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Policy Optimization of Residential Rooftop Solar PV System Adoption in Indonesia: Considering Stakeholders

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Abstract.

Indonesia is an equatorial country with considerable renewable energy potential. However, the utilization of solar energy in Indonesia remains low due to policy factors related to solar PV capacity and the applicable Feed-in Tariff (FiT). This study aims to optimize the FiT, generation capacity, and average billing rate to maximize stakeholder profits, namely, those of consumers (electricity users who use conventional generation without self-generation), prosumers (consumers as well as rooftop solar photovoltaic (PV) users), and Indonesian utility, namely PT PLN. Stakeholder economic modeling is conducted using a case study of 1,300 VA customers. The model for prosumer savings and utility profit is optimized using a multi-objective genetic algorithm optimization problem. The constraint function is formulated using the FiT, generation capacity, energy demand, average bill, and cost of generation supply as the decision variables. Finally, a workflow is designed for obtaining the optimal FiT and solar PV capacity in the system to provide practical policy recommendations for stakeholders. The Solar PV design used in optimization modeling has a capacity of 1,100 Wp using 2 scenarios that are distinguished from the use of PV module types, JAM5®-72-220 PV modules and Longi LR5-72HPH-550M pv modules. Thus, from the optimization results using the genetic algorithm method, the most optimal solution is the second scenario with the recommended FiT scheme of Rp522.41/kWh because the payback period, prosumer savings, and utility profit generated are more optimal.

Keywords: Feed-in Tariff, rooftop solar PV, policy, optimization, genetic algorithm

1. Introduction

The rapid development of technology has increased energy demand. Indonesia's national per capita electricity consumption increased by 178.6 GWh from 2015 to 2020 (MEMR, 2021b). This increase in energy consumption must be compensated by transitioning to renewable energy sources to reduce the currently severe levels of carbon emissions as part of implementing Sustainable Development Goals (SDGs) 7 and 13 (BAPPENAS, 2020).

Indonesia is an equatorial country with high renewable energy potential, of which approximately 442 GW and 207.8 GWp come from solar energy. According to Government Regulation No. 79 of 2014, or the National Energy Policy, the renewable energy mix targets for 2025 and 2050 are at least 23% and 31%, respectively. (Peraturan Pemerintah Republik Indonesia Nomor 79 Tahun 2014 Tentang Kebijakan Energi Nasional, 2014; National Energy However, at the end of 2021, the utilization of renewable energy in Indonesia was only 11.5% of the total national energy utilization (EBTKE, 2022). Thus, the utilization of renewable energy in Indonesia, especially solar energy through solar photovoltaic (PV) systems, remains low (EBTKE, 2021).

This low utilization of solar energy in Indonesia is due to issues related to the government and stakeholders, which are compounded by technical, management, economic, and social policy barriers. The policy factor is essential for solar energy development, as it can support the market through solar energy investment (Hamdi, 2019; Karakaya & Sriwannawit, 2015; National Energy Council, 2019) Stable, adequate policies are vital for the advancement of solar PV systems (Osseweijer et al., 2018; USAID ICED II, 2020). Policy design should consider feed-in tariff (FiT) parameters, generation capacity, and average billing rates to maximize the benefits of rooftop solar PV usage for stakeholders, namely, consumers (electricity users who use conventional generation without self-generation), prosumers (consumers as well as rooftop solar photovoltaic (PV) users), and utility (Mohan et al., 2022). Stakeholder analyses have been conducted for rooftop solar PV scenarios in the Indian states of Jammu, Kashmir, and Jharkhand (Dutta & Das, 2020; Frey et al., 2017). These papers discuss the stakeholder inputs that play important roles in developing rooftop solar PV systems in various socioeconomic and professional categories in both the government and private sectors. In (Danne et al., 2021), an FiT scheme was proposed considering electricity price dependency, capacity pricing, and energy pricing to address individual and societal benefits. The use of residential solar PV systems can be encouraged using tax incentives provided as a rebate of 20% of the investment cost (Tongsopit, 2015). Economic analysis was conducted on grid-connected residential rooftop solar PV systems in Turkey using the FiT scheme to analyze the effects of various FiT and PV initial costs on system feasibility and identify their policy implications (Duman & Güler, 2020).

