Estimating Effectiveness and Efficiency of Solar Energy Policy for Indonesia: A Hybrid Agent-Based Model Analysis

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Abstract
Our study analyses four solar energy policies and their impacts on photovoltaic (PV) market potential, government expenditure, economic growth, and environment. The analysis uses a hybrid energy agent-based model dedicated to capturing the specific economic and institutional features of developing economies, particularly in Indonesia. We undertake an integrated approach to ABM by combining input-output analysis, life-cycle analysis, socio-economic data, and urban-rural analysis to obtain a comprehensive assessment. The result is a recommendation to abolishing PV grant policy in rural electrification programs. As a substitute, first, the government should encourage PV industry to improve production efficiency and provide after sales service. Second, the government then should arrange financing scheme for the PV investment. Both policies will create PV market in 2050 for 65.1% and 67.6% respectively of rural households without electricity. Capital and interest subsidies cannot further increase PV market potential in rural area. In contrast, our study found policies of previous feed-in tariff and existing tariff cannot diffuse PV in urban households without additional capital and interest subsidies. Indeed, the net metering scheme is recommended as the most effective policy to develop PV market in urban area.

Keywords: energy model, developing country, renewables policy, impact assessments

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1 Introduction

Most developing countries, like Indonesia, still lack of energy access and thus, renewable energy is commonly used to improve rural electrification (Sovacool, 2013). However, renewable energy development is challenged by various barriers, e.g. technical reliability, economic feasibility, and social acceptance (Blum, Wakeling, & Schmidt, 2013; Byrnes, Brown, Foster, & Wagner, 2013; Jacobson & Delucchi, 2011; Nepal, 2012). On account of this, Sovacool (2013) emphasises the importance of appropriate policies in determining the implementation level of renewables-based rural electrifications. Indonesia uses two types of renewables policy for rural electrification (i.e. donor gift policy and independent power producer (IPP) scheme) as alternatives of grid extension by the Stated-owned Electricity Company (PLN). The donor policy has been widely criticised for misunderstanding people needs and poor coordination between institutions (Sovacool, 2013). As a consequence, recently in 2016 the government allows IPP to directly sell electricity to households having no electricity access from PLN. The IPP could use renewable energy technology and then claim a subsidy from the government.

Indonesia used the feed-in tariff (FIT) policy to encourage renewable energy investments by IPP in on-grid electricity system. However, the policy can no longer be implemented due to rejections from PLN which monopolises the electricity market. The FIT was argued to increase the electricity subsidy since the electricity price is already lower than PLN's production cost. In earlier 2017, the FIT is finally replaced by the policy setting of PLN's regional production costs as the maximum reference tariffs to buy renewables-based electricity from IPP. The purposes of the policy are to reduce the PLN's generation costs in the long-term and at the same time, to force IPP to improve their production efficiency.

In this light, our study assesses the effectiveness and the efficiency of those policies by using a hybrid energy model, called Agent-based Renewables model for Indonesia Sustainable Energy (ARISE). Energy model is a standard analytical tool in policy-making to evaluate the costs and benefits of a proposed energy policy. However, most energy models are designed for advanced economies as characterized by commercial energy uses, high industrial energy demand share, dominating formal activity, reliable energy supply, lower income inequality, and liberal energy markets (Al Irsyad, Halog, Nepal, & Koesrindartoto, 2017; Bhatia, 1987; Bhattacharyya & Timilsina, 2010a; Pandey, 2002; Shukla, 1995; Urban, Benders, & Moll, 2007; Van Ruijven et al., 2008). Using such energy models for analysis in developing economies requires significant adjustments namely by considering rural – urban area, traditional – modern energy uses, and heterogeneity of society's characteristics. ARISE is designed to consider those unique characteristics and, most importantly to our knowledge, ARISE is the first energy model integrating the four perspectives (i.e. engineering, macroeconomic, environment and socio-economic perspectives). Nevertheless, we admit that our ARISE is still limited to photovoltaic policy.

The structure of the rest of the article is as in the following. Section 2 discusses energy model in general and the need to integrate social and economic perspectives. Section 3 describes methodology and data, while Section 4 and 5 present the results and policy implication respectively. Section 6 is the conclusion.

