Estimating the Economic Value of Distributed PV Systems in Australia

S. J. Oliva, *Student Member, IEEE*, and I. F. MacGill

***Abstract*--Australian commitment to reduce CO_2 emissions by 2020 has risen a set of policies that attempts to promote investments in low emission technologies in the electricity sector. Given the excellent solar resources in this country, PV systems have been subsidised through a state and territory-based feed-in tariffs scheme (FiTs) whose design doesn't take into account many of the positive externalities that this energy offers. This paper discusses on the full value of electricity generated by PV systems (PVelec) coupled with an economic analysis of this value for a residential PV system located in Sydney. The outcomes show that its investment is economically beneficial when social discount rates are applied under the current technology and costs whereas a discussion of the results provides some insights to potential FiTs improvements.**

***Index Terms*— Australia, Economic analysis, Feed-in tariffs, PV systems.**

I. Introduction

SOlar photovoltaics (PV) have experienced remarkable progress in terms of increased deployment government policy. Some 96 countries have implemented policies to support renewable power generation as of 2010 and many of these have been targeted at PV. Feed-in tariffs (FiTs) which provide a premium 'tariff' for eligible renewable generation are the most widely implemented policy mechanism, and were in place in more than 61 countries and 26 states/provinces worldwide in 2010 [1].

FiTs have demonstrated their effectiveness in promoting PV deployment in a growing number of countries [1], however, the success of PV has raised growing concerns about the expense of these FiT policies on other energy users who pay the program costs [2]. While PV costs are falling, it generally doesn't make financial sense for energy users to install systems given current retail electricity market arrangements and tariffs. FiT payments have played a key role in making PV financially attractive for home owners and businesses. The policies have been justified on the basis that current energy markets do not price the adverse environmental impacts of conventional fossil-fuel generation or appropriately capture other market benefits such as reduced losses and network expenditure, on PV's investment and job creation potential and on the promise of reduced future PV costs.

S. J. Oliva and I. F. MacGill are with the Centre for Energy and Environmental Markets and School of Electrical Engineering and Telecommunications, University of New South Wales, Sydney, Australia (email: s.olivahenriquez@student.unsw.edu.au).

However, there have only been limited efforts to actually estimate the societal economic value of PV deployments. Part of the challenge is the complexity of PV generation and its temporal and locational variability and unpredictability. Furthermore, electricity industry economics are also highly complex with electricity value varying by time and location according to varied and uncertain energy user preferences, the mix of generation and network requirements. There is also the range of environmental and societal externalities associated with the electricity industry to consider.

As such, assessments of the economic societal value of PV are very context specific including factors such as the match of PV generation to existing electricity demand and network capacities at different points in the grid, and the electricity market and network expenditure arrangements in place within that industry [2].

Despite these challenges, such assessments could play a valuable role in determining the case for PV support, and tailoring support policies such as FiTs to maximise the economic value that PV can provide the electricity industry and society more widely.

For these reasons there is a growing amount of work undertaking economic valuation of the electricity generated by PV systems (PVelec). For example [3] estimates the market value of PVelec for different locations in California concluding that investments in PV systems are not currently socially beneficial (that is, costs exceed benefits) and government support for PV systems has not been well targeted with no focus on deployment in transmission-constrained areas or to minimise line losses. In the Australian context, [4] calculates the value of PVelec for different location in the South West Interconnected System (SWIS). It also obtained a valuation of benefits lower than costs.

However, there is still no general agreement on how such economic valuations should be undertaken including what costs and benefits should be included (particularly problematic with regard to externalities) and how they might be estimated. Furthermore, the falling costs of PV seen over recent years, rising electricity prices in many countries and growing efforts to price environmental externalities such as greenhouse gas emissions suggest that the gap between costs and benefits may be narrowing.

In this paper we undertake a preliminary and high level investigation of the economic value of PV generation within the Australian National Electricity Market (NEM) and consider its potential implications for PV policy making.

We first outline a possible framework for assessing the different components of economic value for PV generation including energy, losses, network and externality costs. We consider international work but focus particularly on the Australian and NEM context.

In Section III we then apply this framework to the case of a residential PV system in Sydney. Section IV presents a preliminary net economic benefit of such PV deployment given current PV system costs. Some potential policy implications are presented in Section V.

