Designing a System Dynamics Model to Analyze the Effect of Photovoltaic Supporting Policies in Indonesia

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Manuscript received July 30, 2023; accepted March 13, 2024; published September 25, 2024

***Abstract*—The demand of the global climate change issue make Indonesia need to increase the proportion of renewable energy in the national energy mix by 23%. With the Electricity Supply Business Plan (RUPTL), the construction of renewable energy power plants has been targeted to have installed capacity until 2028. Photovoltaic (PV) as a source of renewable electricity from solar power still has obstacles to developing its installed capacity. This study aims to design a Feed-in Tariff (FiT) policy model that supports investment in renewable energy projects, so that the impact of budget availability by the government and environmental impacts can be anticipated by the government. By using a system dynamic and historical data on installed PV capacity, this study explains the effect of the feed-in tariff policy on the development of installed PV capacity and the contribution of PV to reducing CO_2 gas emissions and also the determinants of this effect. This study reveals that the feed-in tariff policy will have an impact on increasing the growth of PV project investment and the achievement of the RUPTL target for installed PV capacity by 2028. Two policies, rooftop solar PV and capital subsidies are being tested on a model to demonstrate the sensitivity of installed PV capacity and the contribution of reducing CO_2 gas emissions due to the tendency to invest in PV.**

***Keywords*—system dynamics, feed-in tariff, photovoltaic, renewable energy**

I. Introduction

Many countries aim to reduce the production of CO_2 emissions to deal with the climate changes. The governments of these countries have set domestic energy conservation goals and approved policies to help the implementation [1]. The Indonesian Government announced a number of electrification and renewable energy targets, including the increasing of the national electrification rate declared in 2017, from 84% to 100% in 2020 and an eleven fold increase in renewable energy use by 2025 [2].

Indonesia is located on the equator, so that Indonesia has an abundant source of solar energy. One of its uses is as a means of solar power generation or commonly called Photovoltaic cells (PV). However, high capital costs, especially in developing countries, remain a major barrier to investment in the development of clean and environmentally friendly technologies of large-scale renewable energy [3]. Experience in the PV development industry has shown that efforts to reduce capital costs and increase the efficiency of new technologies are often closely linked to policies aimed at improving the development of renewable energy technologies [4]. Mousavian explained that policies that have an impact on the growth of renewable energy electricity supply capacity affect the adaptation of technology in building renewable energy systems. Such learning lowers capital costs, which means increasing the Return on Investment (ROI) and attracting new investors [5].

Solangi reviewed solar energy policies adopted in various countries. Based on his study, Feed-in Tariff (FiT) is one of the most impactful energy policies for the development of renewable energy technologies. The FiT policy has become the main mechanism to support the initiation of the renewable energy projects in Europe and the US [6]. However, there was a case that a long-term implementation of FiT might result in a large government spending, raising concerns on the economic efficiency and distributional effects of renewable energy technologies [7].

The Minister of Energy and Mineral Resources issued policy number 19 of 2016 which introduced FiT to support the development of at least 5000 MW of solar power installation. The national photovoltaic power plant (PV) technology installation program in Indonesia is described in detail in the 2019 General Plan for Electricity Supply (RUPTL). The plan has a target year period of installed PV installation with an accumulation of 968.7 MW until 2028. To achieve the RUPTL target in meeting electricity needs, it depends on the interests and desires of investors as well as PV developers to procure PV technology at a low cost and also carry out efficient PV installation projects.

Global climate change has triggered many countries to meet the agreed CO_2 reduction targets. Photovoltaic (PV) is the utilization of solar renewable energy as an alternative to power generation. The main obstacle in PV installation is the high cost of installation. The Indonesian government has been looking for a solution by providing policies that can promote national-scale PV installation to investors and PV technology development companies. Feed-in Tariff (FiT) is a policy chosen by the Indonesian government as an initial step to attract developers and also get developers who are able to offer more economical PV costs. Policies that promote PV installation can increase the capacity of power plants based on renewable energy and can also have a positive impact on the government's efforts to reduce national CO_2 emissions. Thus, this study will investigate Feed-in Tariff (FiT) policies that support the development of installed PV capacity in accordance with the RUPTL target until 2030, as well as its impact on reducing government CO_2 gas emissions. The main objective of this study is to design policies that can increase the adoption of solar PV and its impact on increasing the use of renewable energy and reducing CO_2 emissions.

