A Lifecycle Cost-Benefit Analysis of Low-Carbon Powerhouses in Buildings in China

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Abstract

Building integrated photovoltaics (BIPV) refers to photovoltaic or solar cells that are integrated into the building envelope to generate 'free' energy from sunshine. BIPV product development has been ongoing for the past 30 years, but their practical applications have been limited in China. Clients and end users lack knowledge of cost analysis, to make more accurate decisions on use of PV products. BIPV cost-benefit analysis should include not only initial costs but also ongoing maintenance and repair costs throughout the building life. Moreover, the scope and factors of cost-benefit analysis should be extended to include the community and environment aspects. In a cost-benefit analysis, various risk and opportunity factors such as electricity price, and government support should be considered. However, up until now, there have been limited studies that analyzed cost-benefit factors of BIPV from a supply chain perspective. Most previous studies focused on the Building Attached PV projects. This research aims to gain an in-depth understanding on the costs - benefits of BIPV. A real-life BIPV case drawn from China was studied by using the life cycle assessment (LCA) method. The outcome of this research will contribute to revenue projections to the industry by understanding the investment risk and benefit of using BIPV in buildings. The original contribution of this study is a lifecycle cost assessment model of BIPV projects which include comprehensive cost and benefit factors during the project lifespan.

INTRODUCTION

Building Integrated Photovoltaics (BIPV) refers to photovoltaic or solar cells that are integrated into the building envelope to generate 'free' energy from sunshine. BIPV can be typically installed as tiles, foil products, modules, and solar glazing products (Jelle, Breivik & Drolsum Røkenes 2012). Current BIPV systems are

considered to have a lifespan of 25-30 years based on manufacturers' warranties (Hammond et al. 2012), with some studies also suggesting the lifespan could be as long as 50 years (Azadian & Radzi 2013; Cerón, Caamaño-Martín & Neila 2013).

BIPV product development has been ongoing for the past 30 years, but their practical applications have not yet reached large-scale distribution or application in most countries, including China. A major barrier to BIPV system application in buildings is lack of confidence in BIPV systems due to the high capital cost of purchase and installation (Tyagi et al. 2013). The development of PV technology has been rapid in recent years due to technological advances, cost reductions in materials and increasing government support for renewable energy technologies, which have had a favorable impact on BIPV. However, clients and end users lack knowledge of value analysis techniques needed to make more accurate decisions on use of PV products. BIPV lifecycle cost-benefit evaluation should include not only initial costs, but also ongoing maintenance and repair costs throughout the building life. Moreover, the scope and factors of cost-benefit analysis should be extended to include wider community and environmental aspects. Although there are previous studies on the lifecycle cost assessment of PV projects, most of them focused on Building Attached PV instead of Building Integrated PV. Only limited number of studies provided detail cost information and most of the publications failed to identify the transport and maintenance costs, which could be a signigficant cost proportion of BIPV systems as highlighted by Tominaga (2009) and Cucchiella et al. (2012). Furthermore, previous studies failed to quantify all the benefits into monetary values (Yang and Zou, 2016). A socially responsible company should consider the impacts of its products beyond its own sphere of local operation by including the externalities, with a lifecycle perspective (Chouinard et al., 2001). Therefore, a lifecycle social-benefit analysis should be conducted to aggregate the environmental and economic impacts on the entire BIPV supply chain. A real-life BIPV case drawn from China was studied by using the Life Cycle Assessment (LCA) method. The outcome of this research will contribute to more accurate revenue projections to the industry by understanding the investment risk and benefit of using BIPV in buildings.