This paper promotes prosumer savings and utility profits by considering FiT scheme, solar PV capacity, and average bill rates to increase the use of residential rooftop solar PV systems and achieve net-zero emissions. The analysis in this work covers conflicting multi-objective functions, namely, utility profit, and prosumer savings. The constraint function is formulated using the FiT, solar PV capacity, prosumer energy demand, and average billing rate as decision variables to generate Pareto fronts using a genetic algorithm. Pareto optimal is a condition if and only if there is no alternative state that will make the objective function better without making other objective functions worse (Inayati & Rahmawati, 2020; Rao & Lakshmi, 2021).

This paper is organized as follows: Section 2 covers the methodology adapted to model stakeholder benefits and the genetic algorithm optimization performed to derive the Pareto fronts. Section 3 presents rooftop solar PV scenario analyses, installation investment cost, stakeholder economic modeling parameters, and multi-objective optimization analysis results, along with policy recommendations. Section 4 presents policy suggestions with a statement outlining the conclusions inferred from the optimization analysis results.

2. Related works

Chaianong et al. (2019) stated that the net-metering policy in Thailand allows greater flexibility for customers to manage PV system capacity. The net-metering policy creates a smaller variation in customer bill savings when compared to the net-billing policy. Under net billing, customers have to limit their PV system capacity in relation to the load caused by a higher PV-to-load ratio. However, net billing is acceptable if the right buyback rate is attractive to customers. In the research entitled "Thailand's Feed-in Tariff for Residential Rooftop Solar PV System: Progress so Far," by Tongsopit (2015), residential-scale solar PV systems can be stimulated by tax incentives provided as a rebate of 20% of the investment cost.

Hidayatno et al. (2020), in the study "Investigating Policies on Improving Household Rooftop Photovoltaics Adoption in Indonesia," the effectiveness of policy instruments is certainly to improve energy security and reduce greenhouse gas emissions in Indonesia. The system dynamics approach incorporated in the policy analysis allows for a systematic and comprehensive analysis of the state of solar PV development in Indonesia. SFD model simulation is used to assess the effectiveness of net-metering and net-billing implementation by looking at the results of three indicators, namely electricity savings, rooftop PV adopters, and CO_2 emission reduction. This research also integrates four interconnected aspects, namely technical, economic, social, and environmental aspects. The results show that the net-metering policy instrument is more effective than the net-billing policy in increasing the adoption of household rooftop PV (IESR, 2022).

Duman & Güler (2020), in a study entitled "Economic Analysis of Grid-connected Residential Rooftop PV System in Turkey," analyzed the economics of grid-connected residential rooftop PV in Turkey using the Feed-in Tariff (FiT) scheme. The results showed that the discounted payback period (DPBP), internal rate of return (IRR), and profitability index (PI) were in the range of 7.75-14.43 years, 13.68%-6.87%, and 2.02-1.28, respectively. Sensitivity analysis was conducted to analyze the effect of varying FiT and PV initial costs on system feasibility and contain policy implications.

The study entitled "Policy Assistance for Adoption of Residential Solar PV in India: A Stakeholder-centric Approach for Welfare Optimization," by Mohan et al. (2022), a comprehensive analysis of the consumer-centric business model for rooftop solar PV installation in India by optimizing the Feed-in Tariff (FiT), PV capacity, and average billing rate to maximize stakeholder benefits. The stakeholders considered are consumers, prosumers, and utilities. Models for utility profit and prosumer savings are developed, and a multi-objective problem is formulated with FiT, generation capacity (as a function of demand), and average bill rate as decision variables. The suitability of prevailing tariffs and FiT tariffs of two Indian utilities namely, MSEDCL and TATA POWER, Delhi, and their impact on prosumer savings and utility profits.