II. Economic Valuation of PVelec Benefits

As noted above, there is no widely agreed methodology for assessing the economic value of PV. One approach often seen in the literature is to calculate the net present value of PV systems given current retail electricity tariffs. However, these tariffs should not be confused with economically efficient prices reflecting the time and locating varying value of electricity. Instead, retail tariffs in most countries are better thought of as schedules of fees intended more for cost recovery. They also don't include externalities. As such, standard NPV calculations are private economic valuations rather than societal ones [2]. This also has implications for studies on the costs of FiTs as seen in [5] for the state of New South Wales (NSW) and in [6] for the state of South Australia. Failing to quantify the full range of societal economic costs and benefits of PV has important policy implications; for example, [7] explicitly mentions the gap in the accountability of benefits and costs of the proposed solar targets in the state of Victoria.

In this section we present some initial work on a possible framework for full economic valuation, separated into energy, losses, environmental externalities, network, power quality and security of supply values. We also discuss possible methods for estimating these values in the context of the NEM. These methods vary in their likely accuracy compared against the complexity, location specificity and data requirements involved.

A. Energy Value

In a competitive electricity market such as the NEM, the most straightforward way to estimate time and location varying electricity value is through the wholesale spot prices. Ideally, these prices the marginal cost of the generation meeting demand, which is the energy generation that PVelec is offsetting. In practice, these prices do not capture all aspects of energy value including locational aspects. We explore this further below.

B. Avoided Losses Value

Since PVelec is a form of distributed resource its generation will almost always be consumed locally, hence avoiding much of the energy losses associated with transmitting power from large and remote generating plant to end-users within the distribution system. Estimating such losses, however, is highly complex and location specific. Losses occur in the Transmission and Distribution wires yet also other network equipment, notably transformers (which have both so-called 'iron' and 'copper' losses). Most, but not all, of the losses are load dependent. For example, the contribution of PVelec to avoided losses is stronger in summer when daily peak demand can match reasonably well with PV system output.

One approach, as seen in [4], is to estimate avoided electricity losses from average loss factors at a system level or, preferably, according to more detailed location specific loss factors. The value of these losses can be priced at average wholesale electricity prices. The problem with this approach is that it doesn't take into account the non-linear relationship between losses and power flow in network elements. In particular, PV generation at times of higher demand reduces losses more than generation at low demand times.

A most sophisticated methodology is used in [3] where network losses are calculated with regard to the the square of the power flows, and the change in this over time. Ignoring locational issues, then, if G_t is the systemwide central station generation at time t, the overall system losses L_t can be expressed as in (1).

$$L_t = a \times G_t^2 \tag{1}$$

where a is a constant that can be derived by combining half hour system production data with the average aggregate losses in the system. If L is the percentage of the total power generation dissipated through line losses in the network then a can be obtained by (2).

$$L \times \sum_{t=1}^{T} G_t = \sum_{t=1}^{T} a\, G_t^2 \iff a = L \times \frac{\sum_{t=1}^{T} G_t}{\sum_{t=1}^{T} G_t^2} \tag{2}$$

Then the change in systemwide losses when one unit of delivered electricity is replaced by one unit of electricity from on-site solar PV is equal to (3).

$$\frac{dL_t}{dG_t} = 2aG_t \tag{3}$$

Finally, considering that the reduced line losses must be valued at wholesale price of electricity (4) shows the expression of this value per kWh plus the value of the avoided marginal cost of the central station generation.

$$v_t = w_t + w_t \cdot 2aG_t = w_t(1 + 2aG_t) \tag{4}$$

where w_t is the wholesale price of electricity. More sophisticated approaches are also clearly possible, including separating fixed and variable losses, and including locational network factors.

C. Avoided CO_2 Emissions Value

Unlike electricity generation from fossil-fuel power plants electricity from PV systems doesn't emit pollutants to the atmosphere during operation. Key pollutants include CO_2 emissions which contribute to global warming, and regional

NO_x and SO_2 emissions that have a direct impact on community health [8]. The environmental benefit of each kWh generated by a PV system is that it avoids the equivalent emissions of the generating plant who's output is displaced. Commonly, the value of this benefit can be assessed by multiplying the reduction in emissions (eg. tCO_2) by an estimated societal cost of those emissions (eg. $\$/tCO_2$).

We will only consider CO_2 emissions here but would note that some estimates of the NO_x, SO_2 and particulate pollution externality costs of Australian NSW coal fired generation are around the same as their direct operating costs [9].

There are significant challenges in estimating both the avoided emissions of PV generation, and the marginal value of these reductions. In theory, emission reductions will result from reduced output of the marginal (partially dispatched) generator in the power system. This generator varies with changing demand and mix of available plant over time and, given network losses and potential constraints, location. The simplest approach is to estimate emission reductions from the emissions intensity of the predominant generation technology in the power system [3] (eg. black coal plant for NSW and Queensland). It is also possible to use the estimated average emissions intensity over all generation. More accurate estimates could be based on the emissions intensity of the marginal plant. The impact of this approach can be significant; the marginal plant in some NEM regions at night will generally be coal plant whilst during the day it may often be Open Cycle Gas Turbines (OCGT) –with an emission intensity typically only 60-70% of coal plant [10].