COST BREAKDOWN of BIPV

A number of existing studies identify the cost breakdown of BIPV system components (such as Rahman et al., 2012; Cucchiella et al., 2012; Aristazabal et al., 2011; Haque et al., 2012). All of the studies mentioned are solely focused on BIPV roofing modules. The costs/expenses are broken down into manufacturing, transport, installation, and maintenance components. The major cost component of a BIPV system is the PV module expense which ranges from 43% to 77% of the construction cost. The cost of electrical Balance of System (BOS) components, which refers to the components and equipment that move DC energy produced by solar panels through the conversion system that in turn produces AC electricity, are typically between 10-16% of construction cost with one exception as 50% in the study by Haque et al. (2012) in Bangladesh. This may be due to the large physical system size. The structural support system costs jumped dramatically from 3% to 18% in previous studies. Inverter replacement costs, which are the main expenses during the operation stage of life, account for around 10% of construction cost. There were only two studies which provided information on the transport and monitoring costs. Cucchiella

et al. (2012) carried out a simulation on performance evaluation of a rooftop BIPV system in Italy. The transport and mounting costs were identified as 19% of the construction cost. A literature review has shown that no similar studies have been conducted in China to provide detailed information on BIPV cost across the whole project lifecycle.

BENEFITS of BIPV

Despite the high capital cost of BIPV, there are several benefits to clients and society. These include building material cost offsets, energy bill savings, reduction of carbon cost, and transmission loss (Yang and Zou, 2016).

Building Material Cost Offsets

By providing the functions of protecting the building from the weather and avoiding the use of other building materials, the costs of the BIPV system can be split between building envelope function and electricity generation (Oliver & Jackson 2000). BIPV systems result in a cost offset by replacing traditional building materials in the building's envelope (Hammond et al. 2012; Jelle, Breivik & Drolsum Røkenes 2012; Pagliaro, Ciriminna & Palmisano 2010; Seng, Lalchand & Sow Lin 2008; Sozer & Elnimeiri 2007). Hammond et al. (2012) concluded that in the replacement of concrete roof tiles with BIPV tiles, a cost reduction equivalent to 2% of the BIPV tile system expense was achieved. Koinegg et al. (2013) showed that the cost of BIPV façade systems is not significantly greater than other façade materials. They highlighted that the cost of BIPV glazing systems can in fact be around 20% cheaper than polished stone facades and can result in reduced installation costs. Similar 'cost offset' studies have not been completed for glass type facades in building applications in China.

Savings on Electricity Bills

The generation of electricity on-site results in a reduction in the amount of electricity imported from the electricity supply grid by the building (Seng, Lalchand & Sow Lin 2008). When the BIPV system is generating electricity in excess of the building's requirements, electricity is exported, back into the electricity supply grid (Cerón, Caamaño-Martín & Neila 2013). This displacement can result in cost savings equivalent to the rate electricity retailers charge end users for the supply of electricity (Hammond et al. 2012). For net exporters of electricity, the cost is reduced to zero, and where Feed-in-Tariffs are in place, the exported electricity results in revenue for the end users, ultimately reducing the cost of BIPV over its life time (Abdullah et al. 2012). Although clients and end users are aware of the bill savings, they still lack knowledge of lifecycle cost analysis to make accurate decisions on the use of BIPV products.

Reduction of Carbon Cost

The US Department of Transport estimated that the global effects of carbon emissions are around $US33 per ton (Vinson & Elkins, 2012). With a national carbon price being introduced in Australia during 2012, the price of $US25.4 per tonne was predicted in 2014-2015 to increase costs of conventional electricity and would thus

have a further impact on the social cost of carbon (Clean Energy Regulator, 2014). Similarly in Italy, a price of $US21 per tonne of carbon emissions was identified (Cucchiella et al. 2012). In China, the carbon emission trading markets have been only piloted in five major cities including Beijing, Shanghai, Shenzhen, Guangzhou and Tianjing, as well as a central province Hubei (Chinese Carbon Trading Web, 2015). The carbon prices ranged from RMB¥20-130 ($US3.2-21) per ton, which are much lower than developed countries. The installation of BIPV systems can reduce carbon emission by replacing coal to produce electricity; thereby generating social benefits to the society.

