Social and Private Valuations of Commercial Photovoltaic Systems in Australia

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Abstract— **Commercial distributed PV systems present different economic values for each stakeholders in the electricity industry. While societal valuations are driven by PV performance and environmental cost, the private value depend on commercial arrangements between participants and PV policies. These estimations can play an important role helping to tailor PV policies that maximize PV benefits for industry participants. In this paper we assess the current and future social and private value of a particular commercial PV system for the society, retailers, DNSPs and PV customers using different pricing arrangements and carbon cost scenarios. Our results show that the economic value varies considerably for stakeholders, that the system is socially beneficial and that payback periods for PV owners range from 8 to 10 years.**

Keywords-Economic Analysis, Commercial PV systems, Feed-in tariffs, Australia

I. INTRODUCTION

Photovoltaics (PV) has experienced remarkable growth in deployment over the past decade [1]. Whilst system costs have fallen significantly over this time, this deployment has been largely driven by supportive government policies in a number of key countries. Some 109 countries have implemented policies to support renewable power generation by early 2012 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 65 countries and 27 states/provinces worldwide in 2012 [1].

FiTs have demonstrated their effectiveness in promoting PV deployment in a growing number of countries [1], however, this success has raised growing concerns about the expense of such FiT policies on other energy users who pay the program costs [2][3]. Although PV costs are falling, it still generally doesn't make financial sense for energy users to install systems given current retail electricity tariffs around the world. FiT payments have played a key role in making PV financially attractive for home owners and businesses. The policies have generally 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, and because of PV's investment and job creation potential and the promise of reduced future PV costs and eventually an economically self-sufficient PV industry.

FiT policies provide a means to 'price' PV's wide range of potential societal benefits into current private commercial arrangements for energy market participants. There are, however, two key challenges in appropriate policy design:

- the overall societal economic value of PV is highly complex to assess given the variable and uncertain nature of PV generation, its location within the distribution network and its potentially wide range of environmental benefits that are still externalities in many industries
- the current private commercial arrangements for small energy users in almost all electricity markets are not economically efficient in terms of pricing the time and location varying value of electricity. Furthermore, the integration of PV systems at energy user premises has complex interactions with these arrangements in terms of the costs and revenue flows for different market participants

An improved understanding of these social and private costs and benefits of PV could be of considerable value in appropriate PV policy design to maximize the societal economic value of PV through appropriate incentives for private electricity industry participants.

In this paper we undertake a preliminary and high level investigation of the economic value of PV generation (PVelec) on electricity retailers, Distribution Network Service Providers, PV customers and society more generally within the Australian National Electricity Market (NEM). The focus is on medium size (10-200kW) PV systems placed on commercial buildings. We use PV data from a particular commercial installation in the Australian State of New South Wales (NSW), and explore these valuations using different possible future pricing arrangements and carbon price scenarios. This work focuses on PV's economic value on the margin – that is, we ignore dynamic effects of PV deployment that become material in the longer term with a high PV penetration.

The remainder of this paper is organized as follows. In the first part of this article Section II describes the current literature on PV value, Section III outlines a possible framework for assessing PV value for society as a whole, and key stakeholders in the context of the Australian NEM and Section IV provides details on our datasets and assumptions. Our results are presented in Section V while Section VI presents some preliminary conclusions on the work, and possible future directions.

II. LITERATURE REVIEW

There is a diverse and growing literature on PV economic valuation. Our social PV valuation is based upon an analysis framework that we initially presented in [4], whilst the private PV valuations are estimated according to current commercial arrangements in NSW.

Previous works on social PV valuations include [5] and [6] which undertook social PV valuations in the US context. Both [5] and [6] didn't explicitly address long term environmental PV values and obtained total social benefits lower than system costs. In the Australian context [7] found that societal PV benefits in the South West Interconnected System of Western Australia were lower than its costs as well. However, PV costs have reduced considerably since those estimations were carried out. More recently [8] valued PV benefits in the Australian NEM although ignoring environmental PV benefits. This estimation of a value close to the wholesale price of electricity [8] did acknowledge the potential need for PV policy support to account for PV benefits that the current market arrangements don't provide to parties who deploy PV systems.