Valuing the social costs of CO_2 emission costs is highly abstracted and hence controversial. These cost have been usually deemed by two approaches; as a control cost criteria which ultimately is materialized in a carbon price imposed on the electricity industry, and as a more general damage cost estimate arising from unchecked greenhouse emissions. Neither can be determined with any certainty given present uncertainties in both the climate science (particularly on adverse impacts from warming) and with respect to our greenhouse abatement options.

As such, carbon prices differ depending on the context and modelling used. At an international context [11] models global carbon 'control' prices obtaining an initial value of $\$25/tCO_2$ in a called medium global action scenario and $53\$/tCO_2$ in a called ambitious global action scenario.[1] The same report projects future domestic carbon prices in a called core policy scenario and a called high price scenario assuming initial carbon prices of $\$20/tCO_2$ and $\$30/tCO_2$ respectively. The International Energy Agency (IEA) estimates a carbon price of $\$43/tCO_2$ by 2020 [8].

On the other hand damage cost approaches calculate generally higher carbon costs because the economic risks of unchecked climate change may be extremely high, including the societal costs of drought, flooding, socially contingent effects, impacts on human health, as well as on the ecosystems upon which we depend [9]. Reference [12] estimates a damage cost of 31 $\$/tCO_2$ whereas [13] estimate 85 $\$/tCO_2$ in a called business as usual scenario.

Thereupon if I_t is the emission intensity of the marginal generation plant at time t and C the CO_2 emission cost then the value of the total energy, losses and externalities components of PVelec can be expressed as in (5).

$$V_t = w_t(1+2aG_t) + I_t \cdot C \tag{5}$$

D. Deferring Network Augmentation Value

Appropriately located PV systems in the grid may defer or avoid the augmentation of transmission and distribution infrastructure offering significant economic value. The key challenge is to estimate how much PV in what locations at what times and with what expected operational characteristics might be able to contribute to avoided network expenditure through reduction in peak loads.

This is enormously complex. Simplified approaches are available such as that of [3] where the reduction in transmission constraints, reflected in the California nodal prices, attempts to capture in some way this value by using such prices in the valuation of PVelec. This simplified method generally can't capture the reality of this value since it tries to generalize a calculation that intrinsically depends on the potential deferral of particular network investments.

By comparison [4] obtains this value for particular locations in the SWIS and with the calculation based on an assumed indicative deferral investment cost. Neither of these approaches is ideal.

An improvement to the mentioned approaches may be the use of estimated savings from the deferral of particular planned network investments – a process undertaken, for example, by NSW Distribution Network Service Providers (DNSPs) as part of their demand management obligations [19][20]. Such deferrals are triggered by the reduction of the peak demand in that location therefore if S is the financial savings per each kW of reduced peak load the contribution of PVelec to such a reduction has to be estimated to obtain this value. Then, defining for the day of peak demand a coincidence peak factor A as the ratio between the reduction of peak demand due to solar output and the maximum solar output during the day and a performance of the panels P as the ratio between the maximum solar output during the day and the total capacity of the PV system, the value of deferral investments per kW of PV installed can be expressed as in (6).

$$D = S \times A \times P \tag{6}$$

where D is the final PVelec deferral value per kW.

E. Impact on Power Quality Value

PV's contribution to power quality can be either positive or negative with respect to issues including intermittency, islanding, harmonics, voltage support and power factor correction. Reference [4] argues that if inverters that conform to Australian Standards are used, PV is unlikely to have a significant negative impact on power quality. Regardless, the

[1] Note that we have converted all $US estimates into Australian dollars at an exchange rate of 1 and haven't corrected for different $years.

impacts are likely to be extremely context and location specific. We do not attempt to quantify the costs or benefits of PV with respect to power quality in this work.

F. Security of Supply Value

As a form of distributed resource relying on a renewable energy source it has been argued that PVelec can contribute to the security and reliability of power systems through greater fuel diversity and decentralised infrastructure [14]. However, the quantification of these benefits may be very complex depending on the particular network, the reliability criteria and the electricity market itself. Reference [3] argues that monetary valuations of these effects are not particularly convincing.