Reduction of Transmission Losses

Transmission and distribution losses occur in the transportation and distribution of electricity between generation plants and consumers (Bishop, Amaratunga & Rodriguez 2010). With the electricity generators usually located at a long distance from cities and towns, these losses can be significant (Australian Energy Regulator 2009). Lazos and Bruce (2012) pointed out that the costs associated with transmission and distribution losses are recouped by the retailer in the electricity price to Australian society. In 2010, transmission and distribution losses in Australia accounted for 6.6% of electricity output, $US representing a cost to the producer of around $US3.2 billion annually (based on an electricity price of $US0.20/kWh). In China, transmission and distribution losses are around 9% according to the Chinese Electricity Loss Calculation Standard (2000). In BIPV systems, the removal of the need for the transmittance of electricity over long distances from power generation stations to users has potential savings through the reduction in capital expenditure for infrastructure and maintenance (Bakos, Soursos & Tsagas 2003; Sharples & Radhi 2013) and the avoidance of associated transmission and distribution losses.

Government Incentives

Government policy support plays a crucial role in the value analysis of BIPV. Subsidies can create significant cost benefits for end users and developers, and have been used to great effect in various countries (Tominaga 2009; Zhang, Song & Hamori 2011)). For example, in Japan, subsidies of 50% have resulted in significant cost benefits for BIPV and resulted in Japan being the largest PV market in 2004 (Zhang, Song & Hamori 2011). In Germany, a PV support scheme funded by the state-owned German Development Bank provides low interest loans to private PV investments by communities and their enterprises and loans for investment in the infrastructure projects to reduce energy consumption and change to renewable energies (Grau, Huo & Neuhoff 2012). The Chinese government also encourages developers to apply PV systems in new buildings. The Golden Sun program implemented in 2009 in China offers subsidies of 50% of total costs for grid connected PV systems greater than 300kWh (Grau, Huo & Neuhoff 2012). The PV Building Scheme subsidizes capital investments for on-grid BIPV, with a potential subsidy of greater than RMB¥9 ($US1.45) per watt (China Ministry of Housing and Urban-Rural Development, 2011). These incentive schemes provide significant cash incentives for large scale BIPV installations. These policy support mechanisms provide benefits to clients and end users, making BIPV systems more affordable, and encouraging the installation of such systems.

CASE STUDY

Project Background

The case project is an office building located in Zhenzhou, Henan Province China, which integrated roof of BIPV panels. Figure 1 shows the outside and inside of the final product. The BIPV system in this project adopted the quasi-monocrystalline technology which uses a casting process instead of the slow and expensive Czochralski process (CZ) to manufacture monocrystalline ingots. This can increase the efficiency of PV cells to 17.5% or above for a small cost penalty. Compared to the monocrystalline silicon, the quasi-monocrystalline cells' attenuation rate is of about 1/4 to 1/2. The installed capacity of the BIPV system, which consists of 750 BIPV modules, is 60kW. The construction started in January 2013 and lasted for 60 days. The whole building was commissioned to operation at the end of 2013. A BIPV monitoring system was used after hand-over to record the system performance and electricity generation data.

