Journal of Environmental Management 230 (2019) 464–473

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Estimating the impacts of financing support policies towards photovoltaic market in Indonesia: A social-energy-economy-environment model simulation

Muhammad Indra Al Irsyad[a,b,*], Anthony Halog[b], Rabindra Nepal[c]

[a] Research and Development Centre for Electricity, Renewable Energy and Energy Conservation Technologies, Ministry of Energy and Mineral Resources, Jakarta, Indonesia
[b] School of Earth and Environmental Sciences, University of Queensland, Queensland, Australia
[c] Tasmanian School of Business and Economics, University of Tasmania, Hobart, Tasmania, Australia

ARTICLE INFO

Keywords:
Developing country
Socioeconomic
Agent-based modelling
Input-output analysis
Solar energy policy*JEL Classification:*
C60
Q21
Q43
Q48
Q51
Q58
R15
R51

ABSTRACT

This study develops a hybrid energy agent-based model that integrates the input–output analysis, environmental factors and socioeconomic characteristics of rural and urban households in Indonesia. We use the model to estimate the effects of four solar energy policy interventions on photovoltaic (PV) investments, government expenditure, economic outputs, CO_{2e} emissions and the uses of steel, aluminium, concrete and energy. The results of our analysis call for the abolition of the PV donor gift policy, the improvement of production efficiency in the PV industry and the establishment of after-sales services and rural financing institutions. A 100 W peak (Wp) PV under this recommendation would be affordable for 80.6% of rural households that are projected to be without access to electricity in 2029. Net metering is the most effective policy for encouraging urban people to invest in PV in a situation where fossil energy prices are increasing and PV prices are declining. A donor gift policy may induce USD 51.9 new economic outputs for every Wp of PV operating to capacity in 2029, but would require a subsidy of USD 18.6/Wp. The recommended policies do not require subsidies and reduce CO_{2eq} emissions and the consumption of aluminium, energy, steel and concrete by between 83.1% and 89.7% more than the existing policy. Several policy implications are discussed in response to these findings. As a contribution to energy modelling literature, the model can be used for other developing countries by merely changing its data.

1. Introduction

A lack of universal electricity access is a common problem encountered by developing economies (Doll and Pachauri, 2010; UN, 2017). Secure access to affordable, reliable, sustainable and modern energy for all by 2030 has become a sustainable development goal. However, the achievement of this goal is challenged by low-density loads, especially in island countries. Island topography means that energy distribution via grid access is challenging and uneconomical because necessarily small electricity markets prohibit the significant scale economies of power plants (Timilsina and Shah, 2016). Therefore, most island economies are heavily dependent on oil-based power plants, which are available on a small scale and at low investment costs, but that make these economies vulnerable to the effects of oil prices and climate change (Lazrus, 2012; Nurse et al., 2014).

Indonesia provides an interesting case study. Rural electrification in Indonesia was first developed in Java Island and then distributed to the outer islands, from a small isolated diesel programme in the 1950s to a micro-hydro plant programme in the 1970s—the funding for which, while originally from foreign aid, came from the local government budget (McCawley, 1978). Oil-based power plants have been a priority in the acceleration of rural electrification since the Dutch colonisation period (McCawley, 1971). The massive development of oil-based power plants caused significant growth in capacity from 230 MW in 1974 to 784 MW in 1984, 2128 MW in 1994 and 3354 MW in 2016. As a result, the electrification levels increased from below 10% in 1975 to 89.1% in 2016 (McCawley, 1978; PLN, 2017; WB, 2017). However, under the high oil price era, oil-based power plants, together with a policy to keep electricity prices low, were responsible for enormous electricity subsidy increases from USD 302 million in 2000 to USD 7538 million in 2011[1] (Ahadi and Al Irsyad, 2012).

However, the island topography constraint poses a unique

* Corresponding author. Research and Development Centre for Electricity, Renewable Energy and Energy Conservation Technologies, Ministry of Energy and Mineral Resources, Jakarta, Indonesia.

E-mail address: muhammad.alirsyad@uq.net.au (M.I. Al Irsyad).

[1] The exchange rate is assumed to be IDR 13,000/USD.

https://doi.org/10.1016/j.jenvman.2018.09.069
Received 4 April 2018; Received in revised form 29 August 2018; Accepted 21 September 2018
0301-4797/

opportunity to serve the electricity needs through distributed renewable energy (Khodayar, 2017; Kuang et al., 2016). The renewables-based mini-grid provides a viable means of access to electricity for the rural population that is remote from power grids (Sovacool, 2013). Though advancements in technologies and the associated environmental benefits have placed off-grid renewables high on the global rural electrification agenda, the deployment of renewable energy still encounters various barriers, such as technical reliability, social acceptance, environmental impacts and economic feasibility (Blum et al., 2013; Byrnes et al., 2013; Nepal, 2012). For instance, the solar home system project in Indonesia from 1997 to 2003 failed because of ineffective financing, a lack of domestic PV industry and service companies for sales and maintenance, subsidised fossil energy, grid extension and the misunderstanding of household characteristics (Siddaiah and Saini, 2016; Sovacool, 2013). This project not only cost USD 118.1 million, but also negatively affected the environment because the production process of PV produces emissions and requires significant natural resources (Hertwich et al., 2015; Sovacool, 2013). Another concern in promoting renewable energy is its macroeconomic impacts as a consequence of its relatively high electricity production costs; however, the renewables investments may foster economic output (Dannenberg et al., 2008; Hasudungan and Sabaruddin, 2018).