Despite this value is not quantified in this work it's clear that a first approach to handle it is to have a look to those investments exclusively devoted to improve level of reliability in the power system and calculate what level of PV penetration may avoid them.

G. Available firm Capacity Value

PVelec can provide firm capacity to the system with high degree of reliability at a high level of penetration. However, electricity markets with no capacity payments like the NEM, known as "energy only markets", assume that capacity payments are getting paid in the energy component of the tariff. On the contrary, in those electricity markets that support capacity payments like the SWIS this value must be deemed separately from the energy valuation.

H. Reduction Stress in the System and Wholesale Prices Value

The value of PVelec can be maximized when it is generated during the peak hours of demand providing generally a more efficient use of the existing infrastructure. Regarding the energy value itself, during the peak demand PVelec offsets the production of high-cost peaking generation plants which may contribute as well to reduce wholesale prices. Reference [15] argues that PV deployment is a viable option to effectively hedge excessive spot market electricity prices in summer in the NEM given the highlighted coincidence of PV output with peak loads. None of their values have been addressed yet. This valuation is not addressed in this work.

III. Value of PVelec for a Residential PV System in Sydney

In this Section the total economic value of PVelec benefits during 2010 is estimated for a 1kW (approx.) north-facing PV system located in the western Sydney suburb of Blacktown. Actual half hour PV generation data for the full year 2010 has been obtained. Advice on this installation suggested appropriate orientation and tilt without obvious shading issues. Total annual production, however, was 945kWh/kW considerably less than the 1300-1400kWh/kW typically estimated by standard PV system models for Sydney. As such, our results may under-estimate the economic value of typical systems.

For the estimation of the energy and avoided losses value of each kWh of generated PVelec, each half hour of generation in 2010 was valued at the regional reference price for NSW (RRP) obtained from AEMO [16]. Whilst the NEM does estimate average loss factors for the inter-regional transmission these were not considered as they have little impact in the Sydney region.

An estimated 7% of the total power generation in the NEM is dissipated as network losses [17]. Applying the technique described for [3] above (and hence equation (2)) to the NEM for 2010 yields a value for a of $2.9\text{x}10^{-6}$ where half hour scheduled generation data from AEMO is used for G_t.

The value of avoided CO_2 emissions is estimated based on the emissions of the assumed marginal power station in the NEM every half hour during 2010. As noted above, identifying the marginal generator is not always straightforward. From AEMO's website generation data [18] it was confirmed that OCGT power plants somewhere in the NEM were generating during every daylight hour in the NEM. As an approximation, we assume that abatement will be typically at around the emissions intensity of OCGT plant –an average 0.76 [tCO_2/MWh] based on [10]. Furthermore, given that the Australian Federal Government has announced a carbon price of \$23/tCO_2 for the first year of its implementation in 2012 [11] this value will be firstly taken as the CO_2 emission cost.

Using these estimates suggests that the total value of PVelec during 2010 for this particular residential PV system is around \$94, with 69% (\$65), 12% (\$11) and 19% (\$18) corresponding to energy, avoided losses and avoided emissions values respectively.

Fig. 1 shows the total value of PVelec per month in 2010 and the contribution of each component. It is interesting to note that this monthly value is more than three times higher during summer than the rest of the year which is explained by the higher production of PVelec in this season, but mostly by the much higher observed wholesale prices. Also from March to November avoided CO_2 emissions value averages around 33% of the total value since they are not affected by the generally low wholesale prices over that period. Overall, an estimated 60% of the total economic value in 2010 is obtained from the months of December, January and February.

We believe our methodology provides more realistic estimates of energy value than common approaches based on average PV generation and market prices.

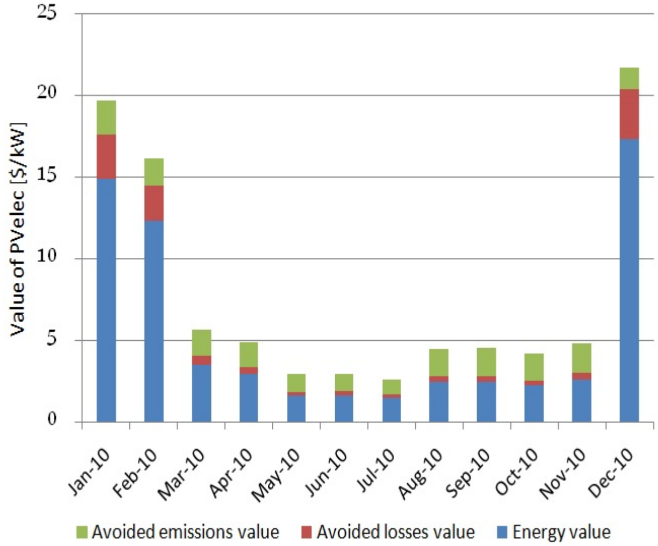

Fig. 1. Monthly PVelec energy value during 2010.