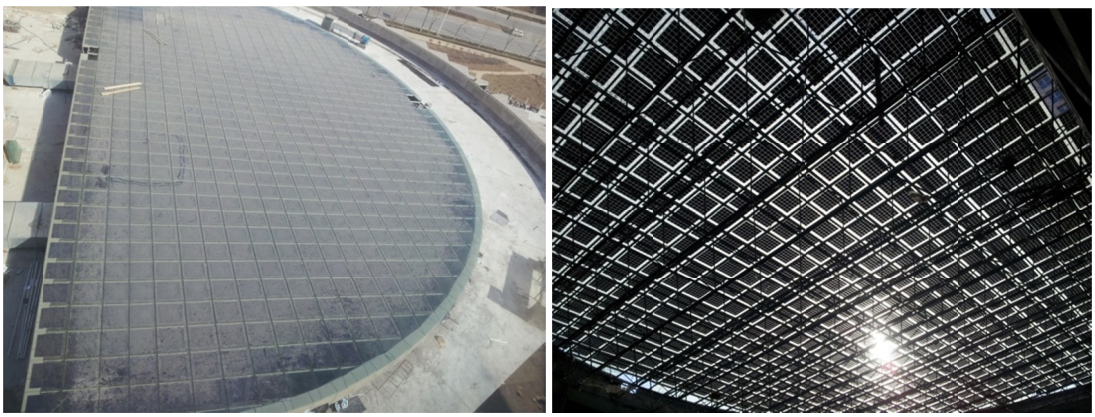

Figure 1: The BIPV roof system

Lifecycle cost-benefit Analysis

An analysis of LCA is conducted with the case project from the client's perspective. The construction cost of this project is RMB¥ 2,150,000 ($US345,398) which equals to RMB¥36/W ($US5.8/W). It should be noted that the unit prices include the direct costs (material, installation, transportation) and indirect costs (design, administration and profits). The cost breakdown is shown in Table 1. The major cost is the BIPV modules which account for 59.8% of the total cost. All costs are paid in cash. The BIPV contractor also stated that the average value of the BIPV system at the end of the project lifecycle can be considered as zero by offsetting the demolition expenses. An estimation of conventional construction cost was provided by the contractor as well. The traditional concrete roof will cost RMB¥368,271 in this project. The government subsidy to this project is RMB¥960,000 equalling to RMB¥16/W. Table 2 shows the additional cost of using the BIPV system by deducting the cost of traditional roof and government subsidy from the BIPV construction cost.

The BIPV contractor indicated that the maintenance cost is about 12% of the total construction cost across the project lifespan (25 years) starting from the 6th year; it is assumed that the maintenance cost spreads equally each year (from Year 6 to

Year 25) to generate an RMB¥12,943 ($US2,081) expense per year. The NERL model, which is a world popular platform used to estimate the energy production of grid-connected PV systems, is applied to estimate the electricity outputs across the lifespan (Table 3). The default system loss was 14%.

Table 1: The construction cost breakdown of the BIPV system

BIPV Components	Unit	Quantity	Unit Price (RMB¥)	Price (RMB¥)	%
Steel Structure	T	19.71	11,455.93	225,796.36	10.5%
Glass				80,635.49	3.8%
Aluminium	M^2	340.00	555.14	188,120.91	8.7%
Electrical components	W	60,000.00	27.59	1,655,447.23	77.0%
• PV modules	W	60,000.00	21.43	1,285,726.20	59.8%
• Others (Balance of System, Monitoring system)				369,721.03	17.2%
Total				2,150,000.00	100.0%

Table 2 Additional cost of applying BIPV system

Items	Cost
BIPV construction cost	2,150,000.00
Cost of Traditional concrete Roof	(368,271.00)
Government subsidy	(960,000.00)
Additional Cost of using BIPV	821,729.00
NPV of Cost at the beginning of 2013*	807,691.51

* Discount rate is 7.2%.