2. Methodology

This discussion focuses on a consumer-centric model, specifically a stakeholder model consisting of consumers (electricity users who use conventional generation without self-generation), prosumers (consumers as well as rooftop solar photovoltaic (PV) users), and Indonesian utility, namely PT PLN. Prosumers bear the capital and operational expenses of installing rooftop solar PV systems and have full ownership of their systems. The prosumers have an energy generation capacity of 1.3 kW and are matched with customers with a power demand of 1,300 VA. The benefits to the prosumers are modeled in terms of the savings derived from the adoption of rooftop solar PV systems after the monthly installment of the investment (annuity) against the installation cost and the revenue from the sale of locally generated rooftop solar energy. The rooftop solar PV design has a capacity of 1,100 Wp in scenarios 1 and 2. The system design used in the modeling of scenario 1 is that of a JAM5(R)-72-220 PV module (manufactured by JA Solar) with a Solis-1K-2G PV inverter. The scenario 2 rooftop solar PV design used in the modeling is that of a Longi LR5-72HPH-550M PV module (manufactured by Longi) with a Solis-1K-2G PV inverter. The utility benefits are the profit earned from the sale of energy at the average billing rate after the cost of supplying generation (Mohan et al., 2022).

3.1 Stakeholder economic modeling

The analyzed consumer-centric business model is shown in Figure 1. Prosumers bear the overall capital and operational expenses of installation through an engineering, procurement, and construction company. Based on the Minister of Energy and Mineral Resources Regulation No. 26/2021, which covers rooftop solar PV systems, financial, and energy settlements are made through applicable net-metering policies (Peraturan Direksi PT PLN (Persero) Nomor: 0733.K/DIR/2013 Tentang Pemanfaatan Energi Listrik Dari Fotovoltaik Oleh Pelanggan PT PLN (Persero), 2013). In this case, utility companies supply the electrical energy needed by the prosumers. If the prosumers have excess energy, the prosumers will export energy to the utility grid under the FiT scheme (Peraturan Menteri ESDM Nomor 26 Tahun 2021 Tentang Pembangkit Listrik Tenaga Surya Atap Yang Terhubung Pada Jaringan Tenaga Listrik Pemegang Izin Usaha Penyediaan Tenaga Listrik Untuk Kepentingan Umum, 2021).

A methodology that can be used by policymakers to identify the ranges of the following parameters is shown in Figure 2. The amount of the monthly electricity bill of the prosumers without rooftop solar PV systems is expressed by Eq. (1); this is the cost of purchasing energy at the average tariff bill and the monthly fixed load bill without solar PV systems.

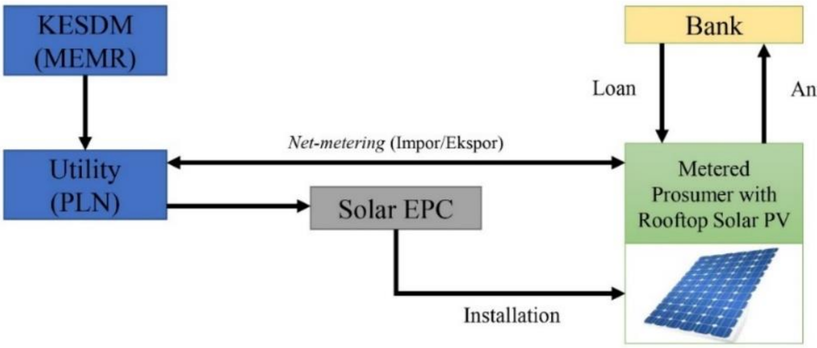

Fig. 1 Consumer-centric business model

$$B_{ws}(x_2) = (x_2 \times c_2) + (c_4 \times c_5) \quad (1)$$

Where: x_2, c_2, c_4, and c_5 are the energy demand of prosumers (kWh), average billing rate (Rp/kWh), fixed load cost (Rp) and number of prosumers respectively and B_{ws} is prosumers' monthly electricity bill without rooftop solar PV (Rp).