2 Literature Review

An energy model in general can be viewed in engineering and economic approaches (Bhattacharyya & Timilsina, 2010b; Connolly, Lund, Mathiesen, & Leahy, 2010; Jebaraj & Iniyan, 2006; Nakata, Silva, & Rodionov, 2011; Suganthi & Samuel, 2012). Engineering approach, also called the bottom-up approach, has the characteristics of a comprehensive database of technologies, energy potential, and costs. However, the bottom-up approach has weaknesses; one of them is a lack of macroeconomic analysis (Li, Trutnevyte, & Strachan, 2015). On the other hand, economic approach, or the top-down approach, emphasizes the interaction of economic sectors in the market. This feature allows assessing the impact of the proposed policy to macroeconomic indicators, such as economic growth, employment and energy prices. Unfortunately, the top-down approach generally has less specifications of energy sector that eventually leads to bias (de Koning et al., 2015). Therefore, integrating both approaches is a common practice to solve the weaknesses of each.

The application of agent-based modelling (ABM) for energy system is evolving because its features could surpass the limitations of conventional energy models. ABM could integrate engineering and economic approaches to social analysis in energy system (Ventosa, Baıllo, Ramos, & Rivier, 2005; Veselka et al., 2002). Initially, ABM is used to assess strategic management of utility companies in liberal electricity market (Sensuß, Genoese, Ragwitz, & Möst, 2007; Weidlich & Veit, 2008), but now ABM is also widely used for analysis in developing countries. For example, Tang (2013b) assesses the impact of clean development mechanism (CDM) on wind energy investment decisions in China, India, and Brazil. Smajgl and Bohensky (2013) analyse the impact of fuel price changes to poverty and deforestation in Indonesia. Recently, Alfaro, Miller, Johnson, and Riolo (2017) develop BABSTER (Bottom-up Agent-Based Strategy Test-kit for Electricity with Renewables) model to compare the impact of five strategies of renewable energy development in Liberia.

However, none of previous studies on renewable energy analyses the perspectives of engineering, macroeconomic, social, and environment simultaneously. Alfaro et al. (2017) discuss engineering and macroeconomic perspectives but exclude environmental and social issues. Meanwhile, Tang (2013b) does not consider the macroeconomic relationship. Integrating these four perspectives could provide comprehensive solutions for multi-interest research in developing countries (Al Irsyad et al., 2017). Therefore, ARISE includes these four issues for analysing potential photovoltaic (PV) markets in Indonesia.

In the macroeconomic perspective, input-output (IO) analysis has been widely used to assess the impact of clean energy supply impact. Markaki, Belegri-Roboli, Michaelides, Mirasgedis, and Lalas (2013) evaluate the impact of targets of renewable energy and energy conservation to economic outputs and employments in Greece. Tourkolias and Mirasgedis (2011) and Simas and Pacca (2014) assess employment growth by viewing renewable energy development in Greece and wind energy projects in Brazil respectively. Chun et al. (2014) estimate economic impact of hydrogen energy development in South Korea for the period 2020 – 2040.

In the social perspective, non-monetary factors have a significant influence to renewable energy investment. Tang (2013a) notices the importance of investors' experiences; an experienced investor is assumed to have higher discount rate for the investment. Graziano and Gillingham (2015) examine the significances of several factors, e.g. neighbour distance, rented house share, household income, race, age, political views, and unemployment rate, to 3,833 PV adopters in Connecticut State during 2005 - 2013. Similarly, by using 2,738 PV adopters in Austin City, Robinson and Rai (2015) confirm the significant influences of location, home value and tree cover to the investment decisions.

In the environmental perspective, providing greener electricity supply is one of the motives of renewable energy development; on the contrary, renewable energy has higher upfront environmental impact (Hertwich et al., 2015). Life-cycle analysis (LCA) has become a powerful analytical tool to compare the total environmental impact of power plant technologies during their lifetime. LCA also has been commonly combined with other approaches to advance system modelling framework (Earles & Halog, 2011; Halog & Manik, 2011).

3. Methodology and Data

The main feature of ARISE is to assess a policy from technical, economic, environmental and social perspectives. Figure 1 shows the interaction of those four perspectives. At the initial stage, ARISE calculates the investment cost and monthly instalment of PV 100 Wp (for off-grid) and 1,500 Wp (for on-grid) based on technical data (e.g. capital cost, operational and maintenance cost) and policy scenario. If the monthly cost is lower than the willingness threshold, a household would invest in the PV. ARISE then uses the number and the monetary values of PV investments to estimate the environmental and macroeconomic impact. The detailed descriptions of each perspective are discussed in the following sub sections.