Most previous work has focused on private assessments for PV customers rather than societal ones. References [9], [10] and [11] investigated the impact of different electricity retail arrangements on PV customer returns in California. Reference [12] assessed the Net Present Value (NPV) for PV owners in Western Australia obtaining a negative value. Reference [13] assessed the PV value not only for PV customers but also retailers and distribution network service providers (DNSPs) in NSW, whilst the most recent determination of the Independent Pricing and Regulatory Tribunal (IPART) also estimated the value of PV exports to the grid, coming up with a value close to the wholesale price of electricity [14].

We observe from this literature review that there is still no general agreement on how social economic valuations of PV should be undertaken including what costs and benefits should be included (particularly problematic with regard to externalities) and how they might be estimated. Moreover private valuation is very context-specific depending on the particular PV pricing arrangements and PV policy support in place within a given jurisdiction.

III. METHODOLOGY

In this section our approach to estimate the PV value for participants is presented. Key electricity industry stakeholders in the Australian context for distributed PV include:

- The society as a whole;
- Retailers (known as suppliers in some other industries such as the UK) who purchase electricity from the wholesale market and sell to energy users through retail tariff contracts;
- Distribution Network Service Providers (known as DISCOs in some industries) who are regulated monopolies within their service region that own and operate the distribution network, and charge regulated network tariffs to retailers;
- Customers who are potentially ready, willing and able to install a PV system on their premises;
- Large generators selling into the wholesale market; and
- Other electricity consumers that don't have PV systems.

We begin by presenting our approach to estimate the PV value for the society, then our methodology for estimating PV costs and benefits for private participants in NSW and finish with a brief discussion on the dynamic value of PV.

A. Social PV Value

Our approach to estimate this economic value is based upon the one used in [4] where energy, avoided losses and environmental benefits were considered. Below briefly this methodology is described but for more detailed explanations refer to reference [4].

1) Energy: 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 represent the marginal cost of the generation meeting demand. That marginal generation is offset by PV generation. As such, if at time t, E_t is the energy component of the PV value, $PVelec_t$ is the PV generation in kWh and w_t is the wholesale price of electricity adjusted by loss factors then this value is as in (1).

$$E_t = w_t \times PVelec_t \tag{1}$$

2) Avoided Losses: Since PVelec is a form of distributed energy 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 transmission and distribution systems. Estimating such losses, however, is highly complex and location specific.

As such, our approach to estimate this value, based upon a method described in [6], calculates power losses with regard to the square of the power flows, and the change in this over time. Thereby, ignoring locational issues, if G_t is the system-wide central station generation at time t, the overall system losses l_t can be expressed as in (2).

$$l_t = \alpha \times G_t^2 \tag{2}$$

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Where α is a constant that can be derived by combining half-hourly system production data with the average aggregate losses in the system. If L is the average percentage of the total power generation dissipated through losses in the network then α can be obtained by (3).

$$L \times \sum_{t=1}^{T} G_t = \sum_{t=1}^{T} \alpha \times G_t^2 \Leftrightarrow \alpha = L \times \frac{\sum_{t=1}^{T} G_t}{\sum_{t=1}^{T} G_t^2} \quad (3)$$

Then the change in system-wide losses when one unit of delivered electricity is displaced by one unit of electricity from on-site solar PV is equal to (4).

$$\frac{dl_t}{dG_t} = 2 \times \alpha \times G_t \quad (4)$$

Finally, considering that the reduced losses have to be valued at wholesale price of electricity adjusted by loss factors, (5) shows the final expression of this value L_t.

$$L_t = 2 \times \alpha \times G_t \times w_t \times PVelec_t \quad (5)$$

3) Avoided Emissions: 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 SO_2, NO_x and PM_{10} emissions that have a direct impact on community health. The environmental benefit of each kWh generated by a PV system is the avoided equivalent emissions of the generating plant who's output is being displaced. Commonly, the value of this benefit can be assessed by multiplying the avoided emissions (eg. tCO_2) by an estimated societal cost of those emissions (eg. $\$/tCO_2$).