Table 3: Electricity output

Year	Month (kWh)												Total (kWh)
	1	2	3	4	5	6	7	8	9	10	11	12	
2014	1,999	1,786	5,007	4,142	5,918	4,294	5,785	4,094	2,844	3,604	3,326	4,796	47,595
2015	3,336	3,324	4,286	5,204	5,668	5,431	4,421	4,424	4,068	4,176	3,885	3,522	51,746
2016	3,351	3,326	4,272	5,168	5,628	5,393	4,390	4,393	4,040	4,147	3,858	3,497	51,462
2017	3,328	3,302	4,242	5,131	5,588	5,355	4,359	4,361	4,011	4,118	3,831	3,472	51,097
2018	3,304	3,279	4,212	5,094	5,548	5,316	4,328	4,330	3,982	4,088	3,803	3,448	50,732
2019	3,280	3,255	4,181	5,058	5,508	5,278	4,297	4,299	3,953	4,059	3,776	3,423	50,366
2020	3,256	3,231	4,151	5,021	5,468	5,240	4,265	4,268	3,925	4,029	3,748	3,398	50,001
2021	3,232	3,208	4,121	4,984	5,428	5,201	4,234	4,237	3,896	4,000	3,721	3,373	49,636
2022	3,209	3,184	4,090	4,948	5,388	5,163	4,203	4,205	3,867	3,970	3,694	3,348	49,270
2023	3,185	3,160	4,060	4,911	5,349	5,125	4,172	4,174	3,839	3,941	3,666	3,323	48,905
2024	3,161	3,137	4,030	4,874	5,309	5,087	4,141	4,143	3,810	3,911	3,639	3,299	48,540
2025	3,137	3,113	3,999	4,838	5,269	5,048	4,110	4,112	3,781	3,882	3,611	3,274	48,174
2026	3,113	3,090	3,969	4,801	5,229	5,010	4,078	4,081	3,753	3,853	3,584	3,249	47,809
2027	3,090	3,066	3,939	4,764	5,189	4,972	4,047	4,050	3,724	3,823	3,557	3,224	47,444
2028	3,066	3,042	3,908	4,727	5,149	4,933	4,016	4,018	3,695	3,794	3,529	3,199	47,078
2029	3,042	3,019	3,878	4,691	5,109	4,895	3,985	3,987	3,667	3,764	3,502	3,174	46,713
2030	3,018	2,995	3,848	4,654	5,069	4,857	3,954	3,956	3,638	3,735	3,474	3,150	46,347
2031	2,994	2,972	3,817	4,617	5,029	4,819	3,923	3,925	3,609	3,705	3,447	3,125	45,982
2032	2,971	2,948	3,787	4,581	4,989	4,780	3,891	3,894	3,581	3,676	3,420	3,100	45,617
2033	2,947	2,924	3,757	4,544	4,949	4,742	3,860	3,862	3,552	3,646	3,392	3,075	45,251
2034	2,923	2,901	3,726	4,507	4,909	4,704	3,829	3,831	3,523	3,617	3,365	3,050	44,886
2035	2,899	2,877	3,696	4,471	4,869	4,665	3,798	3,800	3,495	3,588	3,338	3,025	44,521
2036	2,875	2,854	3,666	4,434	4,829	4,627	3,767	3,769	3,466	3,558	3,310	3,001	44,155
2037	2,852	2,830	3,635	4,397	4,789	4,589	3,736	3,738	3,437	3,529	3,283	2,976	43,790
2038	2,828	2,806	3,605	4,361	4,749	4,551	3,704	3,707	3,409	3,499	3,255	2,951	43,425

The Net Present Value (NPV) of this project is shown in Table 5, in which:

- The saving of energy bills per year is calculated as:

$$\text{Electricity output in Year i} * \text{FiT} * (1 + \text{Power price growth rate})^{i-1}$$

Where the current power price in Zhenzhou and Feed-in-Tariffs in China is RMB¥1/kWh; and the power price growth rate is at 0.5% annually.

- The reduction of carbon cost each year is calculated as:

$$\text{Electricity output in Year i} * (1 + \text{Transmission and distribution loss rate}) * \text{Carbon Dioxide Emission per thousand kWh (ton)} * \text{Carbon price per ton}$$

Where the Transmission and distribution loss rate is 9%; Carbon Dioxide Emission per thousand kWh is 0.77 ton; and the Carbon price per ton is RMB¥25.

To properly calculate the current value of the project at initiation, this research adopts Discount Cash Flow model. The discount rate is in accordance with the required rate of return of the project or at least the financing cost of the project. Since the case project is invested fully by local government, it is assumed that there is no risk premium in the discount rate, and the government finances the project entirely with the proceedings of municipal bond around that time. Therefore the coupon rate of bond is the discount rate which is set at 7.2%. As indicated in Table 4, the NPV of this project is negative RMB¥333,264.