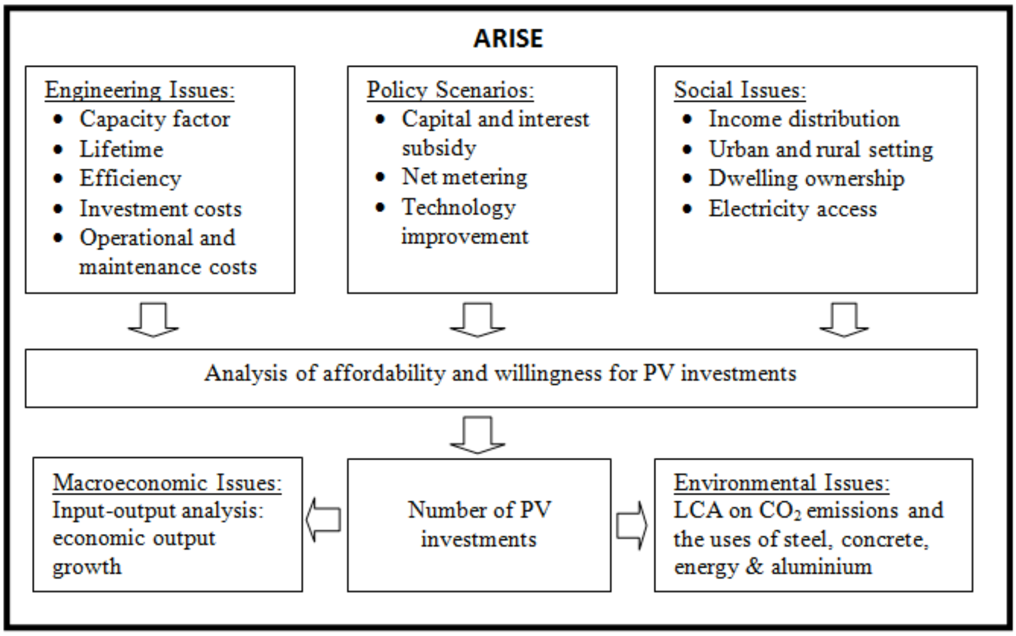

Figure 1: The linkage of four perspectives in ARISE

3.1 Engineering Perspective: Electricity System in Indonesia and Policy Scenarios

Current tariff for renewable energy must refer to PLN's regional generation costs. In regions where the generation cost is higher than the average national generation costs, PLN could buy IPP's PV-based electricity at maximum 85% PLN's regional costs. Meanwhile, the maximum tariff for other regions equals to the regional generation costs. Current solar energy market in on-grid system is limited by a quota in each region. However, to assess full potential of PV market in urban households, our study assumes no quota and a household could sell their PV-based electricity to PLN.

Indonesian government also implements two regulations of renewable energy for rural electrification. First, the government decides giving renewable energy equipment for free (MEMR, 2012, 2017a) and the second one is allowing integrated IPPs (MEMR, 2016c). The first regulation for PV technology started since 1995 and has widely been criticised especially due to the inability of villagers to maintain the PV (Sovacool, 2013). Second, the government encourages IPPs to invest renewable energy in areas without electricity access by giving subsidy to the IPPs (MEMR, 2016c). The subsidy amount constitutes of the difference between IPP's generation costs and the lowest PLN's electricity tariff but is limited to 84 kWh per household per month

Our study compares the effectiveness and the efficiency of four PV policy scenarios. Table 1 shows assumptions on each scenario with descriptions as follows.

a. Scenario 1: Previous renewable energy policy
   Previous FITs (MEMR, 2015a, 2015b, 2016a, 2016b), which were higher than provincial PLN's electricity generation costs, are used. On the other hand, the government supplies free PV equipment to rural households without electricity. Consequently, PV market in rural area remains undeveloped and thus PV after sales service is unavailable. The annual OM cost becomes zero, causing PV lifetime to become 2 years. In this scenario, the government is assumed to have unlimited budget to give free PV each year for all rural households without electricity access.

