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Economic performance of photovoltaic water pumping systems with business model innovation in China

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ABSTRACT

Expansion by photovoltaic (PV) technologies in the renewable energy market requires exploring added value integrated with business model innovation. In recent years, a pilot trial of PV water pumping (PVWP) technologies for the conservation of grassland and farmland has been conducted in China. In this paper, we studied the added value of the PVWP technologies with an emphasis on the integration of the value proposition with the operation system and customer segmentation. Using the widely used existing PV business models (PV-roof) as a reference, we evaluated discounted cash flow (DCF) and net present value (NPV) under the scenarios of traditional PV roof, PVWP pilot, PVWP scale-up, and PVWP social network, where further added value via social network was included in the business model. The results show that the integrated PVWP system with social network products significantly improves the performance in areas such as the discounted payback period, internal rate of return (IRR), and return on investment (ROI). We conclude that scenario PVWP social network with business model innovation, can result in value add-ins, new sources of revenue, and market incentives. The paper also suggests that current policy incentives for PV industry are not efficient due to a limited source of revenue, and complex procedures of feed-in tariff verification.

1. Introduction

By the end of 2014, the total installed capacity globally for solar photovoltaic (PV) amounted to at least 177 GW in the world, of which 38.7 GW was the newly installed PV capacity, according to the International Energy Agency's Photovoltaic Power Systems Program [1]. Of all new PV capacity installed worldwide in 2014, roughly 25% (10.6 GW) was connected to the state grid in China [1]. The total installed PV capacity connected to the state grid was 28.05 GW in China. Total electricity generated by PV reached 250 TW h in 2014, an increase of more than 200% over 2013. Among the new 10.6 GW on-grid PV power capacity, about 2 GW is from small-distributed PV systems in China [2]. By the end of 2015, the additional photovoltaic capacity of 2015 reached 15 GW, the total installation photovoltaic capacity reached 43 GW, according to the National Energy Administration's statement. 16% of this installation capacity comes from distributed PV systems [3]. In spite of the remarkable increase in new installations, the distributed PV system industry is still in the beginning phase of development supported by the Chinese government's policies of the Feed-in Tariff of 0.42 RMB/kW h and other on-grid subsidies [4]. According to the working plan of the National Energy Administration of China, the proportion of installed distributed PV system capacity was set to reach to 60% of all new solar power installed capacity in 2014 [5]. However, the actual realized proportion in 2014 was only 20%, far below the set goal. The working plan of the National Energy Administration of China set the goal for 2015 to reach 60% of all new solar power installed capacity in 2014 with distributed PV system. The current distributed PV system has a discounted payback period over 15 years without grid-connected, 12 years with the grid-connected revenue, which is a significant hindrance for its implementation [6]. Thus, an improved business model to distribute PV systems is crucial for achieving the aforementioned goal for distributed PV systems [7]. It is important to study how the existing business models operate. Do these business models need to be changed? What are the changes that should be made to improve the economic performance of business models?

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Nomenclature

Abbreviations

DCF	discounted cash flow
IRR	internal rate of return
LCC	life cycle cost
NPV	net present value
PV	photovoltaic
PVWP	photovoltaic water pumping
ROI	return on investment

Business model innovation is a process to create competitive advantages for economic entities with the creation of customer value and appropriating value in the marketplace [8]. It focuses on the unique concept of value creation instead of value appropriation [8] and one can employ various business models to create value for specific market segments [9]. The strategic potential of business model innovation lies in identifying new sources of value creation, based on innovations in the different components of a business model and/or the interactions between these components [10]. There are two main dimensions of value creation from business model innovation: efficiency and novelty [11]. There are also two ways of handling transactions in economic exchanges, corresponding to a cost leadership and product differentiation strategy, respectively. While the focus of efficiency is on cost reductions of existing transactions, novelty emphasises new ways to conduct transactions [11]. Business model innovation can be employed to create value based on one of these sources, but they could also use a combination of different sources [12]. In this study, we evaluate the business model innovation process upon existing PV markets with special consideration to PVWP systems.