II. Literature Review

A. *PV Development in Indonesia*

Indonesia has an international commitment to contribute to the issue of global climate change. The commitment is poured by the Central Government into the National Energy General Plan. One of the plans is through the development of New Renewable Energy (EBT) to reduce the proportion of fossil and coal energy mix in Indonesia. Solar Photovoltaic (PV) as one of the EBT power plants has a big development target for electricity projected at 6.5 GW in 2025 and 45 GW by 2050 or 22% of the solar potential of 207.9 GW. In the RUPTL, the target PV capacity is actually far from the target. This is happened because of eight obstacles in building PV. Obstacles in large-scale PLTS (IPP) projects at the domestic component level [8]: Domestic component level, availability of land in suitable locations, unattractive rates, unbalanced risk allocation, unusual rate of return (IRR), financing scheme, high interest rates, procurement transparency.

B. Important Factors for Investor Improvement

There are several variables that support the development of renewable energy in Indonesia [9]:

1) Project economic outlook

Renewable energy projects must be able to provide a risk-adjusted rate of return. Energy subsidies are a major obstacle in meeting Indonesia's renewable energy targets [10].

2) Access to financing

Financing must not only be available at a fair interest rate, but also provide a proper risk tolerance [11].

3) Politics-economics

Investors need assurance that the projects will sustain across different regimes [9].

C. Policies

There are several PV supporting policies that have been implemented in Indonesia as well as reference policies obtained through benchmarks from other countries.

1) Feed-in Tariff Policy

FIT refers to the regulation of the minimum guaranteed price per kWh that power companies must pay to independent private producers for renewable power put into the network. Here, private independent producers could obtain a minimum long-term guaranteed price for [1]. Hence, FIT might assure a certain level of financial clarity for the energy producers.

2) Rooftop PLTS Policy

One option to increase Indonesia's solar energy production is to build a solar Photovoltaic system (PV) connected to large-scale networks [12]. However, it needs large expenditures that cannot currently be financed by the government. Hence, the government depends on the household because it contributes 36% of national energy consumption [13]. Distributed PV systems, including rooftop PV, are one of the viable methods of incorporating this sector into energy generation [14]. Two policies were then introduced to increase the energy production in the household sector: net meter and clean bill [15].

D. System Dynamics

System dynamics is a method of supporting learning to be able to observe and analyze a complex system. The system dynamics itself has been widely used for a variety of issues ranging from corporate strategy, government policy, to things like system dynamics for dengue fever. System dynamic focuses on the behavior of complex systems, which means dynamic systems are based on the theory of dynamics that are not linear and also responses from feedback that until now have been developed/studied by several disciplines such as mathematics, physics, and engineering [16]. System dynamics can build a model that can test the impact of certain policies and scenarios [17]. The system dynamics integrate several approaches, i.e., control theory, computer simulation, strategic management, and system thinking [18].

III. Materials and Method

This study comprises four main stages. The stages include:

A. Early Stage

The first stage introduces the contextual basis of topics and learning from sources such as books, journals, annual reports, and other sources. The next step is to create a system diagram and causal loop diagram and validate the diagram. Then, this stage also designed about what data needed to create system dynamics models.

B. Modeling

The stage of creating a model begins by collecting data that corresponds to the design of the data needed that have been created in the early stages. Furthermore, based on the theory of system dynamics contained in the journal that has been selected as the basis of research, the authors will determine variables used to compile Stock and Flow Diagram (SFD). Furthermore, to finalize system dynamics design, policy simulation will be carried out using Powersim Studio©.

C. Model Verification and Validation

The next step, after the dynamic system model has been successfully designed, is validation and verification of the model. Model validation will be done by rechecking the accuracy of data and correlation between variables in the model. Then, verification is done by starting a simulation of system dynamics models and then checking whether the model can run without any bugs or still have to be fixed in terms of variables or formulas.

D. Policy Analysis and Conclusions

In the latter stage, there will be several policy scenarios that may be implemented in a future context. The policy scenario can then be released by inserting a section of the SFD model. Lastly, the conclusion of which policy is the most optimum can be recommended to the government.

IV. Model Development

Installed PV capacity development in Indonesia is modeled in 3 stages, namely system diagram model, causal loop diagram, and stock and flow diagram. The data used to build the model is the result of literature studies and interviews with several experts in the PV industry.

A. System Diagram

System diagrams are essential to assist modelers in understanding the complexity of the systems being researched, because it gives an overall concept of the model. The system diagram contains the following components shown in Fig. 1: problem owners, the purpose of problem owners to the system under review, stakeholders, policies that can be applied by problem owners to the system under review, external variables inserted into the system because it affects the system, processes that occur within the system, for dynamic system modeling, are used causal loop diagrams to map the processes that occur within the system, and the output indicator of the system under review determines whether the problem owner's goal is achieved or not. The Process Structure can be seen more clearly in Fig. 2.