b. Scenario 2: Existing renewable energy policy
   Current maximum tariff in MEMR (2017b) is simulated. The purpose of the new tariff is to push efficiency in PV manufacturers and, therefore, we assume that the costs and prices are reduced. Moreover, the government is assumed to stop giving free PV unit, yet encouraging PV retailer sales in rural area. However, the contribution of banking sector is still absent in financing PV investment in rural area, meaning zero loan period.

c. Scenario 3: Obligation for banks to finance renewable energy projects
   Scenario 2 is modified that government mandates financial sectors to provide micro-finance for PV investment in rural area. The financing period is five year with interest rate of 12% per annum and maximum loan of 70% total costs. The government then provides 30% capital subsidy and 5% interest subsidy. The new reference tariff in MEMR (2017b) grows due to increasing fossil fuel which

still dominates fuel mix of power plant. The cost growth is assumed to be 9.25%/ year, which was average retail electricity price growth rate in 2010 - 2015.

d. Scenario 4: Net metering scheme
This scenario replaces the maximum tariff with net metering scheme, allowing urban households to export their PV-based electricity to PLN's electricity grid. Export tariff is equal to PLN highest electricity price, which is for 6,600 VA customers. Therefore, the price, which is also assumed to grow 9.25%/ year, is used as a threshold of PV investments by urban households.

Table 1: Assumptions used in the simulation

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
PV capacity unit (Wp)	100 (rural) 1,500 (urban)	100 (rural) 1,500 (urban)	100 (rural) 1,500 (urban)	100 (rural) 1,500 (urban)
PV lifetime (years)	2 (rural) 20 (urban)	20	20	20
Inverter life time (years)	10	10	10	10
Capacity factor (%/year)	16	16	16	16
PV price (USD/ Wp)	1.91	1.15	1.15	1.15
Inverter price (USD)	1,000	615.38	615.38	615.38
Annual OM costs (¢USD/ Wp)	0 (rural) 2.96 (urban)	0.12 (rural) 2.96 (urban)	0.12 (rural) 2.96 (urban)	0.12 (rural) 2.96 (urban)
Cost of equity (%/ year)	15	15	15	15
Value added tax (%)	10	10	10	10
Inflation (%/year)	5.1	5.1	5.1	5.1
Escalation (%/year)	1.0	1.0	1.0	1.0
Loan period (years)	0 (rural) 5 (urban)	0 (rural) 5 (urban)	5	5
Equity ratio (%)	0 (rural) 30 (urban)	30	30	30
Loan interest (%/years)	12	12	12	12
Debt reserves (% of yearly loan instalment)	100	100	100	100
Interest rate on debt reserves (%)	1.3	1.3	1.3	1.3
Incentives	Feed in tariff	New tariff	New tariff	Net metering
Capital subsidy (%)	100 (rural) 0 (urban)	0	30	0
Interest subsidy (%)	0	0	5	0

* Exchange rate is assumed at IDR 13,000 / USD.

3.2 Social Perspective: Heterogeneity of Willingness for PV Investments

Based on the literature review, heterogeneity in ARISE represents different households' incomes, which determine households' ability for renewable energy investment. Moreover, households in each province are also distinguished by urban - rural regions, electricity access types, and home ownerships. PLN's customers in urban area are assumed to invest in PV only if it has economic benefits, while rural households without electricity access will invest in PV if it is affordable. Home ownership status also determines the investment decision since rented houses will not likely have renewable energy installation (Graziano & Gillingham, 2015).

The Central Bureau of Statistics (BPS) provides data of socio-economic aspect through annual National Socio Economic Survey (Susenas). To match the 2010 I-O table, our analysis uses Susenas 2010, involving 293,715 households as the sample from the total 61,387,200 households (BPS, 2010, 2017). Data collected in Susenas includes income distributions, home ownership status, and electricity access type of households in rural and urban areas in each province. The number of households and their income are growing based on trend in Susenas 2010 – 2011 (BPS, 2010, 2011).

