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Making Economic Sense of Green Energy: Photovoltaic Application in Two Houses, Bangi, Malaysia

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Abstract: The reality bites for 'green energy' when the economic assessment shows it as not a viable investment. Economic assessment for projects normally uses Return on Investment (ROI), Payback Period (PBP), Life Cycle Assessment (LCA), Life Cycle Cost (LCC) and Cost Benefit Analysis (CBA). Several studies have argued against these tools; but they are common due to lack of alternatives. To demonstrate the detrimental effect of these tools, they are applied in two simulation cases known as Passive Architecture (PA) case and non PA case that intend to use photovoltaic (PV) as a power source for mechanical cooling in the living/dining area. In all situations, ROI, PBP and LCC portrayed PV as unfavorable investment mainly due to its high capital cost that dwarfs the likely financial gain of not having to pay electricity bills. The study found LCA and CBA as inappropriate for the purpose because their considerations exceed the boundary of house owner's concern. These methods miss to capture investment in PV as a process from the status quo, i.e., using mains electricity from the grid. They do not account for the marginal benefits of associated actions such as using Energy Efficient equipment or making a house to be climatic responsive as shown in the PA case. Indifferent use of these gauges had resulted for economic misrepresentation of PV and consequently hinder public acceptance of such 'green energy'.

Key words: Investment · Costs · Benefits · Photovoltaic and Green Energy

INTRODUCTION

'Green energy' is a casual term for renewable energy such as from wind power and solar power. The abundance and perpetual nature of 'green energy' offers credible benefits to mankind and planet Earth. However, the reality of built environment requires 'green energy' to not only claim technical benefits but also economic benefits for the stakeholders because that is a major element that influences the uptake of such endeavour [1]. A study has shown that whilst the society claims to be concerned on the environment and aware of the technical benefits of 'green energy', they are not willing to spend on it [2].

A popular 'green energy' scheme is photovoltaic (PV) system that generates electricity from solar power. The PV cells are made of two thin silicon layers with different amount of impurities that generate electrical field when exposed to sunlight. An inverter in the system converts the direct electrical current from sunlight to be alternating current for household's consumption [3]. Unfortunately, PV is well-known as unfeasible investment mainly because the capital cost of such system is relatively high compared to the alternative, i.e., mains electricity supply from the national grid. This paper assesses the economic sense of using PV to power the mechanical cooling requirement for a living/dining area in two simulated detached houses of different designs; one is designed with climate while the other is without consideration to the climate. The idea is to demonstrate the effect of using common economic tools such as Return on Investment (ROI), Payback Period (PBP), Life Cycle Assessment (LCA), Life Cycle Cost (LCC) and Cost Benefit Analysis (CBA) that normally make or break projects. This study hopes to demonstrate the inadequacies of these common economic gauges for assessing PV in domestic application.

METHODOLOGY

The methodology is divided into two stages. The first stage involves computer simulation to ascertain the indoor air temperature of the living/ding area. Whenever,

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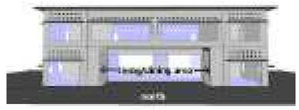
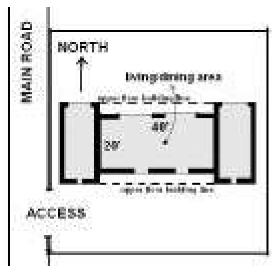
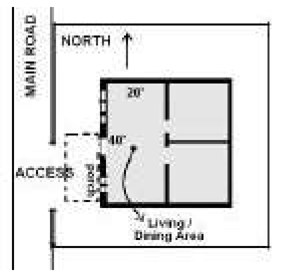
Table 1: Technical Comparison between PA and non PA Cases

	PA Case	Non PA Case
Simulated elevation of two detached houses in the same locality		
Simulated site plan based on design strategies		
Design strategies as the cause	■North orientation; ■Slender form elongated east-west; ■Large openings on the north facade; and ■Recessed floor plan on the north and south sides.	■ West orientation; ■ Square form with concentric rooms arrangement; ■ Medium-sized openings on all facades with undersized shading devices; and ■ Porch at the front, not for climatic reasons but for vehicle parking.
Effect of the design strategies	=> long period of thermal comfort => need less mechanical cooling => low operational energy => need less commercially supplied energy	=> short period of thermal comfort => rely heavily on mechanical cooling => high operational energy => need more commercially supplied energy

it exceeds the thermal comfort zone recommended by the experts, it is assumed that the occupants will need mechanical cooling. The second stage is to translate findings in stage one into monetary value of electricity consumption, i.e., Malaysian Ringgit (MYR). For comparison purposes, the study measures two types of electricity consumptions: mains electricity from the national grid as the status quo and electricity from PV as the intervention. The study is based on simulation that justifies for several variables such as occupants, building materials and weather to be constant and would not effect the economic assessment.