The amount of the monthly electricity bill of the prosumers with rooftop solar PV systems is shown in Eq. (2). It consists of the cost of purchasing the prosumer energy deficit at the average billing rate, the revenue from selling the energy surplus at the FiT of the prosumers, and the annuity fee to be paid by the prosumers.

$$B_s(x_1, x_2, x_3) = \{(1 - c_3) \times (x_2 - x_1) \times c_2\} + \{(x_2 - x_1) \times x_3 \times c_3\} + (c_4 \times c_5) + c_8 \quad (2)$$

Where: x_1, x_3, c_3, and c_8 are the total energy generated by prosumers (kWh), Feed-in Tariff (Rp/kWh), difference between generated energy and required energy of prosumers, and monthly installment of prosumer investment/annuity (Rp) respectively and B_s is Prosumers' monthly electricity bill with rooftop solar PV (Rp).

The value of c_3 is determined using Eq. (3) and indicates whether the prosumers are experiencing an energy surplus or deficit.

$$c_3 = \begin{cases} 1, & (x_1 - x_2) \geq 0 \\ 0, & (x_1 - x_2) < 0 \end{cases} \quad (3)$$

c_8 is the monthly investment installment (annuity) that the prosumers must pay; it is solved as follows:

$$c_8 = p \times i \times \frac{(1+i)^n}{(1+i)^n - 1}. \quad (4)$$

Where: p, i, and n are the total installation cost (Rp), interest rate, and payback period

The resulting prosumer savings are shown in Eq. (5).

$$f_1(x_1, x_2, x_3) = B_{ws}(x_2) - B_s(x_1, x_2, x_3)$$
$$= c_2(1 - c_3)x_1 + (c_2 . c_3)x_2 + c_3(x_1 - x_2)x_3 - c_8 \quad (5)$$

Where: f_1 is prosumer savings (Rp).

The utility revenue is expressed as Eq. (6) and consists of energy sales at the average bill rate to the consumers, revenue from energy deficit sales at the average bill rate from the prosumers, and fixed monthly charges from both the prosumers and consumers.

$$R_u(x_1, x_2, x_3) = (c_1 \times c_2) + \{(x_1 - x_2) \times (c_3 - 1) \times c_2\} + c_4 \times (c_5 + c_6) \quad (6)$$

Where: c_1 and c_6 are the energy demand of consumers (kWh) and number of consumers respectively and R_u is utility revenue (Rp).

The utility expense is shown in Eq. (7) and consists of purchasing energy from the prosumers under the FiT scheme and purchasing residual energy to meet the system demand of the prosumers at the cost of supplying generation.

$$E_u(x_1, x_2, x_3) = c_3 \times (x_1 - x_2) \times x_3 + [c_1 - (x_1 - x_2)] \times c_7 \quad (7)$$

Where: c_7 and E_u are the cost of generation supply (Rp/kWh) and utility expense (Rp).

Thus, the utility profit is the difference between utility revenue and utility expenditure, and it is solved as follows:

$$f_2(x_1, x_2, x_3) = R_u(x_1, x_2, x_3) - E_u(x_1, x_2, x_3)$$
$$= \boldsymbol{(c_7 - c_2(1 - c_3))x_1 - (c_7 - c_2(1 - c_3))x_2 - c_3(x_1 - x_2)x_3 + c_1(c_2 - c_7) + c_4(c_5 + c_6)} \quad (8)$$

Where: f_2 is utility profit (Rp)

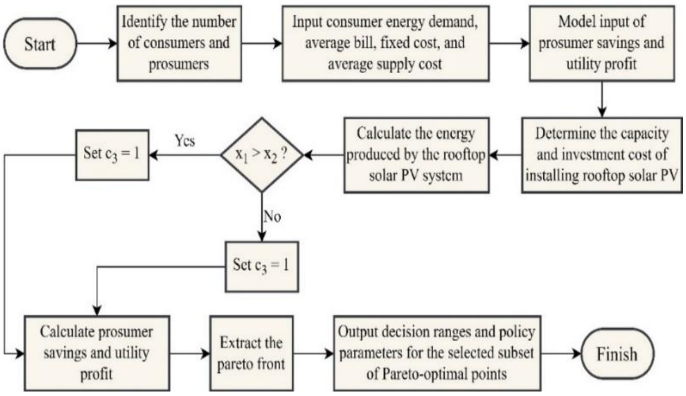

Fig. 2 Flowchart of policy decision-making for rooftop solar PV system installation

