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Grid-connected photovoltaic systems for Malaysian residential sector: Effects of component costs, feed-in tariffs, and carbon taxes

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ABSTRACT

Blessed with abundant solar radiation, Malaysia has a huge potential for grid-connected PV (photovoltaic) installations, particularly for its fast-growing residential sector. Nevertheless, Malaysia's PV installation capacity is relatively small compared with the global PV capacity. Significantly, the pricing mechanisms for grid-connected PV projects need to be appropriately assessed to build up the public's confidence to invest in PV projects. In this paper, we analyze the effects of component costs, FiTs (feed-in tariffs), and carbon taxes on grid-connected PV systems in Malaysian residential sector using the HOMER (Hybrid Optimization of Multiple Energy Resources) software. Results demonstrate that the implementation of grid-connected PV systems is highly feasible with PV array costs of $ 1120/kW or lower. For higher PV array costs up to $ 2320/kW, introducing an FiT rate three times higher ($ 0.30/kWh) than the grid tariff for a 100 kW grid sale capacity will, NPC-wise, prioritize grid-connected PV systems over the utility grid. By implementing the FiT ($ 0.50/kWh) and the carbon tax ($ 36/metric ton) schemes simultaneously, grid-connected PV systems will remain as the optimal systems even for costly PV arrays (up to $ 4000/kW). The findings are of paramount importance as far as PV pricing variability is concerned.

1. Introduction

Renewable energy systems have become increasingly popular worldwide due to the many advantages – clean, sustainable, and maintenance-free – of these power generation systems in comparison with conventional power generation systems utilizing coal, oil, and gas. According to the recent UNEP's (United Nations Environment Program) report [1], global investment in renewable energy projects (excluding large hydro-electric projects) in 2014 was nearly 17% higher than in 2013, and this corresponded to an additional 103 GW of capacity added by renewable energy sources. This was mainly caused by a boom in PV (photovoltaic) installations in China and Japan for utility-scale projects over 1 MW and small-scale projects less than 1 MW, respectively. Globally, investments in PV approached $ 150 billion for a capacity of 46 GW in 2014.

Malaysia has welcomed the development of renewable energy sources since 2000 through its Five-fuel Diversification Policy [2]. Non-hydroelectric renewables such as solar, wind, biomass, biogas, and geothermal have been recognized for power generation, placing them on par with oil, gas, coal, and hydro-electric. As of 2013, Malaysia's electricity generation mix consisted of 50.4% natural gas, 38.0% coal, 8.4% hydro-electric, and 2.3% oil, showing a significant change from the share of generation mix in 1980, where oil then accounted for 87.9% of electricity generation, followed by natural gas (7.5%), hydroelectric (4.1%), and coal (0.8%) [3,4]. Although Malaysia has successfully diversified its fuel mix for electricity generation from oil to natural gas, and efforts have been undertaken to increase the share of coal in the fuel mix, the share of renewable electricity has thus far been negligibly small (except for large hydropower), standing at about 1% of total electricity generation mix nationwide. According to Energy Commission, Malaysia [5], Malaysia's total installed electricity generation capacity in 2013 was recorded at 29,748 MW, with the gross electricity generation registered at 143,497 GWh – an increase of 6.8% from the previous year. The peak electricity demand, on the other hand, was recorded at 19,219 MW, with 123,076 GWh electricity consumed – an increase of 5.8% from the previous year. Clearly, the peak demand and average electricity consumption will continue to rise in the future, and renewable resources have to be incorporated to ensure sustainable electricity generation [6,7].

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Among the renewables, Malaysia benefits largely from solar energy due to its strategic geographical location that receives a huge amount of solar radiation, ranging from 1400 kWh/m^2/yr to 1900 kWh/m^2/yr, averaging to 1643 kWh/m^2/yr with more than 10 sun hours per day [8–11]. It was even estimated that PV panels installed in an area of 431 km^2 in Malaysia could generate enough electricity to satisfy the country's 2005 electricity requirement [10]. Nevertheless, the number of PV installations in Malaysia, especially those connected to the utility grid, is quite minimal. As of 2004, Malaysia's cumulative grid-connected PV was 468 kW [12], and the figure was largely due to the installation of a 362 kW project undertaken by Technology Park Malaysia in 2001 [13]. According to Haris [12,13], there were only three residential PV installations done in early 2000, corresponding to about 9 kW. They were the grid-connected PV systems installed for a house in Port Dickson and two houses in Subang Jaya, with PV output ratings of about 3 kW each. Later in 2010, the total grid-connected PV capacity successfully installed and commissioned in Malaysia increased to 1516 kW with 109 projects completed – 64 projects were undertaken on residential houses, corresponding to about 459 kW PV capacity [14]. Although the capacity of the grid-connected PV increased further to 1651 kW in 2011 [14], the number falls well behind Malaysia's total electricity installed capacity and remains relatively small compared with the global PV capacity.