Therefore, if at time t, I_t is the emission intensity displace by PVelec, SCC_t is the damage social carbon cost a CO_2 emissions and H_t is the health damage costs avoided with the PVelec, then the environmental PV value ENV_t can be expressed as in (6).

$$ENV_t = \left(I_t \times SCC_t + H_t\right) \times PVelec_t \quad (6)$$

As noted earlier, this assessment focuses on the energy, losses and environmental PV value. Hence this approach leads us to a social PV value S_t at time t as in (7).

$$S_t = \left(w_t + 2\alpha \cdot G_t \cdot w_t + I_t \cdot C_t + H_t\right) \times PVelec_t \quad (7)$$

B. Private PV Value

To estimate this value we calculated the immediate or marginal financial impact of PVelec on operational revenues and costs for industry participants. This approach requires estimating the change in cash flows for participants when a commercial PV system is implemented, from those cash flows prior to system installation. As noted earlier, this estimation considers only the immediate impact of commercial PV systems and ignores dynamics effects of the second order such as movements in generation, network and retail prices. Also, under current pricing arrangements in NSW PVelec doesn't change financial streams of participants obtained from fixed charges, hence those have also been ignored.

We undertake this private valuations under current arrangements for commercial PV system in which owners experience only electricity bill savings. These arrangements and PV financial impact are explained below.

1) Electricity Bill Savings: Unlike residential loads, commercial loads peak generally during hours of high PV generation. Given this, and the relatively high loads of many commercial installations by comparison with available roof space, it is assumed that these commercial facilities consume all their PV generation rather than exporting to the grid [14]. This assumption will not hold for all installations and all time periods (for example, weekends).

This assumption means that there's no need to consider potential finacial arrangemetns for exported PV generation, a controversial issue in Australia and many other jursidicctions. Instead, these customers experience only bill savings since they don't have to purchase PVelec from electricity retailers. Thereby, (8) shows this cash flow where at time t, again $PVelec_t$ is the PV generation and R_t is the electricity retail tariff. We note that R_t may include demand charges in which case PVelec must be separated in kWh and kW at the time of the peak demand (usually during the day).

$$\Delta PVc_t = R_t \times PVelec_t \quad (8)$$

At the same time retailers experience less sales of electricity while DNSPs lose revenues for the electricity they cannot charge to retailers.

Retailers sell less electricity therefore avoiding its purchasing costs. These costs include network charges N_t, green obligations g related with the Federal Renewable Energy Target (RET), retail operating costs ROC and costs of purchasing electricity from the wholesale market including losses plus other minor costs. Equation (9) shows this impact.

$$\Delta R_t = \left(-R_t + N_t + w_t + g + ROC\right) \times PVelec_t \quad (9)$$

DNSPs charge retailers per kWh sold to end-users and per kW peak consumed. DNSPs lose these revenues streams with the PV generation as (10) shows.

$$\Delta DNSP_t = -N_t \times PVelec_t \quad (10)$$

For both retailers and DNSPs N_t must include demand charges if it is the case.

C. Dynamic PV Value:

High levels of PV penetration can impact on industry participants moving prices and/or offering potential additional benefits or generating additional costs. However, this impact will be material in the longer term with the increase of PV installation.

Some clear dynamic impacts of a high PV penetration in the NEM is the reduction of total demand which in turn reduces wholesale prices; particularly in hot weather periods where high demand and very high spot prices match well with high PV output. Also, high PV generation may defer or avoid the network augmentation, offering financial value of capital expenditure that reduce network charges and hence retail prices. Others potential impacts include an better security of supply through greater fuel diversity and decentralised infrastructure and an either positive or negative effect on grid power quality