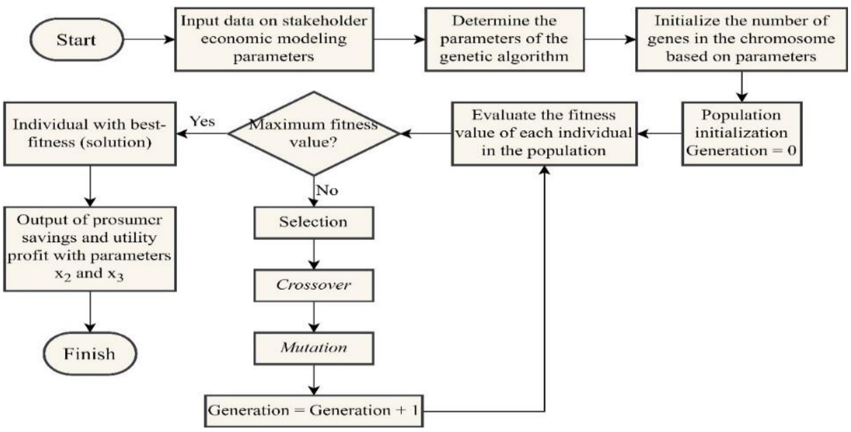

Fig. 3 Flowchart of genetic algorithm optimization

3.2 Genetic algorithm

The genetic algorithm, which mimics natural selection, and the principles of genetic science, was developed by John H. Holland. In natural selection, individuals compete to survive and reproduce (Gautama, 2016; Qin et al., 2023). Fit individuals have the opportunity to survive and reproduce (produce offspring). On the contrary, less fit individuals are eliminated (die) and become extinct; this principle is also called survival of the fittest. Furthermore, in natural selection, individuals who are fitter than their parents are born through crossover and mutation. Crossover, or interbreeding, is the process of exchanging some genes in one chromosome with those in another chromosome; thus, two chromosomes are required to exchange genes (Arkeman et al., 2014; Liu et al., 2023; Rana & Ranjan Srivastava, 2017; Rudiyanto et al., 2023). The recommended crossover probability is 0.8–0.95 (Galiana et al., 2023; Tiandini, 2017). Mutation is the process of changing the composition of genes in a chromosome to replace missing genes in a population resulting from selection and crossover (Arkeman et al., 2014; Qin et al., 2023). The recommended mutation probability is 0.005–0.01 (Galiana et al., 2023; Liu et al., 2023; Tiandini, 2017). Crossover and mutation occur in the chromosomes of individuals who reproduce. These processes of selection and reproduction (crossover and mutation) occur repeatedly until the fittest individual is produced (Arkeman et al., 2014). The flowchart of the genetic algorithm method used for optimization in this paper is shown in Figure 3.

Genes are parts of chromosomes and can be represented as strings, bits, real numbers, lists of rules, permutation elements, and program elements that can be implemented in genetic operators (Liu et al., 2023; Tiandini, 2017). In genetic algorithm optimization, for finding the maximum, or minimum value of a function $f(x)$ with variable constraints, x is (a_x and b_x), and it has an accuracy of d numbers (Berlianty & Arifin, 2010; Utami et al., 2014):

$$a_x \leq x \leq b_x \tag{9}$$

$$2^{m-1} < (b_x - a_x)10^d \leq 2^m - 1 \tag{10}$$

Where: x, a_x, b_x, d, and m are variable with a range of values a_x to b_x, lower limit value of variable x, upper limit value of variable x, number of digits after comma (accuracy), and bit code length (chromosome length).