3.3 Macroeconomic Perspective: Input-Output (IO) Analysis

I-O analysis, developed by Wassily Leontief (1936), uses interindustry transaction table which shows the flow of output produced by industry *i* to industry *j* as an input and to final demand. The latest Indonesia's IO table consists of economic transactions in 2010 for 185 sectors and was published by BPS (2015). Energy sector in the I-O table 2010 is represented by coal and lignite (sector 37), oil (sector 38), gas and geothermal (sector 39), and electricity (sector 145) sectors. Electricity sector is then disaggregated into specific following power plant types (and its abbreviation):

- Coal-based power plant (PLTU)
- Combined cycled gas turbine power plant (PLTGU)
- Open cycled gas turbine power plant (PLTG)
- Geothermal power plant (PLTP)
- Hydro power plant (PLTA)
- Small and Micro-hydro power plant (PLTM/H)
- Wind turbine power plant (PLTB)
- City waste to energy power plant (PLTSa)
- Biomass-based power plant (PLTBio)
- Solar power plant (PLTS)
- Oil-based power plant (PLTD)

We adopt a disaggregation method by McDougall (2002) who used a reference IO table to disaggregate another I-O table. MEMR, Agency of Fiscal Policy (BKF) and Central Bureau of Statistics (BPS) collaborated to modify the updating I-O table 2008 (BPS, 2009) by extending energy sectors to more detailed sectors (Wargadalam, 2014). The modified 2008 table is then used as a reference to extend electricity sector in the I-O table 2010. As a consequence, we assume that economic structure of electricity sector does not change during 2008 – 2010 and, indeed, we also hold this assumption for analysis until 2050. Sectors beyond electricity are aggregated into two sectors, i.e. services and industry sectors, for simplicity reasons. The final IO table is then converted into Leontief inverse matrix, which is included in ARISE.

3.4 Environmental Perspective: Life Cycle Analysis (LCA)

LCA could estimate all environmental impact from the spare part manufacturing process until electricity production process (Noori, Kucukvar, & Tatari, 2015);

however, ARISE focus is only to estimate direct environmental impact in power plants' construction and operation. The impact is estimated by multiplying electricity production and new power plant capacity by environmental impact factors in Table 2.

Table 2: Environmental impact factors of PV

Construction (per MW capacity)					Emission in operating (kg CO_{2e}/ MWh)
CO_{2eq} (kg)	Steel (ton)	Aluminium (ton)	Concrete (ton)	Energy (GJ)	
4,039,116.9	103.5	4.0	50.0	491.6	148.0

Source: Tahara, Kojima, and Inaba (1997)

3.5 Structures in ARISE

ARISE is developed in Netlogo 5.3.1 programming software and has an interface as shown in Figure 2. ARISE operates through three steps, i.e. data load, policy scenario setting and simulation process. First, ARISE will open all data needed, i.e. initial values for variables and parameters, Leontief inverse matrix, and regional database in Geographic Information System (GIS) files. ARISE uses the number of households and their income distributions in GIS files to create agents of households. Each household agent contains properties of province, urban-rural area, electricity supply type, dwelling ownership, income, and PV ownership. Second, users define the values for policy scenarios by using sliders or default button. The third step is the simulation process which in sequence estimates PV investments costs, investment decisions, policy impact, and growth of income and households. The analysis outputs are displayed in a thematic map, two graphs showing environmental impact and subsidy expenditure, and several output boxes showing I-O analysis result and cost calculation results. In addition, ARISE will store numeric data of several important indicators to three spread sheet files.