IV. DATA AND ASSUMPTIONS

To carry out these estimations actual PV generation data is used for a one year period from July 2009 to June 2010 (2009/10) obtained from a 42 kW PV system installed on the Quad building of The University of New South Wales. The campus is located in the distribution network of Ausgrid in the eastern suburb of Kensington, Sydney, Australia. The generation of this system over that year was 50,000 kWh/year or 1,255 kWh/kW/year. This value is close to the average 1,286 kWh/kW/year for 1 kW PV systems during 2010/11 in the Ausgrid distribution area in Sydney [14]. Furthermore we use actual wholesale electricity prices data for 2009/10 obtained from the regional reference price (RRP) for the state of NSW published by the Australian Energy Market Operator (AEMO) [15]. These prices were adjusted by the corresponding marginal loss factor (MLF) and the distribution loss factor (DLF) for that area whose values are 0.8% and 5.7% respectively [15]. This approach captures the correlation between PVelec and wholesale prices which is a key driver of PV value for most electricity industry participants.

This dataset appears reasonably representative of the long term average wholesale prices in NSW. The average wholesale price during 2009/10 was 44 \$/MWh while the average wholesale price of the last 7 years is 46 \$/MWh [16].

Private commercial cash flows between market participants were estimated using time of use (TOU) 2011/12 Ausgrid network charges and AGL retail electricity tariffs for business customers in Sydney [17][18]. It was assumed that the customer is on the so-called ‘PowerSmart’ and ‘LoadSmart’ AGL tariff whose corresponding Ausgrid network charges are called EA225 and EA302 respectively. These charges are shown in Table I.

TABLE I. RETAIL TARIFFS AND NETWORK CHARGES

Type of Charges	PowerSmart	LoadSmart	EA225	EA302
Peak [¢/kWh]	44.11	29.81	24.17	10.29
Shoulder [¢/kWh]	18.7	24.53	5.85	8.16
Off-peak [¢/kWh]	10.34	12.32	2.28	4.39
Capacity [¢/kW/day]	-	29.7	-	29.7

For the retailer PV value we use a reference value of *g* of 9.8 \$/MWh and *ROC* of 11.5 \$/MWh obtained from the retailer cost component of regulated retail prices for 2011/12 [19].

Regarding the societal PV environmental value in this paper avoided CO_2 emissions are estimated based on the weighted half-hourly average emissions intensity in tCO_2/MWh over all fossil fuel generation in NSW. Likewise, it is assumed regarding health damage costs that PVelec avoids the half-hourly weighted average health damage costs in \$/MWh over the total generation between black coal, brown coal and natural gas power plants, technologies that have well known health damage costs in Australia [20]. We estimated these averages values using actual 2009/10 NEM generation data obtained from AEMO, emission intensity factors of NSW plants from [21] and health damage costs of black, brown coal and natural gas power plants in Australia from [20]. Given that this emission factors and damage costs are based on full lifecycle assessments we consider as well in our estimations a PV lifecycle emission cost of 5 \$/MWh according to [20].

Social carbon costs are incorporated by using two climate change policy scenarios from the PAGE2009 model [22] called A1B with gives a value of 130 AUSD(2009)/tCO_2 and Low emission scenario (LES) with a value of 68 AUSD(2009)/tCO_2. While the A1B scenario is a business as usual scenario that assume a more integrated world with a balanced emphasis on all energy sources and LES aims to have a 50% chance of keeping the rise in global mean temperatures below 2 degC obtained from [22].

Finally, to estimate power losses value through (3) an average losses value in the NEM of 10% is used according to [14] besides total half-hourly scheduled generation data in the NEM in 2009/10 published by AEMO [15].

V. RESULTS

In this section we present the economic value of this commercial PV system for different stakeholders over the 2009/10 and over the life of the PV system. First, the current PV value during one year period is shown to finish with a NPV analysis to determine when this system is economically beneficial for participants under current technology costs.

A. Current PV value

Using 2009/10 PV data, generation and wholesale prices; and 2011/12 network charges and retail costs and prices; Fig. 1 shows the estimated annual value of this commercial PV system for the electricity retailer, the DNSP, the PV customer and the society under different pricing arrangements. Notwithstanding the societal value doesn’t vary with the commercial arrangements, we show it in this chart for comparative purposes.