The fitness function expresses an objective function and depends on the particular problem of the representation used (Tiandini, 2017). In a maximization problem in genetic algorithm optimization, the fitness value is the function value; in a minimization problem, the fitness value is the inverse of the function value (Liu et al., 2023; Qin et al., 2023). This paper deals with the maximization case, so the fitness function is expressed as Eq. (11).

$$Fitness[i] = w_1 f_1(x_1, x_2, x_3) + w_2 f_2(x_1, x_2, x_3) \tag{11}$$

$$0.1 \leq w_1 \leq 0.9 \tag{12}$$

$$0.1 \leq w_2 \leq 0.9 \tag{13}$$

Where: $\boldsymbol{w_1}$ and $\boldsymbol{w_2}$ are weights of objective function 1 and 2 respectively and $\boldsymbol{Fitness[i]}$ is is the i-th objective or evaluation function.

4. Results and discussions

4.1 Stakeholder economic modeling parameters

The optimal range of stakeholder economic modeling decision variables in this case study is shown in Table 1.

Table 1

Ranges of decision variables and constraints

Parameter	Value
c_1 (kWh)	4,315,924
c_2 (Rp/kWh)	1,257.16
c_4 (Rp)	75.124
c_5	11
c_6	10,771
c_7 (Rp/kWh)	995.98 (MEMR, 2021a)
Electricity tariff for 1,300 VA utilities (Rp/kWh)	1,444.7
Total installation cost (Rp)	
Scenario 1: JAM5(R)-72-220 PV module	16,408,198
Scenario 2: LR5-72HPH-550M PV module	
c_8 (Rp)	
Scenario 1 (payback period: 12.16 years)	182,043
Scenario 2 (payback period: 10.01 years)	186,329
i (%/year)	8.66 (OJK, 2022)
x_1: total energy generated by prosumers (kWh)	
Scenario 1	1,418
Scenario 2	1,455
x_2 (kWh)	50% to 100% of x_1

x_3 (Rp/kWh)	500–1.444,7

4.2 Genetic algorithm optimization parameters

The optimization process begins with initialization, which forms a population for each individual by presenting a chromosome form that eases the determination of the desired optimization solution. Initialization is based on the parameters or variables to be optimized, including the chromosome length, crossover probability, mutation probability, number of individuals, and number of generations (iterations). During this process, the objective function is calculated until the best solution value is obtained. Table 2 shows the parameters of the multi-objective optimization value of the genetic algorithm for optimizing the adoption of residential rooftop solar PV systems through a stakeholder approach.

Table 2 Genetic algorithm optimization parameters

Genetic algorithm parameter	Optimization value
Number of generations (iterations)	200
Chromosome length of 1,100 Wp rooftop solar PV capacity of scenarios 1 and 2	48
Number of individuals	100
Weight functions (w_1 and w_2)	0.1–0.9
Crossover probability	0.8
Mutation probability	0.01

4.3 Stakeholder economic modeling optimization results with genetic algorithms

4.3.1 Scenario 1: 1,100 Wp rooftop solar PV system with JAM5(R)-72-220 PV module

Five trials are conducted to determine the prosumer savings and utility profit using the genetic algorithm method. Table 3 shows a comparison of the best fitness values from each trial for scenario 1.

Table 3 Comparison of best fitness optimization results of five trials of 1,100 Wp rooftop solar PV scenario 1

x_2 (kWh)	x_3 (Rp/kWh)	*Best Fitness*	Prosumer Savings (Rp)	Utility Profit (Rp)
765.91	531.83	1,743,883,043	1,127,806	1,937,522,513
731.24	531.20	1,743,895,669	1,101,738	1,937,539,440
786.25	545.47	1,743,869,568	1,150,525	1,937,505,018
735.50	523.13	1,743,898,305	1,099,913	1,937,542,571
711.58	542.44	1,743,896,028	1,095,707	1,937,540,508

According to Table 3, the best fitness value (1,743,898,305) is in the fourth experiment. The energy required by the prosumers is 735.5 kWh (51.87% of the energy generated by the prosumers) under the FiT scheme at Rp 523.13/kWh, resulting in prosumer savings in FiT of Rp 1,099,913 and a utility profit of Rp1,937,542,571.

