

Co-benefit of polycrystalline large-scale photovoltaic power in China

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ABSTRACT

Recognized as an indispensable player in the future electricity supply mix of China, photovoltaic (PV) power has experienced a fast expansion in recent years. Owing to the higher cost compared with traditional coal-fired power, financial subsidy is crucial for the development of PV power. Although a series of policies have been implemented to subsidize PV power, strong and steady policies to stimulate China's PV power installation is still in need. One important reason for the lack of such policies is that whether the benefits associated with PV power cover the cost of subsidy is unclear. In this paper, we carry out a detailed study to quantify the co-benefit from the replacement of traditional coal-fired power by the large-scale photovoltaic power (LS-PV) comprised of polycrystalline cells in China. Our life cycle analysis (LCA) shows that the estimated co-benefit of polycrystalline LS-PV is 0.167 yuan/kWh, and the year of grid parity will come about 4 years earlier in China if the co-benefit is internalized.

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1. Background

Rapid economic growth has led to increasing demand of electricity in China, and the growth of electricity consumption is faster than that of the economy. The electricity consumption elasticity parameter (ratio of electricity consumption growth to GDP growth) was above 1 consecutively from 1999 to 2007 [1]. Though the growth rate is slowing down with the strict “energy saving and emission reduction” policy during the 11th Five Year Plan, electricity consumption still has huge growth potential due to the industrialization and urbanization of China.

Among the supply mix of electricity, coal-fired power accounts for about 80% [1]. Fast increase in coal consumption results in huge greenhouse gases emission as well as severe air pollution problems. Extensive emissions of air pollutants including sulfur dioxide (SO₂), nitrous oxide (NO_x), and particulate matter (PM) during the process of energy consumption results in noxious acid rains and diverse disease [2].

Realizing this, China is getting more serious on improving electricity supply mix by implementing sustainable and renewable energy technologies (RETs). RETs are the solutions to satisfying society's electricity demands while at the same time reducing the adverse anthropogenic impacts of fossil fuels [3,4]. However, RETs

have higher cost than traditional technologies generally. Thanks to the great potential of solar resources and the booming production capacity of photovoltaic industry in China, PV power has been considered as a promising RET and enjoys a series of incentives initiated by China central government since 2009. These policies and measures to leverage the PV power development include subsidies for “Golden Sun Demonstration Program” and “Solar PV for Buildings” from 2009 to 2011, two series of concession projects in 2009 and 2010, and the feed-in-tariff policy released in 2011. Nevertheless, the amount of supported installation by incentive programs and concession projects is no more than 800 MW, only about 10% of annual production of China in 2010 [5]. With the present cost of PV power construction, the feed-in-tariff only guarantees about 8% IRR for the LS-PV project with the best resource area in west China. Incentives that can trigger PV power installation are still in need.

In fact, subsidy for coal-fired electricity is much more than that of PV power. Subsidy for electricity in 2007 was estimated at about 76.39 billion CNY in 2007 [6], and the coal-fired power could receive 61.11 billion CNY given its 80% share of total consumption. For the PV power, its installation will be about 1.7 GW every year during the 12th Five Year Plan in average [7]. Assuming the average amount of usable sunlight per year is 1500 h, the subsidy will be only around 1.2 billion CNY per year.

The reason for such a huge subsidy for coal-fired power is that the government believes that maintaining the low electricity tariff can support China's rapid economic growth, competitiveness of Chinese products in foreign trade, and other social economic

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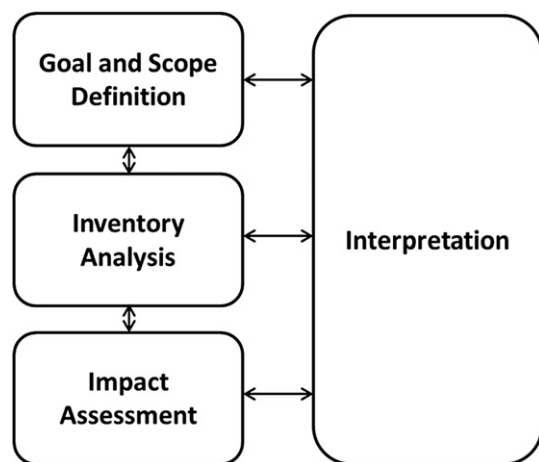


Fig. 1. Phases of Life Cycle Analysis (Source: [15,16]).