Table 4 The Net Present Value of the case project

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Additional cost of BIPV	807,691.5																									
Maintenance							-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-11,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9	-12,942.9
Saved electricity bills		47,595.1	51,827.1	51,543.0	51,177.1	50,811.2	50,445.2	50,079.3	49,713.4	49,347.5	48,981.5	48,615.6	48,249.7	47,883.8	47,517.8	47,151.9	46,786.0	46,420.1	46,054.1	45,688.2	45,322.3	44,956.4	44,590.4	44,224.5	43,858.6	43,492.7
Carbon cost		998.7	1,085.8	1,079.8	1,072.1	1,064.5	1,056.8	1,049.1	1,041.5	1,033.8	1,026.1	1,018.5	1,010.8	1,003.2	995.5	987.8	980.2	972.5	964.8	957.2	949.5	941.8	934.2	926.5	918.8	911.2
Net Cash Flow	(807,691.5)	48,593.8	52,912.9	52,622.8	52,249.2	51,875.6	38,559.2	38,185.6	37,812.0	37,438.4	37,064.8	36,691.2	36,317.6	35,944.0	31,570.4	35,196.9	34,823.3	34,449.7	34,076.1	33,702.5	33,328.9	32,955.3	32,581.7	32,208.1	31,834.5	31,461.0
Discounted Cash Flow	(807,691.5)	45,330.0	46,043.9	42,715.9	39,564.0	36,642.9	25,407.3	23,471.2	21,680.6	20,024.6	18,493.3	17,077.3	15,768.1	14,557.8	11,438.9	12,404.6	11,448.6	10,565.1	9,748.6	8,994.2	8,297.1	7,653.1	7,058.1	6,508.6	6,001.0	5,532.3
Discounted Rate	7.20%																									
NPV	(333,264.5)																									

Discussion

Four scenarios are developed (Table 5) to show the possibility of increasing the NPV in this project:

Scenario 1: The current highest carbon trading price in China is RMB¥130/per ton. If this price is adopted in the case project, the NPV will be increased to negative RMB¥284,151. This situation is still not satisfied from the client perspective.

Scenario 2: To make the NPV as zero, the carbon price needs to be increased to RMB¥737.5/per ton ($US118.8/per ton), which is much higher than the current carbon prices in developed countries, and unrealistic to implement in China currently.

Scenario 3: Increasing government subsidy (from RMB¥16/W to RMB¥21.65/W in this project) can substantially create value for the client.

Scenario 4: Alternatively, if the government subsidy could cover more than 60% of the construction cost, the NPV is also acceptable for the client. This scenario is basically consistent with the Solar Roofs Program in China, which subsidizes capital investments for on-grid BIPV and remote PV systems over 50kW, with a potential subsidy of greater than 50% of the system cost (Huo & Zhang 2012; Moosavian et al. 2013). However, this program is not implemented in the studied city.

Table 5 Scenarios to increase NPV of the case project

Scenarios		NPV
Carbon Price	RMB¥130/ton	-284,151
Carbon Price	RMB¥737.5/ton	0
Government subsidy	RMB¥21.65/W	-55
Government subsidy	60% of construction cost	-8,901

CONCLUSIONS

Building Integrated Photovoltaics (BIPV) is an emerging subsector of photovoltaics where the PV cells replace conventional building materials by integrating them into building envelope. BIPV products development has been ongoing for the past 30 years, but their practical applications have been limited in China. The major limitation of the previous research was lack of detailed BIPV value data, particularly where individual component costs and benefits should be identified. A real-life case in China was studied in this research by using Lifecycle assessment method. The whole supply chain of the BIPV project was mapped out from economic perspective. The Net Present Value of the case project is negative. Government subsidy remains an effective way to promote BIPV application. Alternatively the carbon price needs to be increased to RMB¥737.5/ton ($US118.48/ton). Although

this price is high, it is in line with studies on Social Cost of Carbon. The economic impact or damage caused by carbon emissions is known as the "Social Cost of Carbon" (SCC) (Lazos & Bruce 2012). According to a new study from Stanford University scientists (Moore and Diaz, 2015), an additional ton of carbon dioxide emitted in 2015 would cause $220 worth of economic damages. This research could contribute to lean design and construction by highlighting the strategies to encourage value creation.

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