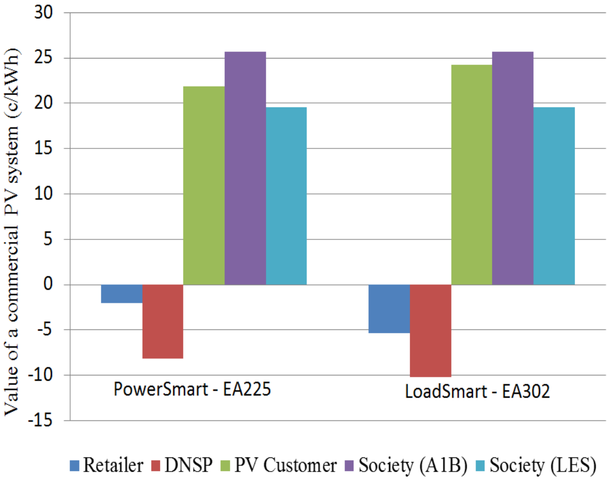

Figure 1. Annual PV value for different industry stakeholders.

It can be seen from Fig. 1 that PV value varies considerably between participants and with pricing arrangements. Using two actual TOU retail tariffs for business customers both retailers and DNSPs experience financial losses led by the less sales of electricity. Unlike retailers, DNSPs experience significant losses in revenues since they don't save immediate costs with PVelec. In the NEM network expenditure is largely driven by the forecast of future demand, yet the installation of PV systems may alter such forecasting. Furthermore with the use of a TOU tariff for bigger loads which adds charges per kW of peak the financial impact on participants is greater. We note as well that PV generation coincides not only with high spot prices but also with high TOU rate causing a greater financial impact than using flat tariffs. Finally it can be seen that PV offers a significant network value for owners through the avoided retail tariff which is transfer in turn from the DNSP. On the other hand, the social network PV value is part of a dynamic valuation that was not undertaken in this work.

Clearly all values shown in Fig. 1 will increase over time driven by the increase in future carbon costs, wholesale prices and retail prices as it can be seen in the NPV analysis below.

B. *NPV Estimations*

To determine if this commercial PV system is economically beneficial for the society and PV customers we estimate its valuations over the whole life of the systems which is assumed to be 25 years. Our assessment starts from the 1st of July of 2012 with the introduction of the Australian carbon price, however, for future years we use the 2009/10 PV generation data adjusted by a 0.5% degradation factor. Also, current monetary valuations were escalated by the future projections prepared for Australian Federal Treasury. For social valuations wholesale prices projections were used under a called 'medium global scenario' which considers Australia without a carbon price, hence we avoid double accounting carbon costs [23][24]. For private valuations future carbon prices were considered and wholesale and retail electricity prices were escalated under two scenarios for the Australian carbon price: A 'Clean Energy Future' (CEF) scenario which assumes an initial price of 23 $/tCO_2$ (current government proposal) and a 'High Price Scenario' (HPS) which assumes a price just under 30 $/tCO_2$ [25]. Further, to estimate the future value for the society we use an annual SCC increase of 2.4% according to [26]. Moreover, we escalate total generation in the NEM by the increase of total future electricity demand based on [25] as well. Furthermore, it is assumed that from the second year of operation onward PVelec displaces CO_2 emission intensities and avoids other pollutants damage costs as in the first year (averages calculated based on 2009/10 data). Additionally we assume that the average systemwide power losses L of 10% and loss factors remain the same in the future.

To determine payback periods for the society we use a technology cost before subsidies of 3,900 $/kW for systems of size up to 5 kW accordingly with [27]. For PV customers it was considered that upfront cost minus the multiplication between the renewable energy certificate price related to the Australian RET, that it was assumed to be 38 $/MWh as in [8], and the annual generation of 1,255 kWh which lead to a net capital cost of 2,708 $/kW. We note that the bigger the size of the systems the cheaper they are; hence we may slightly over-estimate payback periods. However we ignore costs related with PV component replacement such as the inverter which may add around 20% of the total capital costs before subsidies. All future PV valuations are shown in 2012 Australian dollars

As such, first, using (7), the curve of cumulative NPV of this commercial PV system for the society was built using different discount rates and under both the A1B scenario and the LES as Fig. 2 shows.