The market for PV is often driven by factors such as up-front cash rebates, production-based incentives, renewables portfolio standards, and tax benefits which aim to reduce the cost of PV-generated electricity by compensating for the relatively high cost of PV. According to Barbose et al. [15], the 2013 median installed price for residential and commercial PV systems (more than 100 kW in size) in the United States was $ 4000/kW (the estimated price included non-module costs such as inverters, mounting hardware, installation, labor, overhead, taxes, and installer profit). The median installed price, however, varied for major international PV markets such as the United Kingdom, Italy, France, Germany, and Japan, with Germany having the greatest pricing disparity – the median installed price for Germany was about $ 2000/kW. Meanwhile in Malaysia, the average turnkey price (an estimated price of an installed PV system including the costs for PV arrays, inverters, and installation, but excluding taxes, operation and maintenance costs, and additional costs not directly related to the PV system) of a building integrated PV system was about $ 5200/kW in 2010 [16,17], and reduced to $ 3650/kW in 2011 [17]. As far as we were aware, the latest PV system pricings in Malaysia were not reported elsewhere, but were estimated to hover around $ 4000/kW for conservative PV system installations [18]. It is noteworthy that the aforementioned prices may not be directly comparable, but may serve as reasonable estimates indicating relatively high costs of PV installations.

To encourage the general public and business enterprises to invest in PV systems, Malaysia, through its 2011 Renewable Energy Act, introduced the FiT (feed-in tariff) scheme for grid-connected electricity generated using renewables [19]. A regulatory framework for the FiT mechanism was developed by relevant authorities to allow locally produced electricity to be sold to power utilities at a fixed premium over a specified period. In 2014 for example, SEDA (Sustainable Energy Development Authority), Malaysia conducted an inaugural balloting event for PV feed-in-approval applications for non-individuals, for installed capacity of up to 425 kW [20]. This was regarded as an effective measure to offset the high investment cost of PV technology. It is noteworthy that around 72 countries and states worldwide have introduced the FiT support scheme in an effort to increase renewable capacity investments [21–26].

Meanwhile, the clean nature of solar energy (and other renewable energy sources) contributes to the reduction of carbon emissions worldwide. So far, solar, wind, biomass and waste-to-power, geothermal, small hydro, and marine power contributed to about 9% of the world's electricity generation – increasing equivalent fossil fuel sources would have otherwise emitted about 1.3 gigatonnes of carbon dioxide [1]. According to PBL Netherlands Environmental Assessment Agency [27], the three largest carbon dioxide emitting countries/regions were China (10.3 billion tonnes), the United States (5.3 billion tonnes) and the European Union (3.7 billion tonnes), which accounted for 29%, 16%, and 11% of global carbon dioxide emissions, respectively. Although Malaysia contributed to merely 0.2 billion tonnes of global carbon dioxide emissions [28], in terms of carbon emissions per capita, Malaysia registered 7.8 metric ton/capita [29] – a number which surpassed many developed countries. Significantly, further investments in renewable energy will be needed for a less carbon-intensive energy supply and to mitigate climate change [27], and the role of developing Asia, including Malaysia, will be crucial in the context of climate change control [30].

According to the 2010 Population and Housing Census [31] conducted by the Department of Statistics, Malaysia [32], the total population of Malaysia was 28.3 million, and there were 6.34 million private households with an average household size of 4.2 persons [33]. The residential dwellings total about 7.3 million, and were projected to increase by about 150,000 every year [32,34]. With the rapid growth in the residential sector in addition to the commercial and industrial sectors, the demand for electricity will inevitably increase. In 2013 for example, 21% of the electricity generated in Malaysia was consumed by the residential sector with an average annual consumption of 3300 kWh per household [5,35]; a typical house uses more than 40% of the electricity on the fridge, air-conditioning, and water heating [36]. Seemingly, the residential sector offers a huge amount of untapped potential for grid-connected PV installations that can boost Malaysia's PV capacity. This will help to meet Malaysia's effort to increase its solar power's contribution to at least 220 MW to the total capacity mix and to have 9 GW of solar PV installations by 2050 [37,38].

Nevertheless, the pricing mechanisms for a successful PV project need to be appropriately assessed to build up the public's confidence to invest in PV projects. This paper therefore seeks to analyze the potential implementation of grid-connected PV systems for Malaysian residential sector. Since factors such as components costs, FiTs, and carbon taxes will affect the overall cost of a PV project, these variations are addressed with the aid of the HOMER (Hybrid Optimization of Multiple Energy Resources) software.

2. Background information

2.1. HOMER software

HOMER is a computer model that assists the design of renewable micropower systems and facilitates the comparison of power generation technologies based on technical and economic factors [39]. HOMER performs simulation, optimization, and sensitivity analysis by modeling the performance, hence technical feasibility and life-cycle cost of a micropower system, simulating various system configurations to come out with the optimal system configuration, and performing multiple optimizations under a range of input assumptions to account for variations in the model inputs. More detailed descriptions on HOMER's features can be found elsewhere [40].

2.2. Solar radiation

According to Mekhilef et al. [41], cities in Malaysia received annual average daily solar radiation of 4.03–5.21 kWh/m^2/d.