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Economics of Building Integrated PV In China

John Byrne, Gerard Alleng and Aiming Zhou
Center for Energy and Environmental Policy
University of Delaware
Newark, DE 19716
http://www.udel.edu/ceep/

ABSTRACT

This paper presents a technical and economic analysis of building-integrated photovoltaic (BIPV) applications for commercial buildings in Shanghai and Beijing China. The analysis assumes that the array area is 105 m^2 (equivalent to 6.3 kW_p for amorphous silicon thin film technology and 10.0 kW_p for polycrystalline technology). Rooftop and curtain wall applications are considered. BIPV is analyzed as: an energy supply technology delivering bulk energy (kWh); a buildings services technology offering energy demand management (primarily, peak-shaving benefits, i.e., lower kW) and emergency power (through the addition of a modest amount of storage); and finally, BIPV as an architectural element, reducing the materials cost of the building, while providing building services (this typically requires wall-mounting of the PV array). The results of our analysis indicate that the economic value of a PV array would be optimized in a configuration that serves all four functions: energy supply, demand management, emergency power and architectural value. Using software developed at the Center for Energy and Environmental Policy, we estimate that the payback period for multi-service BIPV systems would be less than five years.

1. BACKGROUND

China's rapid economic growth during the last two decades has spurred even more rapid increases in energy demand. This trend is expected to continue to 2020 at an annual average of 8% to 9.5%. Energy use (principally coal), however, has caused serious environmental problems including air pollution, acid rain, and an increase in respiratory disease.

Renewable energy could be an alternative that meets social and economic needs while reducing environmental pollution and health problems. However, a bias in favor of continued reliance on coal and other conventional sources of power will likely remain so long as initial capital costs to build plants using fossil fuels are relatively low and indirect impacts on human health and the environment are ignored.

Successful promotion of renewables in this situation will depend upon steps taken to lower effective capital cost while increasing the range of benefits provided to building owners, managers and users. This paper describes an economic evaluation of different building integrated PV systems configured to serve of a variety of typical building needs. Both amorphous silicon thin film and polycrystalline PV technology is considered for use in rooftop and curtain wall applications on a large hotel hypothetically operating in Beijing and Shanghai. Due to a lack of electricity load data for large buildings in these cities, the load profile of an actual hotel in Seoul – the five-star Lotte Hotel – is employed to facilitate the analysis.

2. BUILDING INTEGRATED PV

The evaluation was conducted using solar resource data for Beijing and Shanghai for a one-year period. This data permits an estimate of the energy (kWh) supplied from a BIPV system in each city throughout the year. In this *energy supply* mode, BIPV can lower grid electricity demand of a building (i.e., the energy provided by a BIPV 'power plant' constitutes a saving in the amount of energy that needs to be purchased from the local utility). If a modest amount of storage is added to the BIPV 'power plant,' the technology can play an additional role – that of an *energy demand management* device shaving monthly peak load (kW). In this case, BIPV offers value to a building owner, manager or user in the form of monthly peak kW demand reductions similar in effect to standard energy efficiency and peak-shaving technologies. A BIPV system with modest storage can also offer important *building services* such as emergency power (e.g., for stairwell lighting or temporary power supply to some receptacle loads when grid power supply is interrupted). Finally, when a BIPV system is configured to be an integrated part of the building ‘skin,’ it can be substituted for façade or rooftop materials while continuing to provide energy and demand savings to the building owner, and selected services essential to a building’s operations.

The Center for Energy and Environmental Policy (CEEP) has investigated the technical and economic feasibility of using BIPV in multi-service applications such as these in more than 25 locations throughout the world. Such applications offer a combination of benefits that include an energy value (i.e., the system’s ability to reduce grid-energy demand), capacity value (in the form of coincident peak demand reduction), service value (through the provision of emergency power during electrical outages) and replacement value (displacing building material). This portfolio of benefits was measured for Beijing and Shanghai and compared to the capital and operating costs of multi-service BIPV. Table 1 summarizes the principal variables that were used in the analysis.

Table 1. Comparison of Key Variables

Policy Variable	Beijing	Shanghai
Solar Resource (kWh/m^2)	0.33	0.28
PV Cell Efficiency		
Amorphous Thin-Film	10%	10%
Polycrystalline	6%	6%
Peak-Shaving Interval (hours)	2-4	2-4
PV System Cost ($/W$_p$)		
Amorphous Thin-Film	3.00	3.00
Polycrystalline	4.00	4.00
Storage cost ($/kWh)	200	200
Investment Tax Credit		
Available in the 1st year	15%	15%
Not available	0%	0%
Rate Structure		
Energy Charge (¢/kWh)	12.08	11.51
Demand Charge ($/kW/Mo)[1]	4.5	4.5
Key Financial Assumptions		
Loan Rate	6%	6%
Loan Duration	8 yrs	8 yrs
Depreciation	5 yrs	5 yrs

3. COMPARATIVE ASSESSMENT OF PV SYSTEM CONFIGURATIONSBIPV

3.1 BIPV as a Building Energy Supply Technology

The basic configuration of PV as a building energy supply technology consists of a PV array connected via power conditioning equipment to the building’s distribution panel. In this configuration, PV operates as an electrical energy supply system, complementing the energy obtained from the grid.