Stage 1: Two houses referred to as Passive Architecture (PA) case and non PA case are simulated using recognized software to obtain the thermal comfort in the living/dining area which space is the focus of this study (Table 1). The PA case uses the building elements to alleviate unfavorable tropical microclimatic effect such as heat gain but optimize natural ventilation and daylight. On the other hand, as suggested by its name, the non PA case disregards tropical microclimatic issues. Nevertheless, the sizes of the living/dining area in the two cases are the same.

The thermal comfort in the living/dining area is simulated for every 15^{th} day of the month for a year. Based on Auliciem's equation, the Thermal Neutrality, i.e., mean temperature for the study is taken to be 26.1°C [4]. It was assumed that when the living/dining area experiences a fluctuation in indoor temperature within 2.5K from 26.1°C (for 90% acceptability), the occupants would not require the aid of mechanical cooling. Beyond that the occupants would need to resort to mechanical cooling via ceiling fan or air conditioning; hence have to consume energy. The living/dining area in both cases are fitted with two types of mechanical cooling equipment serving each half of the space, i.e., two ceiling fans used during most part of the day; and two air conditioning units used in the extreme hot and humid indoor condition.

In this study the energy used by ceiling fan is either 'on' or 'off' and typical power requirement of a ceiling fan is 80 watt [5]. The variation in energy requirement of a typical ceiling fan has no bearing on the actual amount of energy consumption. This is because the variable rheostat that controls the rate of fan blade rotation simply converts the excess energy into heat when the fan speed is slow. Meanwhile, a typical domestic single split unit air conditioning system of 1 horsepower uses 1 kW of energy. Similarly, the air conditioning unit is either 'on' or 'off'. When the simulation suggests for the space to be air conditioned, the set point temperature remains at 28.6°C being the upper limit of thermal comfort zone assumed in this study. Although 1K temperature difference in a room will affect the amount of energy requirement for the air compressor, this study does not consider such fluctuation as a variable so as to generalize the findings.

Stage 2: The cost of monthly energy requirement for mechanical cooling in the two cases are deduced from the electricity tariff rates charged by the mains electricity provider, i.e., Tenaga Nasional Berhad (TNB) which used to be the National Electricity Board. Subsequently, PV power requirement for the two cases can be derived from their annual power consumption for mechanical cooling. One kilowatt peak (kWp) of latest PV technology can generate 1,200 kWh of power, annually. The present cost of PV is RM26,000 per kWp for 30 years service life [6]. Hence, the period of the study is limited to 30 years. Based on these data, the quantum of power consumption for mechanical cooling and the cost of PV installation can be ascertained for use in the equations of PBT, ROI, LCA, LCC and CBA.

RESULTS

Thermal Comfort Analysis: The reading on 15th June shows that the minimum indoor air temperature in the non PA case is 28.9°C and this has exceeded the thermal comfort range of 2.5K from Thermal Neutrality, T_n of 26.1°C (Fig.1).

As such, the non PA case would be highly dependent on mechanical cooling throughout the day and night to bring the room air temperature down into the thermal comfort zone. However, generally the living/dining room is not occupied after midnight till 6:00 a.m., hence the effective time for mechanical cooling is only 18 hours. Simulating the same for one year, it is found that the indoor thermal condition in non PA case is consistent. This is because the diurnal temperature in the tropical climate is fairly consistent. Meanwhile, the indoor air temperature of the PA case measured on 15th June was in the range of thermal comfort in the morning (Figure 2).