objectives. However, the price paid for coal-fired power does not include the cost to the health system due to the associated air pollution, the cost of restoring damaged ecosystems and lost benefit of biodiversity and ecosystem services, and the economic loss from reduced productivity due to illness caused by air pollution and early mortality [8]. Multiple, ancillary benefits, including greenhouse gas emission reduction, public health community improvement and job opportunity creation associated with PV power comparing with coal-fired power, often denoted as co-benefit documented in many studies [9–11], are not fully considered. This is not because Chinese government's unawareness of PV power's co-benefits, but there is no explicit monetary calculation of the co-benefits for policymakers' reference. The lessons from other countries make the government worry about the efficiency of subsidy on RETs. For example, the subsidy program for PV power in Australia in 2000s is considered not efficient enough due to the cost of the policy is too high comparing to the environmental and socio-economic benefits [12]. If the co-benefits such as health impacts are quantified reasonably and accurately, it will be easily compared to monetary costs of investments and costs of CO₂ reduction and energy conservation technology, which will provide a common yardstick to help policymakers choose appropriate subsidy policies to access this goal by taking into account all cost and benefit parameters [13,14].

When measuring the co-benefits, especially when related to environment, life cycle analysis (LCA) methodology described in the Standards ISO 14040:2006 [15,16] is considered as one of the most complete and efficient tools to quantify the environmental effects of a product throughout its whole life cycle, starting with the extraction and processing of raw materials, the manufacturing processes employed for the production, product transport, use and maintenance during its useful life, until its final recycling or management as waste. With the increasing environmental operation standards of modern energy conversion systems, the upstream and downstream processes in LCA, e.g. fuel supply or power plant and infrastructure production, become increasingly relevant [17,18].

Table 1
The average damage cost of typical pollutants in China (source: [30]).

Pollutants	Cost of damage to the environment (yuan/ton)
SO ₂	6320
NO _x	6320
TSP	2750

Table 2

Basic parameter settings for a typical LS-PV project in China (source: [34]).

Basic parameters	Debt ratio (%)	Interest rate (%)	Return on equity (%)	Average hours of power generated annually (h)	Ratio of PV cells to total PV system (%)
Typical value	80	6	8	1320	45

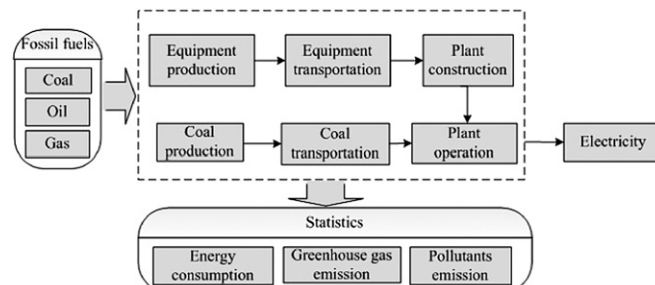


Fig. 2. System boundary of coal-fired power.

Therefore, in order to obtain the co-benefits of PV power compared with coal-fired power in China, this paper carries out LCA both on PV power and coal-fired power. For PV power, we select large-scale polycrystalline PV power as the representative technology considering both its fairness when subsidized and dominant market share; for coal-fired power, we select typical 600 MW coal-fired power units in China. From the results of LCA, we can estimate the monetary value of co-benefits, and the time of grid parity of PV power in China if these co-benefits are internalized.

We structure this paper as follows: in section 2, we give a brief review of relevant studies and introduce methodology of this paper. Section 3 details LCA both on large-scale polycrystalline PV power and 600 MW coal-fired power plants in China. Based on the results in section 3, section 4 assesses the co-benefits of PV power and its influence on time of grid parity. Section 5 concludes the paper.

2. Methodology

2.1. Life cycle analysis

A Life Cycle Analysis is carried out in four distinct phases as illustrated in the Fig. 1. The phases are often interdependent in that the results of one phase will inform how other phases are completed [15,16].

In the first phase (Goal and Scope Definition), the goal and scope of the study has to be defined in relation to the intended use or application of the results. During the second phase (Inventory Analysis), the data on inputs and outputs for all the processes

Table 3

Life cycle emission of 1 kW-hour electricity produced by a 600 MW coal-fired power plant (kg/kWh).

Process	GHG (CO ₂ equivalent)	SO ₂	NO _x	TSP
Coal production	9.888E-02	2.688E-05	1.613E-05	2.285E-05
Coal transportation	1.890E-02	6.310E-05	1.771E-04	1.217E-05
Equipment production	4.136E-04	1.093E-06	5.636E-07	4.884E-07
Equipment transportation	1.537E-05	5.132E-08	1.440E-07	9.897E-09
Plant construction	9.143E-04	1.335E-06	2.413E-06	4.801E-06
Plant operation	9.049E-01	5.000E-04	6.000E-04	1.500E-04
Total	1.024E+00	5.925E-04	7.963E-04	1.903E-04

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