Equation 1 summarizes how the net energy value of the system is estimated. All economic terms have been discounted to reflect the time value of benefits and costs to the building owner.

$$V_E = [O_{PV} * P_E] - C_{PV} \qquad [1]$$

where,

V_E = Energy value of PV system
O_{PV} = Building PV output (kWh)
P_E = Utility energy charge ($/kWh)
C_{PV} = Capital and operating costs of the PV energy supply system.

In this case, it is assumed that a net metering rule is in place so that the customer can sell all generated energy to the grid at the same rate paid for consumption from the grid. Based on Equation [1], an assessment of the economic performance of the technology for Shanghai and Beijing was done using *PV Planner.*[2] Table 2 reports results for rooftop and wall-mounted applications, using a 12% discount rate and a 15% investment tax credit (ITC) available to the building owner in the year of the technology’s installation. The results indicate that the economic value of the system for building owners in Shanghai and Beijing would be negative.

Table 2. Net Present Values and Benefit-Cost Ratios for BIPV ‘Power Plants’ in Beijing and Shanghai

Economic Measure	Beijing		Shanghai	
	Rooftop	Curtain Wall	Rooftop	Curtain Wall
NPV($) Thin Film	-20,440	-21,839	-21,705	-23,107
NPV($) Polycrystal	-39,488	-41,832	-41,620	-43,990
BCR Thin Film	0.54	0.51	0.52	0.48
BCR Polycrystal	0.54	0.51	0.51	0.48

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[1] At this time, electric utilities in Shanghai and Beijing do not employ demand (kW) charges. The rate used in this analysis reflects that charged in Guangzhou.

[2] *PV Planner* is a spreadsheet model developed by CEEP in cooperation with the U.S. National Renewable Energy Laboratory for the purpose of providing resource matching and financial analyses of BIPV under different resource, policy and financial circumstances and for a variety of technology configurations.

3.2 PV as an Energy Demand Management Technology

In a second configuration, PV can be used as a demand management device. This requires the addition of modest amounts of storage to the PV array, allowing the system to operate as a dispatchable peak-shaving technology.

Equation [2] estimates the net demand and energy value of the technology:

$$V_M = [P_D(O_{PV} + O_{BAT}) + V_E] - C_{PV} \qquad [2]$$

where,

V_M = Energy demand management value of a PV peak-shaving system

O_{pv} = PV output at time of building peak demand (kW)

O_{bat} = Battery bank output (net of round trip losses) at time of building peak demand (kW)

P_D = Utility demand (capacity) charge

V_E = Energy value as defined in Equation [1]

C_{PV} = Capital and operating costs of the PV demand management system.

The O_{bat} term represents the output of the battery bank at the time the building is experiencing its peak demand. It is a function of battery bank size and the number of peak-shaving hours needed to maximize the reduction in the peak load of the building for a given PV array size.

The value of BIPV as a demand management tool was not separately evaluated. Instead, this value was combined with the system's capability to offer emergency power and the economic value of this dual-function configuration was then estimated for the two cities (see Table 3).

3.3 PV as a Building Services Technology

The addition of an emergency power (EP) function to the 'traditional' dispatchable PV peak shaving model is a means of further enhancing the overall value of BIPV systems with modest storage. The basic technical and economic implications of using of PV as an EP technology are described below and the potential value of this configuration for hotels in Beijing and Shanghai is reported in Table 3. As before, we assume a 12% discount rate, with a 15% investment tax credit (ITC) available to the building owner in the year of the technology's installation

The economic benefit of adding an EP function to a BIPV peak-shaving system can be expressed as the *avoided cost* associated with the purchase and operation of conventional EP systems. In the analysis reported here, it is assumed that the building owner, manager and/or major user have already identified needs that justify the purchase of an EP system (which include such balance of system components as inverters and battery storage). Here, we assume that the costs of battery storage, the inverter, and controls have already met an economic performance criterion for the building under evaluation. Thus, only the additional capital cost of the PV array (including array structure and installation) must be justified. Accordingly, the payback period for a BIPV *service* system would depend upon the capital costs of the PV array itself, instead of array costs plus balance of systems costs.