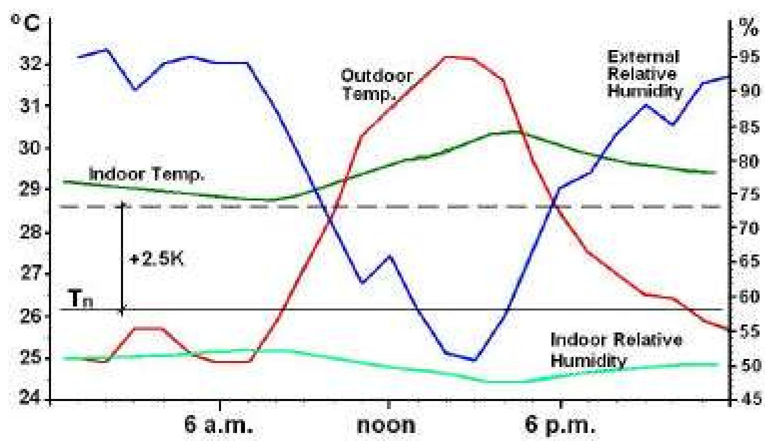


Fig. 1: Indoor Thermal Condition in Living/Dining Area of non PA Case on 15th June

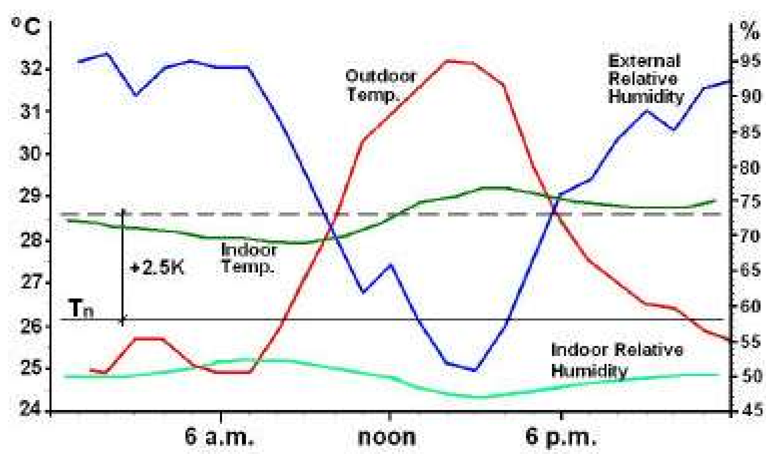


Fig. 2: Indoor Thermal Condition in Living/Dining Area of PA Case on 15th June

Table 2: Power Consumption, Energy Cost and PV Cost in PA Case

PA CASE LIVING/DINING AREA	Ceiling Fan		Air Conditioning Unit	
Wattage per unit	0.08	kW	1	kW
No. of mechanical cooling devices required	2	units	2	units
Hours of mechanical cooling per day (2:1)	8	hours	4	hours
Hours of mechanical cooling per year	2,920	hours	1,460	hours
Mechanical cooling power consumption per year	467.20	kWh	2,920	kWh
TNB charges for consumption below 400 kWh (1st 200kWh = MYR0.218 per kWh, next 200 kWh = MYR0.345 per kWh)				
Total power consumption for mechanical cooling per year	3387.20	kWh		
Total power consumption for mechanical cooling per month	282.27	kWh		
TNB Bill for mechanical cooling per month	*71.98*	*MYR*		
TNB Bill for mechanical cooling per year	863.76	MYR		
TNB Bill for 30 year @1.2% tariff hike per year	26,223.90	MYR		
PV (1 kWp per 30 year = 1200 kWh annual power consumption @ RM26,000 per kWp)				
PV requirement for mechanical cooling per 30 year	2.82	kWp		
Cost of PV for mechanical cooling per 30 year	73,320.00	MYR		
Average cost of PV for mechanical cooling per year	2,444.00	MYR		