These sustainability issues require an integrated assessment (Schlör et al., 2018). Hence, we have constructed a novel, integrated socio-energy-economic-environment (SE3) model to simulate the effects of solar energy policies on the investment behaviours of households, the environment and the national economic outputs. The model has been applied in the Indonesian context to assess the effectiveness and efficiency of five solar energy policies: donor gifts, feed-in tariffs, financing services, partial subsidies and net metering. Effectiveness is defined as the number of installed PV capacities resulting from each policy. Meanwhile, efficiency is defined as the ratio of sustainability indicators and government expenditure to every Wp-installed PV.

The remainder of the article is structured as follows. Section 2 provides an overview of renewable energy policies in Indonesia and energy models in general. Section 3 describes the methodology and data, while Section 4 presents the results. Section 5 discusses policy implications along with the performance of the energy model. Section 6 concludes the article.

2. Literature review

2.1. Renewable energy policy in Indonesia

The use of renewables for rural electrification in Indonesia is undertaken via donor gifts and integrated independent power producer (IPP) programmes. The first programme for PV technology began in 1995 and received overwhelming criticism, principally as a result of the lack of knowledge transferred to villagers about preserving the PV performance. This programme contradicted the global trend towards active participation and cost sharing by rural households, financing institution supports and extensive after-sales service and maintenance (Sovacool, 2013). Donor gifts do not encourage villagers to invest in PV, resulting in an undeveloped PV market, a lack of maintenance and a shorter PV system lifetime. Therefore, the recently introduced second programme (MEMR, 2016b) encourages IPP to sell electricity to rural households without electricity supplies from the state-owned electricity company (PLN), which monopolises the retail electricity market. The selected IPP must use the lowest PLN electricity tariff and can then claim a subsidy for the discrepancy between the production costs and tariff. The subsidy is restricted to a maximum of 84 kWh per household each month.

Renewables policies for the on-grid system in Indonesia experience different trends than the policies of developed countries. The use of feed-in-tariffs (FIT), the most globally successful renewable energy policy (Bürer and Wüstenhagen, 2009), was rejected by PLN and other ministries to prevent escalations in electricity subsidies. In early 2017, FIT was replaced by the 'reference tariff' policy, which stipulates PLN's regional electricity generation costs as the maximum tariff for which to buy renewables-based electricity produced by IPP (MEMR, 2017). Moreover, Indonesia applies a solar energy quota, which is tendered only to IPP to limit feeding in and, therefore, maintains grid stability. This is another policy contrast to developed countries that encourage PV investments by the residential sector through net metering and rebates (Rai and Robinson, 2015; REN21, 2017; Schelly et al., 2017). These differences in energy systems between two contrasting economies have consequences when employing energy models as analytical tools (Al Irsyad et al., 2017; Siddaiah and Saini, 2016).

2.2. Energy modelling studies

Energy models can be classified into engineering and economic approaches. The engineering approach entails comprehensive database detailing technologies, energy potential and cost. Techno-economic analysis, such as the levelised cost of energy, has a role in connecting the intervening policies (e.g., rebates and clean development mechanisms (CDM)) with the modelled energy systems (Rai and Robinson, 2015; Tang, 2013). However, this approach cannot analyse the macroeconomic impacts from changes at the energy system (Li et al., 2015). In contrast, the economic approach emphasises the interaction of economic sectors with energy systems. One of the economic approaches is input–output (IO) analysis, which has a weakness as a static model, but is a useful analytical tool when data are limited (West, 1995). In fact, its simplicity becomes the basis for more complex models and, thus, its application is still growing in current literature concerning clean energy analysis (Chun et al., 2014; Simas and Pacca, 2014). Nevertheless, the economic approach has fewer specifications pertaining to the energy sector (de Koning et al., 2015).

Therefore, the trend of energy modelling entails the integration of multi-approaches, including environmental analysis (Taylor et al., 2014). Environmental awareness is one of the motives for the use of renewables. However, renewable energy produces severe initial impacts on the environment as a consequence of its low power density (Hertwich et al., 2015). In encountering this dilemma, life-cycle analysis (LCA) becomes a useful analytical tool to assess the entire environmental impacts of a power plant across its lifetime. Thus, LCA is typically combined with other methods when advancing the systems modelling framework (Earles and Halog, 2011; Earles et al., 2013; Halog and Manik, 2011). Unfortunately, existing hybrid energy models still lack the features of human and social elements, which are crucial to renewables policy analysis (Sovacool, 2014; Sovacool et al., 2015). For example, the only human and social issues modelled in the MARKAL–MACRO model are growth rates for the population and households (Ko et al., 2010).

The application of agent-based modelling (ABM) for energy systems is an emerging area of literature, since it can integrate engineering and economic approaches to social analysis in energy systems, as shown by studies in Table 1. Social factors, such as income, have been recognised as significant drivers of renewable energy investments (Graziano and Gillingham, 2015). Developing countries usually have high levels of income inequality; however, this condition is ignored in most existing energy models by using an average income value (Bhattacharyya and Timilsina, 2010). ABM can easily model income inequality as it can create agents representing households with heterogeneous characteristics. For instance, Rai and Robinson (2015) modelled the social characteristics of 2738 PV-using households to evaluate the effectiveness of the PV rebate policy in Texas. Tang (2013) assessed the effects of the differences in experience of wind turbine developers in Brazil, China and India in response to financial support from the CDM. Alfaro et al. (2017) developed the Bottom-up Agent-Based Strategy Test-kit for Electricity with Renewables (BABSTER) model to compare the effects of five strategies for renewables development in Liberia.