Consistent with the above assumptions, the PV system payback period was determined by subtracting tax credits (if any), annual net tax benefits, annual energy savings, and annual demand savings from the initial cost of the PV array. We believe that this approach is reasonable for a preliminary analysis because the costs of integrated battery/inverter systems are similar to conventional EP systems.

Equation [3] summarizes the net value of a PV system configured to provide demand management and EP functions to a building:

$$V_S = [(B_{EP} – C_{EP}) + V_M] - \Delta C_{PV} \qquad [3]$$

where,

V_S = Energy services value of a PV-peak shaving and EP system

B_{EP} = Customer designated benefits of EP

C_{EP} = EP system cost (equivalent to BOS cost of a conventional PV system)

V_M = Demand management value of a PV peak shaving and EP system, as defined in Equation [2]

ΔC_{PV} = Additional PV cost (including array structure)

The addition of an EP function increases the value of a dispatchable PV demand management system. The estimated benefit-cost ratios of this application for a hotel in Beijing and Shanghai are given in Table 3.

These results are consistent with earlier CEEP research, which suggested that by reserving modest amounts of storage capacity for emergency power in commercial building integrated PV systems, benefit-cost ratios (BCRs) over 1.0 and payback periods under 5 years are expectable (J. Byrne et al, 1997, 1998, 1999, 2000).

Table 3. Net Present Values, Benefit-Cost Ratios and Payback Periods for BIPV Demand Management and Service Technology in Beijing and Shanghai

PV Type	Economic Measure	Beijing		Shanghai	
		Rooftop	Curtain Wall	Rooftop	Curtain Wall
Thin Film	NPV ($)	+12,184	+ 8,065	+ 7,971	+ 3,716
	BCR	1.48	1.33	1.32	1.16
	PBP (yrs)	4	4	4	4
Polycrystaline	NPV ($)	+18,489	+10,847	+11,370	+ 4,103
	BCR	1.37	1.22	1.24	1.09
	PBP (yrs)	5	5	5	5

3.4 PV as an Architectural Element

A PV array can also serve as an architectural element containing both aesthetic and functional value. Such an application would ordinarily be most appropriate for consideration in the design of a new building. While 'architectural' BIPV can be designed for rooftop or façade use, material cost savings are normally greatest in the case of façades.

The economic benefit of displacing architectural materials with PV can be expressed as the *avoided cost* of the material displaced by the area of the array. Two commonly used façade materials are polished stone (a high-cost material) and aluminum (a moderate-cost material). In the analysis reported here, it is assumed that a building is designed with a PV façade area using one of these materials. Additionally, the BIPV system is configured to maintain the demand management and EP functions discussed above. Thus, the effective capital cost of the BIPV system amounts to the PV array's cost minus the value of the displaced material. As discussed in section 3.3, the inverter, storage and control costs are assumed to be justified by the building's need for emergency power.

The value equation is same as Equation [3], except that ΔC_{PV} is reduced by an amount equal to the avoided cost of the displaced material.

The results of displacing materials are shown in detail in Tables 4 and Table 5. Results in both tables are based on a 12% discount rate. Table 4 includes a 15% investment tax credit, while Table 5 evaluates the economics of BIPV in the absence of an ITC.

Table 4. Net Present Values, Benefit-Cost Ratios and Payback Periods for 'Architectural' BIPV (Thin Film, Wall-Mounted PV) in Beijing and Shanghai
(assuming a 15% Investment Tax Credit)

Material Replaced	Economic Measure	Beijing	Shanghai
Polished Stone	NPV ($)	+18,586	+14,237
	BCR	2.33	2.14
	PBP (yrs)	1	1
Aluminum	NPV ($)	+15,373	+11,024
	BCR	1.89	1.70
	PBP (yrs)	2	2

Table 5. Net Present Values, Benefit-Cost Ratios and Payback Periods for 'Architectural' BIPV (Thin Film, Wall-Mounted PV) in Beijing and Shanghai
(assuming no Investment Tax Credit)

Material Replaced	Economic Measure	Beijing	Shanghai
Polished Stone	NPV ($)	+11,136	+ 7,327
	BCR	1.80	1.59
	PBP (yrs)	3	3
Aluminum	NPV ($)	+ 7,923	+ 4,159
	BCR	1.46	1.26
	PBP (yrs)	4	4

4. CONCLUSIONS

The analysis reported here indicates that building integrated PV can provide positive economic value for a *green buildings strategy* in China's leading cities. To realize positive economic value, BIPV needs to be designed with the aim of incorporating a variety of services and benefits to building owners, managers, and users. Key services and benefits identified from our research include: energy supply, demand management, emergency power, and architectural value (including materials savings). Based on our results, it appears that markets may currently exist for cost-effective building integrated PV in China.

Selected Sources

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