Table 3: Power Consumption, Energy Cost and PV Cost in Non PA Case

NON PA CASE LIVING/DINING AREA	Ceiling Fan		Air Conditioning Unit	
Wattage per unit	0.08	kW	1	kW
No. of mechanical cooling devices required	2	units	2	units
Hours of mechanical cooling per day (2:1)	12	hours	6	hours
Hours of mechanical cooling per year	4,380	hours	2,190	hours
Mechanical cooling power consumption per year	700.80	kWh	4380.00	kWh
TNB charges for consumption above 400 kWh, under 500 kWh (1st 500 kWh = MYR0.30 per kWh, next 100kWh = MYR0.39 per kWh)				
Total power consumption for mechanical cooling per year	5,080.80	kWh		
Total power consumption for mechanical cooling per month	423.40	kWh		
TNB Bill for mechanical cooling per month	*127.20*	*MYR*		
TNB Bill for mechanical cooling per year	1526.40	MYR		
TNB Bill for 30 year @1.2% tariff hike per year	46,341.60	MYR		
PV (1 kWp per 30 year = 1200 kWh annual power consumption @ RM26,000 per kWp)				
PV requirement for mechanical cooling per 30 year	4.23	kWp		
Cost of PV for mechanical cooling per 30 year	109,980.00	MYR		
Average cost of PV for mechanical cooling per year	3,666.00	MYR		

However, during post-meridiem the indoor air temperature has only slightly exceeded the thermal comfort zone by less than 1°C above 28.6°C. There is also not much difference in room temperature for PA case throughout the year, qualifying the reading on 15th June to represent a typical day.

Mechanical Cooling Expenditure: The study assumes the ratio of using fan and air conditioning unit to achieve thermal comfort is 2:1 in both cases. Based on the result of simulation, the power requirement, energy costs and PV cost for mechanical cooling in living/dining area of PA case can be ascertained (Table 2). Similarly, the same can be deduced for living/dining area of non PA case (Table 3).

Return on Investment (ROI). ROI is a calculation used to determine whether a proposed investment is wise and how well it will repay the investor. It is calculated as the ratio of the amount gained (taken as positive), or lost (taken as negative), relative to the basis (Eq. 1).

$$\text{ROI} = \frac{(\text{Gain from Investment} - \text{Cost of Investment})}{\text{Cost of Investment}} \times 100\% \quad (1)$$

Table 4: ROI for PV in PA Case and non PA Case

	PA case	Non PA Case
Savings from not paying electricity bill for 30 years (MYR)	26,223.90	46,341.60
Cost of PV system (MYR)	73,320.00	109,980.00
ROI	- 64%	- 57%

Table 5: PBP for PV in PA Case and non PA Case

	PA case	Non PA Case
Cost of BIPV system per 30 years service life (MYR)	73,320.00	109,980.00
Savings from not paying electricity bill per year (MYR)	863.76	1526.40
PBP (years)	84.9	72.0

The gain from investment in PV is the savings from not having to pay monthly electricity bill from mains electricity supply offered by the national grid. Based on Tables 1 and 2, the ROIs for PA case and non PA case are -64% and -57%, respectively (Table 4).

In this instance, the 'gain from investment' does not include the environmental benefits, but only the savings for not having to pay the electricity bill. Clearly, the negative ROIs for PV in both PA and non PA cases show that investment in PV would be a loss to the owner.

The simple formula of ROI provides a quick checking on the financial viability of a potential investment; hence the very reason for its wide application in other trades. Several authors mentioned ROI as a tool to measure the economic viability of sustainable-related project, but few actually applied it. An example is by Oliver & Jackson [7] who applied ROI to assess building integrated PV. Using ROI, they found that although PV gives technical benefit, its cost significantly higher than conventional sources; hence a proposal for building integrated PV. Kaldellis *et al*. [8] in his study of economic viability of another form of energy in Greece had applied ROI and confirmed that the variation of ROI is largely depended on the capital cost. This makes sense because such sustainable-related project has high capital cost and major change in the denominator of ROI formula will indeed affect the result, significantly.

Payback Period (PBP). PBP refers to the period of time required for the return on an investment to "repay" the sum of the original investment [9]. It is a simple calculation that describes how long something takes to "pay for itself"; shorter payback period is obviously preferable to longer payback period (Eq. 2).

$$\text{PBP} = \text{Capital Cost of PV} \div \text{Savings for not having to pay mains electricity bill} \quad (2)$$

In this instance, the benefit is the gain for not paying monthly electricity bills. Based on data in Tables 2 and 3, PBP assessment shows that PV is not worth the while as the payback time would be too distant in the future upon making the investment, even exceeds the product's effective service life (Table 5).