Average energy used by consumers $= \frac{4,315,924}{10,771} =$ 400.70 kWh

Utility profit without solar PV

$$= (4,315,924 + 11 \times 400.7)(1,444.7 - 995.98)$$
$$= \text{Rp } 1,938,619,240$$

Utility profit without solar PV/consumer

$$= \frac{1,938,619,240}{10,782} = \text{Rp } 179,801/\text{consumer}$$

Difference in utility profit

$$= \text{Rp } 1,938,619,240 - \text{Rp } 1,937,542,571 = \text{Rp } 1,076,670$$

Utility profit after solar PV/consumer

$$= \frac{1,937,542,571}{10,782} = \text{Rp } 179,702/\text{consumer}$$

Prosumer savings/solar PV user

$$= \frac{1,094,004}{11} = \text{Rp } 99,992/\text{prosumer}$$

Thus, the installation of rooftop solar PV with a capacity of 1,100 Wp in scenario 1 benefits all parties when the energy produced by the PLTS is greater than the energy needed by the prosumers (the prosumers export energy to the utility grid) with an FiT of Rp 523.13/kWh, which results in prosumer savings of Rp 99,992/consumer and utility profit of Rp 179,702/consumer. Figure 4 shows the Pareto-optimal solutions of the multi-objective functions, namely, prosumer savings, and utility profit, with 100 individuals.

4.3.2 Scenario 2: 1,100 Wp Rooftop Solar PV System with LR5-72HPH-550M

Table 4 shows a comparison of the best fitness values from each genetic algorithm optimization experiment for the 1,100 Wp rooftop solar PV system in scenario 2.

Table 4 Comparison of best fitness optimization results of five trials of 1,100 Wp rooftop solar PV scenario 1

x_2 (kWh)	x_3 (Rp/kWh)	*Best Fitness*	Prosumer Savings (Rp)	Utility Profit (Rp)
759.09	531.08	1,743,903,005	1,137,431	1,937,543,624
744.78	527.04	1,743,910,119	1,124,425	1,937,552,974
751.17	541.30	1,743,900,140	1,138,662	1,937,540,304
747.63	522.41	1,743,911,900	1,123,081	1,937,555,102
736.63	529.42	1,743,911,763	1,120,020	1,937,555,290

According to Table 4, the best fitness value (1,743,911,900) is in the fourth experiment. Therefore, the energy required by the prosumers is 747.63 kWh (52.74% of the energy produced by the prosumers) with an FiT of Rp 522.41/kWh, which results in prosumer savings in FiT of Rp 1,123,081 and a utility profit of Rp 1,937,555,102.
Difference in utility profit

$$= \text{Rp } 1{,}938{,}619{,}240 - \text{Rp}1{,}937{,}555{,}102$$
$$= \text{Rp } 1{,}064{,}138$$

Utility profit after solar PV/consumer

$$= \frac{1{,}937{,}555{,}102}{10{,}782} = \text{Rp } 179{,}703/\text{consumer}$$

Prosumer savings in FiT/solar PV user

$$= \frac{\mathbf{1{,}123{,}081}}{\mathbf{11}} = \text{Rp } 102{,}098/\text{prosumer}$$

Thus, the installation of the 1,100 Wp rooftop solar PV system in scenario 2 results in a beneficial situation when the energy produced by the rooftop solar PV systems exceeds the energy required by the prosumers (the prosumers export energy to the utility grid) with an FiT of Rp 522.41/kWh, which results in prosumer savings of Rp 102,098/consumer and utility profit of Rp 179,703/consumer. Figure 5 exhibits the Pareto-optimal solutions of the multi-objective functions with 100 individuals.