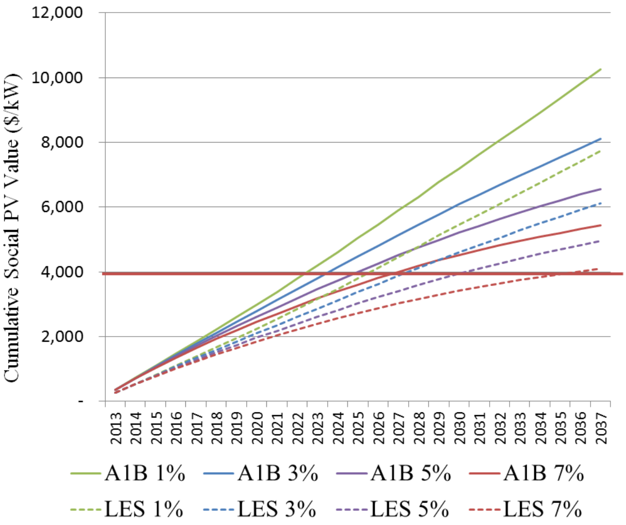

Figure 2. Cumulative NPV of the PV value for the society over the life of the commercial PV system.

Clearly curves vary enormously with the discount rate. [6] argues that a discount rate of 1% and 3% is more suitable for social analysis whereas a 5% and 7% is more suitable for private returns analysis. Considering the mentioned PV capital costs Fig. 2 shows us that this particular commercial PV system is socially beneficial for all the scenarios presenting social payback periods of 11 to 15 years for the A1B scenario and 14 to 23 years for the LES.

From a private perspective, using a discount rate of 5%, Fig. 3 shows the cumulative NPV curves of PV value for this PV customer under our two selected TOU prices and carbon price scenarios.

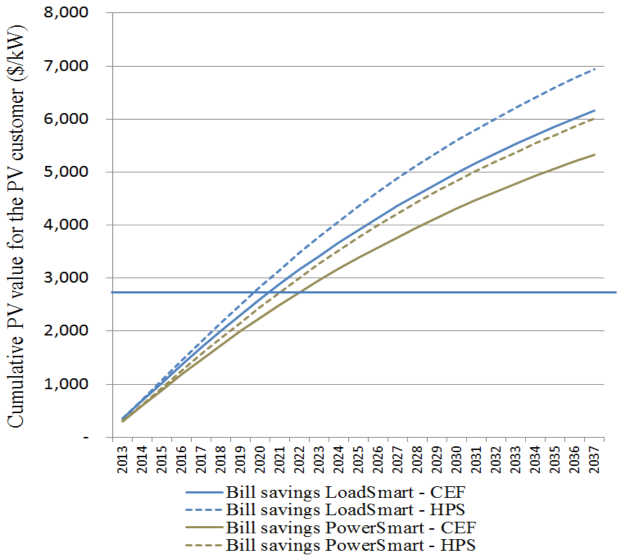

Figure 3. Cumulative discounted PV value for commercial PV customers.

From Fig. 3 we see that under a HPS this commercial PV system is more convenient for owners than under the CEF scenario since it allows them to save higher electricity retail tariffs. Further it can be seen that, with these retail tariffs, bill savings makes financial sense for owners, offering payback periods ranging from 8 to 10 years which is considered an acceptable time [8]. Moreover it seems that business tariffs that include demand charges (commonly large business facilities) offer a higher PV value for owners which can be explained by the general good coincidence between peak demand in commercial loads and high PV output.

VI. CONCLUSIONS AND FUTURE WORK

Our results show that the value of commercial PV systems varies considerably for industry stakeholders. While the value for the society varies with features like the coincidence between PV generation and wholesale prices and carbon costs, the private value varies with commercial arrangements and PV policies. We show that this particular commercial PV system is socially beneficial. Regarding private valuations it can be seen that under current pricing arrangements payback period for commercial PV owners ranges from 8 to 10 years. However we ignore this time dynamic PV economics.

Finally in terms of future work we highlight that further investigation has to be conducted dynamic PV economics and on the opportunities that control and storage may offer to maximize the PV value.

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