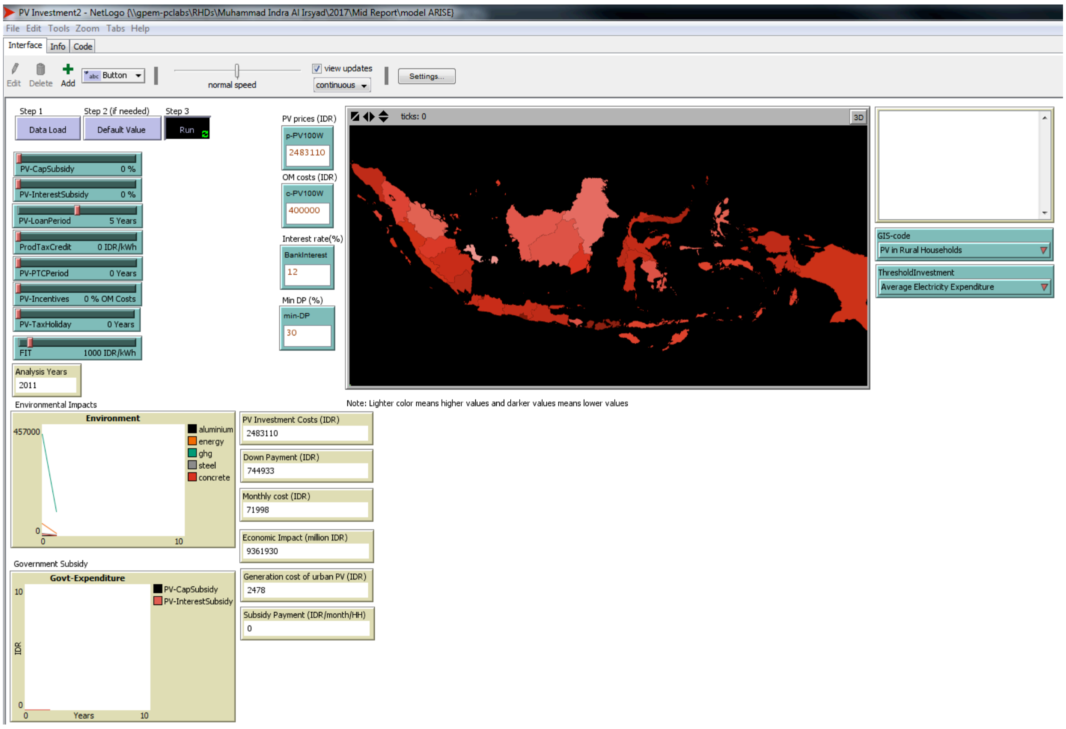

Figure 2: Interface of ARISE

Households with and without electricity access have different purposes for PV investment. For their basic electricity supply, households without electricity access buy a 100 W PV if the PV price or PV monthly cost is lower than the selected threshold (i.e. average electricity expenditure or 30% household expenditure). On the other hand, households with electricity access invest in PV if the revenue requirement exceeds the PV monthly cost. Before simulations, the structure of ARISE is validated by comparing ARISE results with manual calculation using a spreadsheet software. The validation employs various inputs to check the ARISE's outputs on number of households, PV investment costs, number of PV investments, economic impact, and environmental impact. ARISE, its full descriptions and the validation results are available at the OpenABM website[1] and ARISE website[2].

4 Results

We summarise the results of each scenario in Table 3. In Scenario 1, the policy of PV technology grant incurs very high cost. Giving PV 100 Wp for rural households without electricity access will stimulate new economic output for USD 1.6 billion in 2010 but cost the government for USD 559.5 million. Supplying PV to the rural households until 2050 potentially increases the cost by 22 times and leads to severe environment impact, that are 29 million ton CO_{2e}, 26 million kg aluminium, 676 million kg steel, 326 million kg concrete and 3 million giga joule (GJ). Scenario 1 also shows that previous FIT is not attractive for PV investments by urban households.

Table 3: The effectiveness and efficiency of PV policy scenarios in 2050

Policy Scenario	Effectiveness* (MWp)		Efficiency* (per Wp)					
	Rural	Urban	Subsidy+ (USD)	CO_{2eq} (kg)	Aluminium (gr)	Energy (kJ)	Steel (gr)	Concrete (gr)
1	327	0.00	38.15	89	80	9,815	2,067	998
2	234	0.00	0.00	17	9	1,145	241	116
3	227	1,394	0.94	15	8	1,023	215	104
4	228	32,040	0.00	11	7	821	173	83

*Effectiveness and efficiency are measured based on operating PV capacity. + Subsidy only covers capital and interest subsidies.

In Scenario 2, the new tariff also cannot attract urban households to invest in PV. Meanwhile, reductions on PV price and maintenance cost only create PV market in rural area for 227 MWp in 2050. On average, 65.1% of rural households without electricity access could afford PV investments without government assistance. The main markets will be West Kalimantan, East Nusa Tenggara and Papua provinces, whose total market potentially exceeds 1.1 million households. Scenario 2 generates economic output around USD 344.5 million in 2010 and accumulated to USD 4.5 billion in 2050. However, it should be noted that the results are valid by assuming no rural grid expansion by PLN.