It captures the potential correlation between high PV generation and high air-conditioning driven demand (and hence high prices) in summer, and the typical absence of PV at times of peak demand and prices in winter. Our losses methodology also captures the likelihood of higher avoided losses with PV in summer given the generally higher demand during the day and PV's contribution to reducing its peak (as captured in (4)). One key uncertainty in these cost estimates, as noted earlier, is the relatively poor performance of the system being analysed by comparison with modelling estimates of typical PV system performance in Sydney.

As noted in Section II the valuation of PVelec contribution to avoided CO_2 emissions depends primarily on the chosen carbon price. Fig. 2 shows the total value of avoided emissions during 2010 for the range of potential emission costs discussed in Section II, and their share of the total PVelec value during this year.

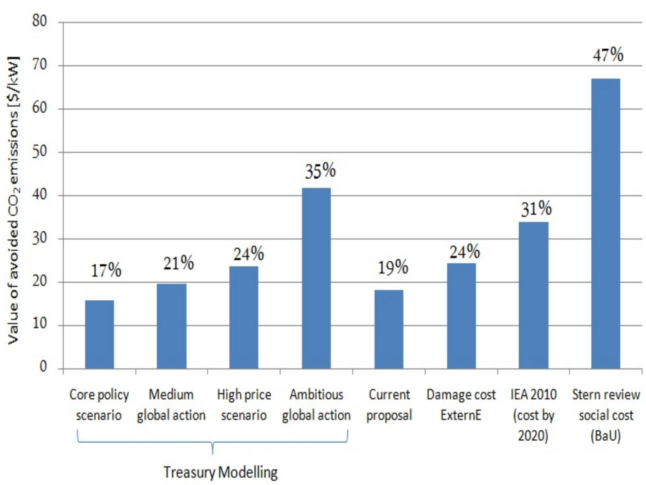

Fig. 2. Total 2010 value of avoided CO_2 emissions and percentage over the total energy valuation for different carbon pricing scenarios.

As expected the impact of using either a control cost or damage cost approach on final PVelec value is significant.

Regarding other pollutants, our assumption of OCGT plant as the expected marginal plant offset by PVelec means that the reduced emissions of particulates (PM_{10}), sulphur dioxide (SO_2) and nitrogen oxides (NO_x) do not have significant value, unlike that expected should coal-fired plant be the displaced generation.

To obtain indicative values of the potential network value of PV in deferring network augmentation, six particular locations around Sydney were chosen for more detailed study. One location was the Rooty Hill zone substation which supplies Blacktown where our PV system is located. We focus on sub-transmission infrastructure for this initial work. It has been argued [3] that solar PV systems are unlikely to offer significant value in reducing distribution infrastructure costs given that these grids are built to handle much greater demand than what is required due to the major economies of scale these systems involve. We intend to investigate this further, however this analysis focuses on deferral primarily at the level of the zone substation.

Demand management reports from the two Sydney DNSPs, Ausgrid and Endeavour Energy were used to estimate potential deferral values. The reports estimate the savings per kVA reduced per zone substation. For the peak load day the residual demand due to PVelec generation was calculated every hour to obtain the coincidence peak factor A between solar output (assumed to be the average output of the actual PV data during the month of that day) and peak demand.

From the Ausgrid website [19], we also obtained the the so called screening test reports that can give rise to a demand management investigation report. These investigation reports suggested that PV systems don't currently offer deferral value in five locations in Sydney, primarily because they presented mostly residential profile loads. On the other hand, in more industrialized areas PV systems can contribute to reduce the peak demand. Table 1 shows A, P, S (savings are given in $/kVA but for simplification we assume them in $/kW) and D from the potential model presented in Section II for five selected locations of the Ausgrid transmission system and for the Rooty Hill zone substation which is part of the transmission system of Endeavour Energy. Particularly the savings in the last case were obtained from [20] and [21] based on the deferral of the planned new North Glendenning zone substation.