Similarly, Ren *et al*. [10] in his study of economic optimization and sensitivity analysis of PV system for residential buildings in Japan found that the increase of capital cost of PV led to more PBP years. He noted that when the capital cost exceeded a certain amount, the investment can never be recovered because the PBP exceeded the life time of PV system. In addition, he observed that the mains electricity sale price had great effects on the PBP because it determined the yearly cost saving especially when the PV capacity was large. On the other hand, an increase in the mains electricity sale price led to the decrease of PBP. Another study by Duke *et al*. [11] on methods to accelerate residential PV expansion, it is acknowledged that the long PBP for building integrated PV is an impediment to its acceptance. He suggested that an effective marketing tool must be developed to convince home owners especially those who are sceptical of this novel technology that has a long PBP.

Life Cycle Assessment (LCA). LCA, also known as life cycle analysis is the assessment of "eco-performances" of a given product or service throughout its lifespan from production to disposal including all associated activities [12]. This is demonstrated in a study by Stoppato [13] where LCA is applied to ascertain the amount of mass and energy flows over the whole production process of PV starting from silica extraction to the final panel assembling. LCA enables researcher to identify at which point of the product process it is most detrimental to the environment and make improvement to the process. Raugei *et al*. [14] in his study of advanced PV modules had performed LCA evaluation based on the International Standardisation Office (EN ISO 14040 and

Table 6: LCC for PV in PA Case and non PA Case for 30 Years

	PA case		Non PA Case	
	Mains	PV	Mains	PV
Capital & installation cost (MYR)	4,100.00	73,320.00	4,100.00	109,980.00
Operation cost, i.e., TNB electricity bill (MYR)	26,223.95	0	46,341.60	0
Maintenance cost (MYR)	*negligible*	5,000.00	*negligible*	5,000.00
Repair & parts replacement (MYR)	*insignificant*	3,666.00	*insignificant*	5,499.00
Estimated disposal cost (MYR)	*not applicable*	5,000.00	*not applicable*	5,000.00
Salvage value @ 20% of capital cost (MYR)	*not applicable*	(14,664.00)	*not applicable*	(21,996.00)
Cost of new installation (MYR)	*not applicable*	73,320.00	*not applicable*	109,980.00
LCC (MYR)	30,323.95	145,642.00	50,441.60	213,463.00

Table 7: Pros and Cons of Intervention (PV) against the Status Quo (Mains Electricity Supply)

Status Quo (Mains Electricity Supply) in PA and non PA cases		Intervention (PV) in PA and non PA cases	
Pros	Cons	Pros	Cons
Low capital cost Common example No maintenance No additional space required	Monthly electricity bill *Increase average emissions of greenhouse gases from fossil fueled power plants MYR0*	No electricity bill *Reduce average emissions of greenhouse gases from fossil fueled power plants MYR0*	High capital cost Precedent example Some form of maintenance Additional floor area to accommodate system
Mature product; hence reliable Does not bear yield losses No material depreciation at 30 years, maybe rewiring after 50 years	*Not helping to conserve commercially supplied energy as part of national energy security agenda MYR0*	*Helping to address national energy security by being less dependent on commercially supplied energy MYR0*	Infancy product; hence experimental Bear yield losses of PV cells PV material efficiency depreciation, requires replacement after 30 years

updates) which listed four stages of the analysis: scoping, inventory analysis, impact assessment and interpretation. He uses LCA indicators such as Global Warming Potential (GWP), Acidification Potential (AP) and freshwater aquatic Ecotoxicity Potential (EP). Each of these three indicators was aimed to assess the potential environmental harm caused by the PV system's emissions with reference to its respective impact category.

Since the main purpose of LCA concerns large geographical and environmental context exceeding the concern of a house owner, it is unlikely for him to have all reliable data and details to ascertain the environmental impact of PV production at a macro level. It is also inapt for a household to resume the responsibility of assessing PV at macro level. In this instance, LCA appears unsuitable to make economic sense of domestic PV from household's viewpoint.

Life Cycle Cost (LCC). LCC measures the eventual total cost of having a system from installation to demobilization that includes operation, maintenance, disposal and re-installation costs [15]. However, LCC is only useful in a comparative scenario, i.e., against another alternative system. As such, in this study LCC is calculated for both scenarios: using PV and using mains electricity supply from national grid (Table 6).

Based on data in Tables 1, 2 and the resultant LCC in Table 6, PV costs 4 times more than main electricity supply and not a worthy investment in both PA and non PA cases. This is made worse when after 30 years PV system needs to be replaced.