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[1] https://www.openabm.org/

[2] https://industrialece.wixsite.com/main/single-post/2017/12/31/Agent-based-Renewables-model-for-Indonesia-Sustainable-Energy-ARISE

The policy of financing scheme with partial capital and interest subsidy in Scenario 3 cannot significantly increase PV adopters in rural area. On average in 2050, only 67.5% of rural households without electricity access could afford USD 24.2 equity cost and USD 1.1 monthly payment for 5 years. However, in 2010 analysis, the number of rural PV adopters in Scenario 3 is 10.4% lower while costs for government is 79.9% lower compared to PV grant scheme in Scenario 1. Another advantage is the emergence of urban PV market, reaching 1,394 MWp in 2050. The main markets are East Nusa Tenggara and West Nusa Tenggara provinces for rural and urban PV demands successively. Consequently, total subsidy is rising from USD 112 million in 2010 to USD 1,524 million in 2050. The total economic output will be USD 954 million in 2010 into USD 21,265 million in 2050.

The financing scheme without subsidy in Scenario 4 can maintain the size of rural PV market in 2050 for 2.3 million households, or equivalent to 67.6% of rural households without electricity access. Scenario 4 has larger rural market than the market in Scenario 3 because rural households in Scenario 4 have higher income randomly determined by ARISE. It means that the higher income has more influence on PV investment decision compared to the presence of subsidies in Scenario 3. The largest market is East Nusa Tenggara province whose 433 thousand rural households could afford loan instalment for PV costs. On the other hand, the net metering scheme is more enticing in fostering PV diffusions in urban area. ARISE output shows that the scheme will pull massive PV investment starting in 2021 once the electricity price is higher than the revenue requirement, i.e. USD 15.8 ¢ /kWh. The initial economic impact of Scenario 4 is USD 889 million in 2010.

5 Policy Implications

We offer two policy recommendations regarding the results of ARISE simulations. First, the government needs to transform PV grant scheme to rural PV market creation. Unattractive PV market in urban area due to the new tariff is an opportunity to shift the market to rural areas. The government should encourage PV industry to improve their technology, especially to reduce the price. One measure is to modify current subsidy scheme for IPP in rural areas from electricity consumption base to the number of customer base. Consumption-based subsidy requires power meter, electricity grid, and a labour to read the meter monthly. Such costs can be avoided in PV-based IPP by using number of customers as a basis for subsidy calculation. For example, IPP can use a solar lighting kit, a PV system with several battery-powered light emitting diode (LED) lamps. The kit does not need power meter and electricity grid; consequently, the electricity produced cannot be measured. The government may select the IPP through an auction scheme and give the subsidy either at commercial operation date (COD) or at a monthly basis. The government should also ask the banking sector to finance PV investment in rural areas. Additional capital and interest subsidies may increase PV market size in rural areas but the increase is insignificant.

In contrast, capital and interest subsidies are the key to create PV markets in urban households since existing tariff and previous FIT cannot cover the PV investment costs. Alternatively, the government could adopt the net metering scheme with automatically adjusted tariff each year to PLN's electricity generation costs. Hence, if fossil fuel cost is continuously increasing until PLN's generation cost is higher than PV revenue requirement, the urban market will be emerged. Moreover, the urban market creation will be accelerated by the rising income of urban households.

6 Conclusions

In this article, Agent-based Renewable energy model for Indonesia Sustainable Energy (ARISE) has been developed to evaluate the effectiveness and efficiency of solar energy policy. The main feature of ARISE is the integration of engineering, socio-microeconomic, macroeconomic and environment perspectives. As results, ARISE suggests a policy reform from PV grant scheme to PV financing scheme for rural households without electricity access. Moreover, the combination of increasing income and net metering scheme are imperative factors for founding PV market in urban area.

Though ARISE has been formulated by using Indonesia data, it remains adaptive to other developing countries. Some required adjustments will be on data of income, electricity demand and incentives in each country. Nevertheless, current ARISE still has several weaknesses. First, it is based on international cost data though the data is obtained from extensive reviews of cases in both developed and developing countries. Second, household number in ARISE is only an estimation by taking sampling share of each household category in Susenas data and then multiplying it by actual total household number. Third, though households have been divided to dwelling owners and non- dwelling owners, ARISE cannot differentiate the types of dwelling, between house and apartment. This issue is important since apartment owner will be less likely to invest in PV. Fourth, ARISE employs static income growth showing negative values in several provinces. The growth should randomly change each year. Fifth, our study assumes static values for technology price and technology efficiency. Indeed, the prices are homogenous for every provinces. Six, electricity demands and other power plants in electricity grid system are not considered yet. Therefore, further research should resolve these problems including to conduct sensitivity analysis on ARISE main parameters.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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