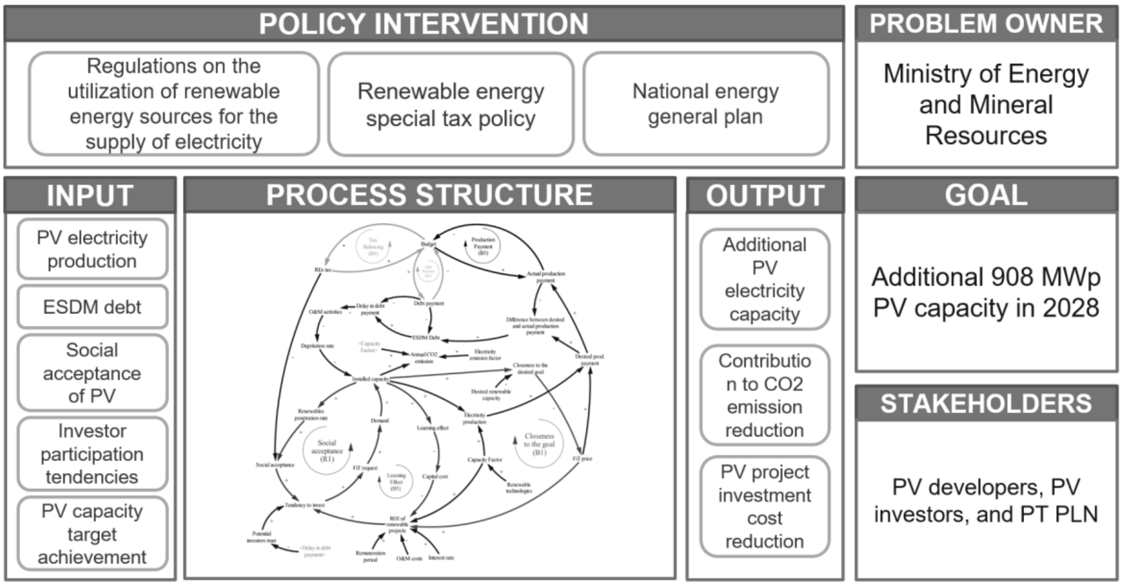

Fig. 1. PV capacity building system diagram in Indonesia.

B. *Causal Loop Diagram*

The author combines both reference models Hsu (2012) and Mousavian *et al.* (2020), and has adapted it to the policy contexts and also the situation of the PV industry in Indonesia. Hsu (2012) in his research on the effects of capital subsidy policy and Feed-in Tariff in Taiwan stated that renewable energy support policies require high investment costs [1, 5]. As for Mousavian *et al.* (2020) in his research on the effects of feed-in tariff policy in Iran has had a fairly relevant coverage to the development conditions of the PV industry. There is a budget availability factor that can describe the government's ability to pay FiT requests. Then, there is also the effect of technology learning that affects the decrease in PV development capital costs each year which is inversely proportional to the amount of PV capacity installed [1, 5].

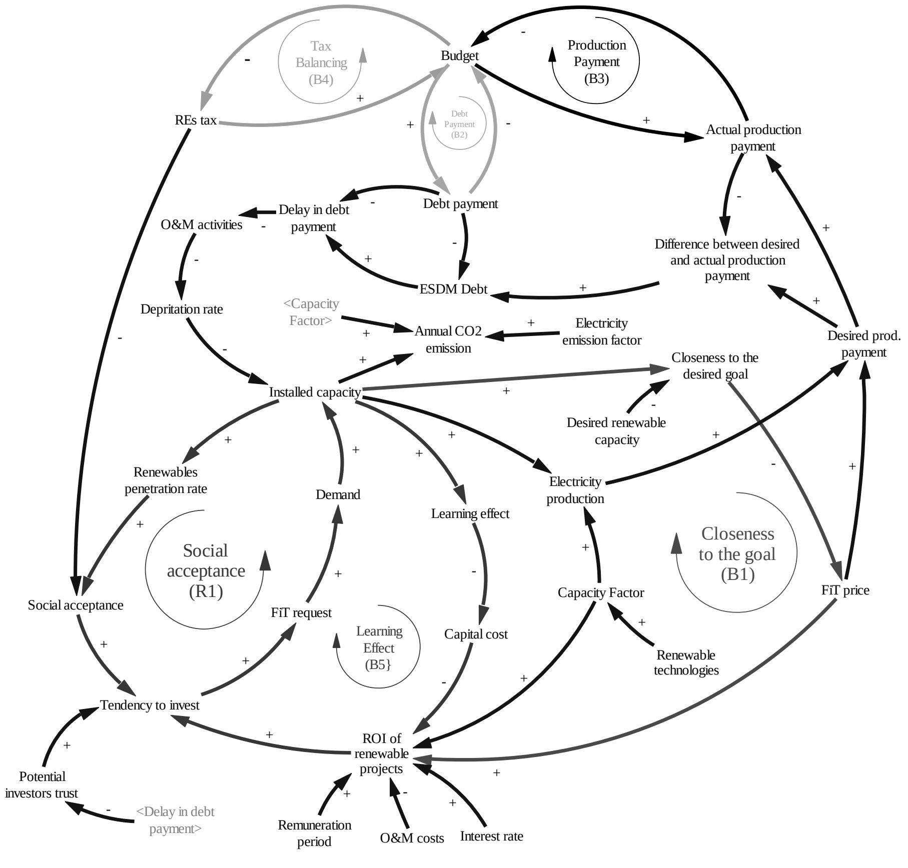

Fig. 2. PV development causal loop diagram.