LCC appears to deliberate about PV in greater details compared to the other economic gauges. The breakdown of costs enables the owner to analyse the impact of each cost at a specific time. For an example, in a study by Lazou and Papatsoris [16] on the economics of stand-alone domestic PV in European and Mediterranean locations, they found that by tilting the PV module with respect to the location's latitude it affected for the LCC of the system to reduce. Similarly, Celik [17] in a techno-economic analysis of PV in Turkey found that based on LCC, if the excess energy can be sold to the grid, both the life time system costs and the cost of electricity per kWh fall sharply when compared to the case where selling back to the grid was not possible.

Cost Benefit Analysis (CBA). CBA is a common economic tool to aid social decision-making and is typically used by government to evaluate the desirability of a given intervention in the market [18]. The aim is to gauge the efficiency of the intervention relative to the status quo. This is ascertained by assigning monetary value to the public's willingness to pay for the benefits or willingness to pay to avoid the costs. In this aspect, there is a high element of value judgment in CBA assessment.

However, applying the tool in the context of only one household may limits the subjectivity to a specific stakeholder (Table 7). Considering the argument that house owner is not willing to pay for neither any benefits nor to avoid any cost at the macro level (Table 7, *italic text*), without even putting the value of owner's willingness to pay for benefits or avoid costs, PV poses various disadvantages for owner to consider. On the other hand, the mains electricity supply has only one distinct disadvantage to the owner, i.e., a monthly electricity bill.

Although there are a few researchers who applied CBA on PV, there are many others who used the tool in studies of other forms of energy but later dismissed it due to several glaring issues. Bebbington *et al*. [19] had raised concern on CBA that has the tendency to monetize every single item. He termed this as "comodification" of everything. By putting price on incommensurable items such as mankind and environment, CBA is seen to dehumanize and devalue them. Dietz *et al*. [20], in his review of Stern's The Economic of Climate Change report felt that the high subjectivity of the value accorded to costs and benefits had rendered the CBA findings in the report questionable.

DISCUSSION

Based on the literature review put forth, the study has ground to dismiss LCA as the economic tool for PV from house owner viewpoint due to its wide geographical considerations that exceed the boundary of a house. On the other hand, ROI and PBP are two simple formulae with limited considerations, i.e., one cost (capital investment) and one gain (savings from not paying electricity bills). As described by the literature review and supported by the result of the case study, these economic tools do not account for other associated costs such as maintenance or any associated gain such as using Energy Efficient (EE) equipment. Hence, these tools are too simple to give true result of PV investment. Whilst both CBA and LCC may have accounted for all associated costs and benefits of PV system, it is only meaningful in a comparative approach, but doing so would only exaggerate the economic gap between PV and mains electricity supply. Literature review also shows that CBA deals with macro aspects of environmental issues beyond a house owner's concern and has huge criticism surrounding the subjectivity of the tool. On these points alone, CBA is deemed unsuitable to measure the economics of PV from household's viewpoint. However, the LCC in PA case fares better than in non PA case. This is due to the climatic responsive design of PA case that has resulted for some energy savings benefit. There appears to be a marginal benefit in doing PA case suggesting a house that responds to micro climate saves money during operation. In this instance, instead of focusing on the monetary "profit", house owner may see the "profit" relative to the building itself, i.e., non PA and PA whereby the latter is designed with the aim to conserve energy in the first place.

One common feature of the economic gauges presented in this paper is that they do not see PV as part of a process towards sustainable built environment from the status quo. For example, one may need to first look into investing in a climatic responsive house before considering investment in PV. Compounded with common sensical use of EE equipment in a house, the demand for energy would lessen and thus reduce the capacity of PV in a house. Such process should be presented as part of investment in PV and there need to be an economic tool that shows the marginal benefit at every marginal cost of the said process.

Economists suggest that when making a decision, people actually think in terms of cost and benefit at a margin because most decisions deal with making additional change to what they already have, not total costs or benefits [21]. Relating this to the economic gauges discussed in this study, they present PV as the end-result; hence the resultant arithmetic is a put off to house owner. There is a need to find a new economic approach to measure PV in the said considerations. Until then, using ROI, PBP, LCC, CBA and LCA as economic gauges for PV in domestic application would hinder household acceptance of such 'green energy'.

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