TABLE I
PARTICULAR CASES OF DEFERRAL NETWORK INVESTMENT IN SYDNEY

Area/Zone Substation	A	P	S [$/kW]	D [$/kW]	Reason
Broadmeadow	94%	52%	103	51	Cheaper Investment
Charlestown	52%	47%	799	194	Deferral by 2 years
North Western Pennant Hills	72%	52%	608	229	Deferral by 2 years
Sydney East	37%	48%	161	28	Deferral by 2 years
Willoughby	91%	44%	550	220	Deferral by 1 year
Rooty Hill	68%	47%	204	65	Deferral by 1 year

Another important issue in the ability of PV systems to defer network augmentation is the degree of certainty of their production in a particular location at particular times in the future [4]. Nevertheless [22] argues that actual system production is less than the rated panel capacity which it can be verified in average terms as well in Table 1 observing the values of *P*. Reference [22] shows, based on monitored data from 28 installations in Newington, that the maximum output per 1 kW array on a high load summer day was 0.68 kW. On cloudy days, production levels are much lower. Therefore, in determining the level of coincidence and reliability of PV driven peak reduction of demand, both timing and cloudiness must be considered. Neither [3] or [4] estimated this value considering cloudiness factors. In a more sophisticated approach cloudiness may be addressed using historical data to build a probabilistic function that helps to calculate the likely contribution of PVelec to reduce the peak demand in areas facing imminent network constraints and hence potential augmentation investment.

IV. PV Systems in Sydney: Economically Beneficial?

This analysis attempts to determine if the investment in this 1kW (approx.) residential solar panel is socially beneficial by comparing the total economic value of PVelec during the lifespan of the system (assumed to be 25 years) against its capital and any ongoing costs. This value will change over time with movements in underlying wholesale electricity prices and, in particular, the potential introduction of a carbon price.

Notwithstanding the Australian Federal Government has already announced a carbon price of 23$/tCO_2$, The Treasury released the modelling of the impact of the carbon price based on a model that considers an initial price of \$20/tCO_2 with an annual increased for the next 2 years (until the transition to a cap-and-trade system) of 5% instead of 2.5%, arguing that “it was necessary to settle on the broad architecture of the global scenarios in late 2010 given the long lead times in commissioning detailed modelling of the electricity generation and other sectors” [11]. As a result this analysis considers future carbon prices and wholesale prices based on that modelling.

Assuming that OGCT plants keep being the peaking marginal plants during the entire lifespan of the solar panels, that the annual degradation factor of the panels is 0.5% and that the percentage of average losses in the NEM together with the total generation don’t change in the future, Fig. 3 shows estimates of the total value of PVelec per year calculated from (5) using the future carbon and wholesale prices modelling in [11] (for the second actual 2010 prices were escalated).

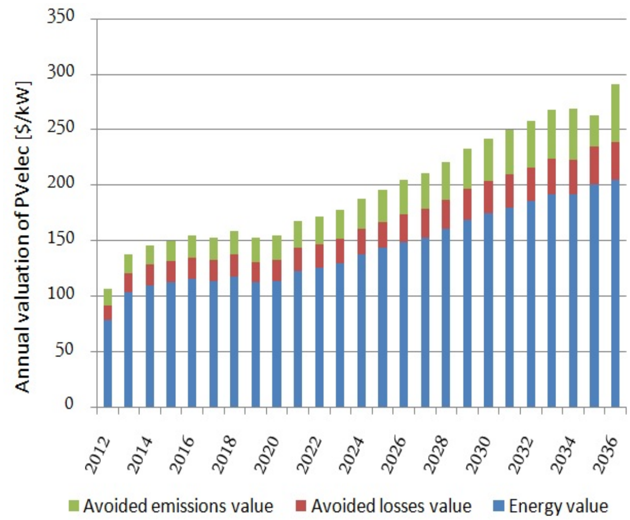

Fig. 3. Future annual value of a 1.1 kW residential PV system located in Sydney.

From Fig. 3 it can be seen that PVelec value increases every year because of the increase in projected carbon and wholesale prices whereas the share of its three constituted components keeps almost the same.

Likewise it’s possible to calculate the payback that the PV system owner would receive if he got paid this economic valuation discounting and summing the already calculated annual values. Fig. 4 shows the estimated cumulative economic value of PVelec (without the value for deferred investments) for the PV system in Blacktown and, given its general mentioned bad performance, for an average output PV system obtained by escalating the actual data to an standard performance in Sydney with an annual production of 1350kWh/kW. Different discount rates are using.