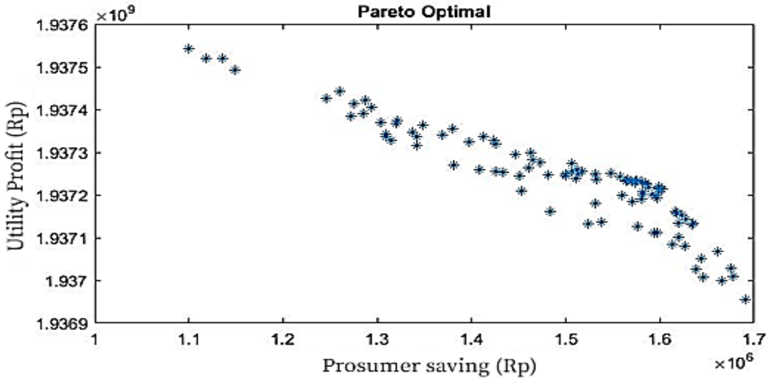

Fig. 4 Pareto-optimal solutions of 1,100 Wp rooftop solar PV scenario 1

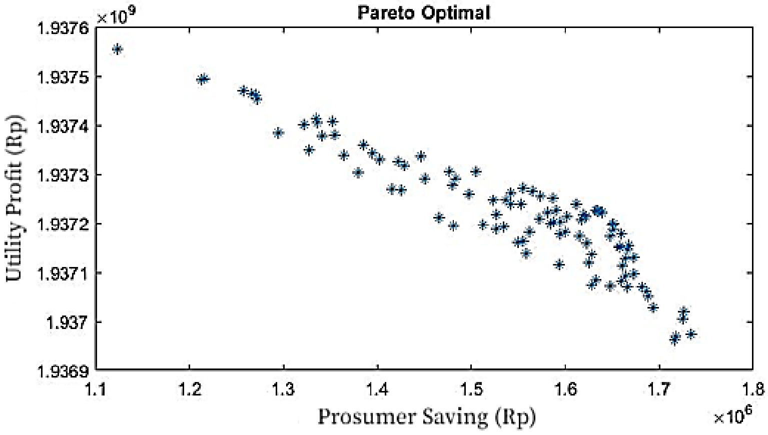

Fig. 5. Pareto-optimal solutions of 1,100 Wp rooftop solar PV scenario 2

Table 5 Comparison of optimization results of scenarios 1 and 2, before and after the payback period

Conditions	Scenario	Prosumer Savings (Rp/Prosumer)	Utility Profit (Rp/ Consumer)	Prosumer Savings (%)	Utility Profit (%)
Before Payback Period	1	99,992	179,702	35.75	64.25
	2	102,098	179,703	36.23	63.77
After Payback Period	1	129,077	179,702	41.80	58.20
	2	131,809	179,703	42.31	57.69

According to Table 5, the genetic algorithm optimization results for scenarios 1 and 2 show optimal FiT values of Rp 523.13/kWh for scenario 1 and Rp 522.41/kWh for scenario 2. The prosumer savings for scenarios 1 and 2 are 35.75% and 36.23%, respectively. The utility profits obtained from scenarios 1 and 2 are 64.25% and 63.77%, respectively. The prosumer savings for scenarios 1 and 2, with payback periods of 12.16 and 10.01 years, are 41.80% and 42.31%, respectively. Therefore, the utility profits obtained from scenarios 1 and 2 are 58.20% and 57.69%, respectively.

5. Conclusion

Cost–benefit analysis is conducted on a consumer-centric business model of rooftop solar PV system installation in Indonesia to identify the optimal policy parameters, that is, those that result in a reasonable trade-off in stakeholder benefits. To this end, a multi-objective optimization problem is formulated, with utility profit, and prosumer savings being the objective functions.

The 1,300 VA residential rooftop solar PV system adoption scheme with a stakeholder approach (consumers, prosumers, and utilities) results in optimal prosumer savings and utility profits in both scenarios. The optimization results of both scenarios show that the most optimal solution is shown in the second scenario, with a payback period of 10.01 years. This is influenced by the different types of PV modules, which will affect the investment costs incurred, the annuity to be paid, and the payback period. The recommended FiT based on the genetic algorithm optimization results for a 1,100 Wp rooftop solar PV system capacity is Rp 522.41/kWh (36% of the utility power tariff), by generating 36.23% prosumer savings and 63.77% utility profit before the payback period conditions, and 42.31% prosumer savings and 57.69% utility profit under post-turnaround period conditions.

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Declaration of ompeting interest

The authors declare that they have no competing financial interests or personal relationships that could influence the work reported in this paper.

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