Business models of PV applications have been previously studied. As suggested by Franzis [13], PV business models have been through three generations: zero, one, and two. The zero generation of PV business model focuses on manufacturing, supply, and the installation of PV systems. This business model is mostly used in current PV technology applications, in which the customer acts as an end users who has ownership of their own systems (arranging for net metering and interconnection with the grid) [14] and there have only been a small group of pioneering customers involved in zero generation geared towards environmental and self-generation benefits. In the first generation of the PV business model, third-party customers appear as new entrants with ownership of the PV systems with a broader market. It therefore has greater access to financial and market incentives. With the second generation PV business model, the PV system is scaled-up and integrated as a part of the electricity supply [14]. The second PV business model merges ownership, operation and control segments with various stakeholders under more technologies and regulatory initiatives. The traditional solar energy business models (zero generation) largely rely on governmental subsidies, rarely gaining access to other possible revenue from third-party customers [15]. Adopting PV systems with zero generation of PV business model to provide electricity for different distributed applications has been widely studied in previous researches [16–22]. The researches mainly focused on optimization, techno-economic analysis [18,19], economic viability studies [22], and energy effectiveness issues [21], etc. There are only a few researches that actually analyse the economic performance of PV systems with its business model analysis [23–25]. With the evolutions of the PV business models, more stakeholders and utilities (besides electricity generation) are involved. The three main drivers in the solar energy market drivers [26], feed-in tariff of policy guidance [27], investment incentives [28], and co-benefits of social issues, have been discussed [29].

The PVWP system acts as an integrated system that utilizes PV panels to generate the power for irrigation equipment on the grassland or farmland. The system improves grass coverage, forage and crop yields with the energy reductions, environmental co-benefits and climate mitigation of the grassland or farmland. Our previous studies have been conducted on the PVWP system, including a pilot demonstration on the technical feasibility [30–32], ecological impacts [35,36] and economic valuation [37,38]. Campana et al. analysed the techno-economic feasibility with water demand consideration in PVWP pilot systems [30–32]; using the LCA method, Jing et al. suggested that PVWP is a good choice for carbon emission reduction [35]. Olsson et al. showed that there is a climate change mitigation benefit of 7.4 Mg (1 Mg = 1 metric ton) CO_2-equivalents/ha/yr emissions reductions realized with the PVWP pilot [36]. Unsurprisingly, the potential benefits of a PVWP pilot varied under different incentives and schemes [37,38]. It is thus of great importance to study the business models of PVWP with an emphasis on the integration of the direct economic benefits as well as indirect benefits in ecological and environmental impacts, and on the values of co-benefits linked to the policy incentives with recommendations by the states. Moreover, we believe such a study needs to include a large-scale deployment of solar PVWP systems in order to improve understandings of such systems from both environmental and economic perspectives.

This paper is to investigate how to improve the PVWP business model under four scenarios of PV systems with market incentives. We have shown the limitations of the current business models of the PV system (generations zero, one, and two). Our major objective is to evaluate the economic performance of PVWP systems with the business model innovation using discounted cash flow (DCF), discounted payback period, and return on investment (ROI) as a tool to assess the impacts of each system and combinations of these systems. We propose market incentives approach to analyse the PVWP systems under different business models, by introducing relevant subsidies and feed-in-tariff indicators. This study uses actual data from PVWP pilot systems in Inner Mongolia to generate realistic estimates of performance. Specifically, we will define and quantify the environmental and economic performance of the PVWP systems with the business model innovation into three metrics: (1) discounted payback period, (2) IRR, and (3) ROI. These metrics of solar PV systems are compared with those of the PV roof system to illustrate the environmental and economic benefits of the PVWP systems under different business models with market incentives.

The structure of the paper is organized as follows: Section 2 is on the methodologies; Section 3 illustrates results and discussions under different scenarios with the business model innovation; and Section 4 makes conclusions and future policy suggestions.

2. Methodology

2.1. Studied system and scenarios

PV water pumping technology is one of the most effective solutions for pasture or crop irrigation farming in rural and remote areas where grid electricity is not available. A typical PVWP system consists of a PV array that powers an electric motor, which drives a

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