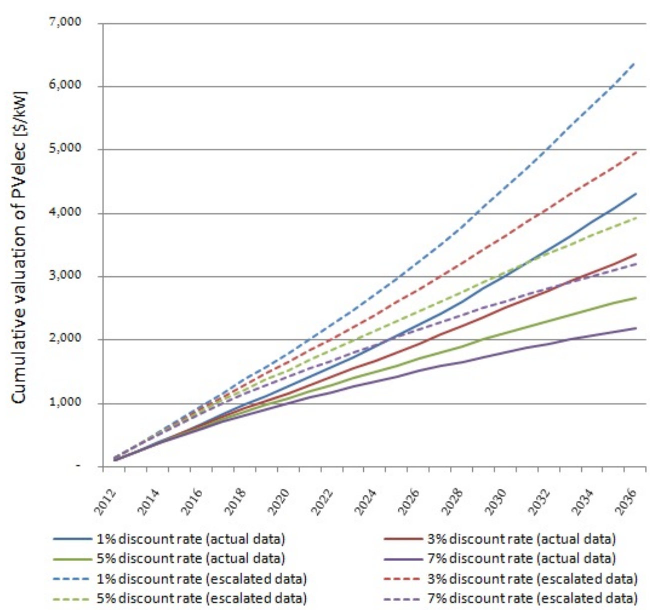

Fig. 4. Cumulative PVelec of a residential PV system.

PV system costs have fallen significantly over the last two years. While prices vary considerably according to brand, location and installation costs, PV systems are now commonly being quoted at around $4000/kW for Sydney (before application of current Federal government support). For simplicity we ignore potential ongoing PV system O&M costs such as inverter replacement. Despite the significant approximations involved in our methodology as outlined in Section II, and specific assumptions required for our case study as shown in Section III, our findings suggest that standard residential PV systems are economically beneficial in Sydney for the three lowest discount rates used where the two lowest are considered by [3] as appropriate rates for social analysis. The particular PV system in Blacktown is economically beneficial just when a discount rate of 1% is used. This outcome includes our estimates of the potential network value of PV at sites which have been identified as having significant network deferral value.

Some significant provisos are in order. The complexity of electricity industry economics poses very significant challenges for the type of study we have attempted here. Our framework does not include all potential electricity industry costs and benefits associated with PV. Some of the estimated costs and benefits that do lie within our framework have very high uncertainty – network value is a particular example. The cost of PV systems continues to fall, whilst electricity prices are rising very significantly under a range of factors beyond carbon pricing. The current expectations for carbon pricing in Australia that we applied appear significantly less than the prices estimated to be required globally in order to reduce emissions sufficiently to avoid dangerous climate change [8]. We have not considered wider potential social benefits such as investment and job creation opportunities with PV, or reduced water, land-use and regional air pollutant externalities. Particularly importantly, we haven't considered the role that early deployment of PV can play in reducing future costs – indeed, a major achievement of the PV industry in recent years. There is also considerable controversy on what discount rates should be applied. For example as it was mentioned, [3] argues that the two lower discount rates are more suitable for public policy analysis whereas the two higher ones can better represent the market opportunity cost of capital for owners.

V. Conclusions and Future Work

Estimating the societal economic costs and benefits of PV is an extremely challenging task. However, it has significant potential value to policy makers and, we would argue, should play a more significant role in policy development.

Our preliminary work, and that of others, has highlighted the different value of PV in different contexts such as location in the network, and match with underlying demand.

At an economic valuation level further investigation is required to quantify the externalities of PV systems whose estimation becomes ever more complex with the level of sophistication desired. Particularly security benefits value of distributed resources is a subject that hasn't been addressed yet and that potentially may provide increase value to PV systems if the level of reliability of power systems are improved and/or investments of project devoted to improve reliability can be avoided. Furthermore, the calculations of the commonly quantified externalities may be improved giving them a higher level of sophistication, for example calculating more accurate power losses in the network or using actual demand management investigations to assess the value of deferral network augmentation for high penetration of PV systems. A key issue to consider is what represents the most appropriate level of complexity in quantifying costs and benefits.

In future work we plan to explore better methodologies, and apply more accurate data to this economic valuation of PV, and then consider some specific policy implications for PV support in Australia.

VI. Acknowledgment

The authors gratefully acknowledge the contributions of Simon Lewis in helping provide PV output data from a residential house connected to Endeavour Energy distribution system. This work is supported in part by Australian Solar Institute (ASI) research funding to support research on solar forecasting and renewable energy integration, and managing high PV penetrations.

VII. References

[1] J. Sawin, and E. Martinot, "Renewables 2011: Global Status Report," Renewable Energy Policy Network for the 21st Century (REN21), Paris, 2011.

[2] B. Elliston, I. MacGill, and M. Diesendorf, "Grid parity: A potentially misleading concept?," Solar2010, the 48th AuSES Annual Conference 1-3 December 2010, Canberra, ACT, Australia.

