities associated with the program. The changes announced by the Liberal-National Party Coalition Government in the May 2007 budget, and carried over by the Labor Government in 2008 and 2009, caused a cost overrun in the program and magnified its flaws.

The Australian experience with the PRVP–SHCP highlights how care needs to be taken to ensure that renewable energy programs are designed and administered to generate public benefit outcomes. Low and zero-emission energy is required to address climate change and there is a need for government programs that help lower the cost of these technologies and incentivise their deployment. However, when poorly targeted and designed, these programs can be wasteful and produce predominantly private rather than public benefits.

Table 1
Proportion of successful PVRP–SHCP applicants from postal areas with low, medium-low, medium-high and high SES ratings, by year of application.
Source: ABS (2006a); ADEWHA (2010).

Year	No.	Proportion in each SES quartile (%)			
		Low (1st quartile)	Medium-low (2nd quartile)	Medium-high (3rd quartile)	High (4th quartile)
2000	2357	26	31	29	13
2001	921	25	26	27	23
2002	1063	24	27	26	24
2003	979	19	25	27	29
2004	911	20	29	28	23
2005	1122	19	29	27	24
2006	1309	18	23	26	33
2007	4876	12	21	27	41
2008	26,564	11	21	32	36
2009	67,554	11	21	35	33
PVRP–SHCP	**107,656**	**12**	**21**	**33**	**33**

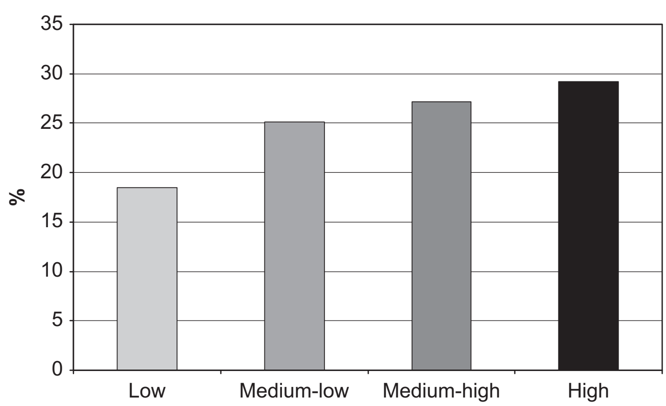

Fig. 9. Proportion of successful PVRP applicants from postal areas with low, medium-low, medium-high and high SES ratings (ABS, 2006a; ADEWHA, 2010).

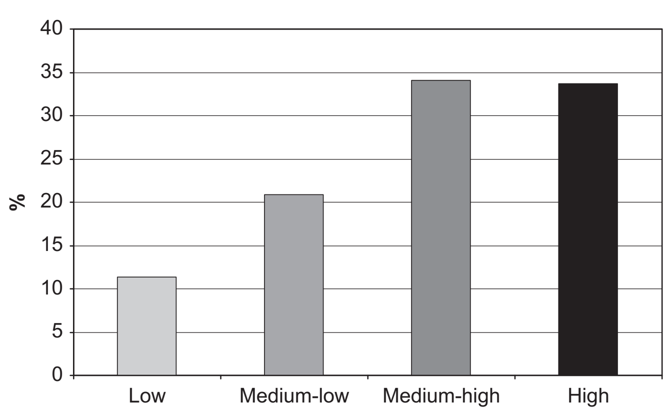

Fig. 10. Proportion of successful SHCP applicants from postal areas with low, medium-low, medium-high and high SES ratings (ABS, 2006a; ADEWHA, 2010).

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Appendix A. Additional information on abatement and abatement cost methodology

To calculate the emissions abatement from the PVRP–SHCP, the PV system output assumptions outlined in Section 3.2 were adopted (i.e. the rebated PV systems were installed in the application year, all systems have a lifetime of 30 years and there is a 20% linear decline in the efficiency of the systems). It was also assumed that all rebated PV systems are grid-connected.[18] On the basis of these assumptions, the marginal abatement costs associated with the rebated PV systems were calculated using Eq. (1) below.

$$MAC_S = \frac{SC_S - \sum_{t=n}^{u} C_{st}\, ZR_s\, LRVC_{sjt}\, DF_t}{\sum_{t=n}^{u} (C_{st}\, ZR_s\, EF_{sjt}) - (C_{st}\, ZR_s\, PVEF)} \tag{1}$$

[18] More than 95% of systems installed under the program were grid-connected (ADCCEE, 2010a).

where MAC_s is the marginal abatement cost of rebated PV system s, SCs is the system cost of rebated PV system s; C_{st} is the capacity of rebated PV system s in year t, ZR_s is the ORER zone rating for the postcode of rebated PV system s, $LRVCs_{jt}$ is the long-run variable cost ($/kWh) of displaced electricity supply in year t in jurisdiction j in which the rebated system s is installed, DF_t is the discount factor (if applicable) for year t, assuming a discount rate of 3.5%, EF_{sjt} is the full fuel cycle emission factor (kg CO_2-e/kWh) in year t in electricity jurisdiction j in which the rebated system s is installed, PVEF is the solar PV life-cycle emission factor (50 g CO_2/kWh), n is the year of application for rebated PV system (i.e. assumed year of installation), u is the $n+30$ years.

All dollar amounts were converted to real $(2009) using ABS (2010) and assuming a long-term inflation rate of 2.5%. GST, feed-in tariffs and carbon prices were treated as transfers and excluded from the cost calculations.

The data sources that were used to estimate the abatement and marginal abatement costs including Australian Department of Treasury (2008), ADCC, 2009, ORER, (2010), Sherwani et al. (2010), KPMG and Econ Tech (2010), Hoch et al. (2009), Queensland Competition Authority (2009), Frontier Economics (2009), Australian Energy Regulator (2009), United Kingdom Department of Energy and Climate Change, 2010 and ABS (2003).

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