[3] S. Borenstein, "The Market Value and Cost of Solar Photovoltaic Electricity Production," Centre for the Study of Energy Markets, University of California, WP 176, Jan. 2008.

[4] R. Passey, M. Watt, H. Outhred, T. Spooner, and M. Snow, "Study of Grid-connect Photovoltaic Systems - Benefits, Opportunities, Barriers and Strategies," Report prepared on behalf of NewSouth Global Consulting for The Office of Energy Western Australian Government, Sydney, Australia, Dec. 2007.

[5] J. Balding, and D. Kua, "Solar Bonus Scheme: Forecast NSW PV Capacity and Tariff Payments," AECOM Australia Pty. Ltd., Sydney NSW, Prepared for Industry & Investment NSW, Oct. 2010.

[6] P. Miley, "South Australia Feed-In Tariff Review–Final Report," Consulting Partners, Prepared for the South Australian Government, Brisbane, QLD, 2010.

[7] Victorian Auditor-General, "Facilitating Renewable Energy Development," Victorian Auditor-General's Report, Apr. 2011.

[8] IEA, "Energy Technology Perspectives 2010: Scenarios and Strategies to 2050," OECD/IEA, Paris, 2010.

[9] T. Biegler, and D. Zhang, "The Hidden Costs of Electricity: Externalities of Power Generation in Australia," Australian Academy of Technological Sciences and Engineering, Mar. 2009. [Online]. Available: http://www.apo.org.au/node/4196. Last accessed July 24, 2011.

[10] ACIL Tasman Pty Ltd, "Fuel resource, new entry and generation costs in the NEM," Final Report, Prepared for the Inter-Regional Planning Committee, Apr. 2009.

[11] Australian Government: The Treasury, "Strong growth, low pollution: modelling a carbon price," 2011.

[12] European Commission, "ExternE, Externalities of Energy: Methodology 2005 Update," Institut für Energiewirtschaft und Rationelle Energieanwendung — IER Universität Stuttgart, Germany, 2005.

[13] N. Stern, "STERN REVIEW: The Economics of Climate Change: Executive Summary," 2006.

[14] P. Asmus, "The War Against Terrorism Helps Build The Case for Distributed Renewables," The Electricity Journal, Volume 14 (2001), Issue 10, pp 75-80.

[15] D. Sivaraman and R. E. Horne, “Regulatory potential for increasing small scale grid connected photovoltaic (PV) deployment in Australia,” Energy Policy 39 (2011) 586–595.

[16] AEMO website, http://www.aemo.com.au/data/price_demand.html, Last accessed 11-08-11.

[17] M. Thomas, “Electrical news,” Quarterly Publication for Members of Engineers Australia’s Electrical College, Issue 27, Feb. 2011.

[18] AEMO website, http://www.aemo.com.au/data/csv.html#scada, Last accessed 11-08-11.

[19] Ausgrid website, http://www.ausgrid.com.au/Common/Our-network/Demand-Management/Program-progress-tracking.aspx, Last accessed 11-08-11.

[20] Futura Consulting, “Audit of Integral Energy’s D-Factor Claim for FY09/10,” Final Report to Integral Energy, Jan. 2011.

[21] Endeavour Energy, “Annual Planning Statement: 2011 Electricity System Development Review,” Jun. 2011.

[22] Ausgrid (2009, Nov.). “Demand Management Investigation Report: Sydney Inner Metropolitan Area,” Energy Australia and TransGrid, [Online]. Available: http://www.ausgrid.com.au/Common/Our-network/Demand-Management/~/media/Files/Network/Demand%20Management/Demand%20Management%202/Progress%20tracking/Investigation%20reports/DMIR_Sydney_Inner_Metro.ashx, Last accessed 08-08-11.

[23] Energy Matters, http://www.energymatters.com.au/specials/nsw-solar-power-deals.php, Last accessed 10-08-11.

[24] NSW Government Taskforce, “NSW Solar Feed-in Tariff Report to Ministers,” Feb. 2009.

VIII. Biographies

Sebastian Oliva received his BH in Electrical Engineering from the University of Chile, Chile in 2008. He is currently pursuing the Ph.D. degree at the School of Electrical Engineering and Telecommunications, University of New South Wales, Sydney, Australia. His research interests include renewable energy policy and energy economics.

Iain MacGill is an Associate Professor in the School of Electrical Engineering and Telecommunications at the University of New South Wales, Sydney, Australia, and Joint Director for the University’s interdisciplinary Centre for Energy and Environmental Markets. His teaching and research interests include electricity industry restructuring and sustainable energy technologies, with a particular focus on distributed resources and energy policy.