Fig. 2 shows causal loop diagram of PV development. There are 5 causality loops in the model: social acceptance (reinforcing), closeness to the goal (balancing), debt payment (balancing), production payment (balancing), tax (balancing), and learning effect (balancing).

V. Discussion

A. Data

Numerical data collected from each module is then sorted and processed so that it can be entered into the model in the form of a constant variable. Table 1 is the result of sorting and processing numerical historical data collected from several sources.

B. Stock Flow Diagram

Based on the causal loop diagram, the authors developed a more detailed and quantitatively measurable simulation model. The simulation model developed is in the form of a Stock and Flow Diagram (SFD). For the simulation model in this study, SFD is divided into 4 modules. The purpose of division is to facilitate understanding of the structure of the model.

Table 1. Constant variables

Channels	Value	Unit	Sources
FiT rejection potency	50%	-	[5]
Interest rate	3.75%	-	Bank Indonesia
Capacity factor	18%	-	IESR
O&P cost	15	$/year/kW	USAID
FiT cost	0.108	$/kWh	EBTKE
PLTS operational time	30	Year	USAID
PV Construction time	1.5	Year	
Remuneration period	20	Year	ESDM
Renewable Energy budget	63,473,301	$	ESDM
Ministry's debt	523,850,754	$	PT PLN
Electricity Emission factor	0.851	$kgCO_2/kWh$	JCM Indonesia

1) Renewable energy development

The renewable energy development is explained in Fig. 3. This module shows the growth of installed PV capacity as a result of increased investment activity in PV projects. The increase in investment occurred due to the increased investment prospects for PV projects as a result of the potential Return on Investment.

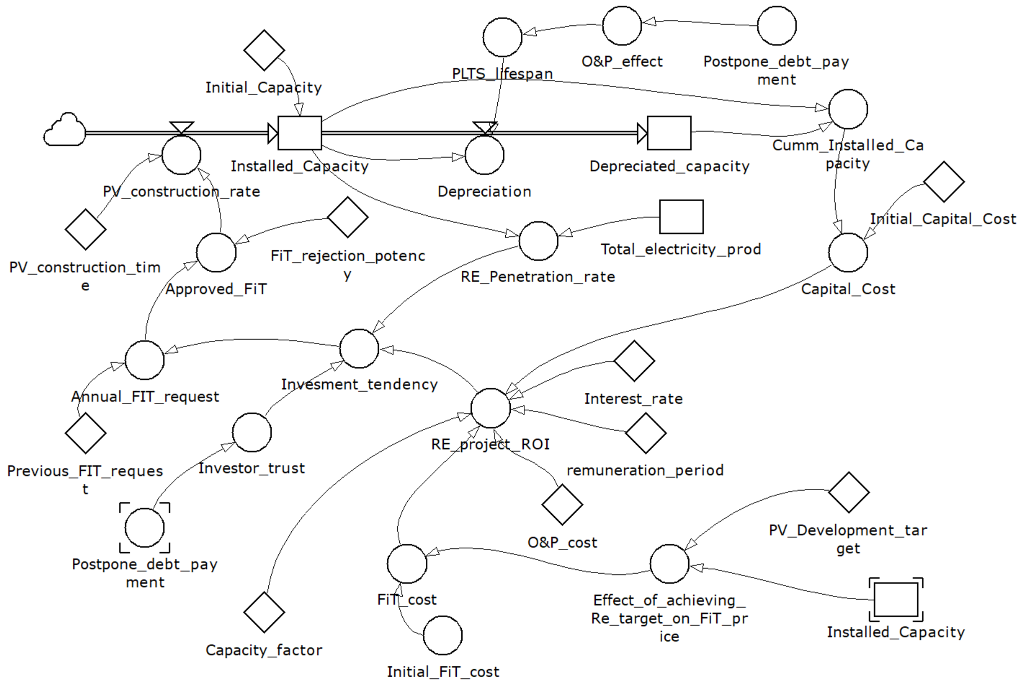

Fig. 3. Sub-model of renewable energy development.

The increasing tendency to invest in PV projects greatly influences the development of installed PV capacity. PV investment potential is influenced by 3 main factors: ROI of PV development projects, level of social penetration of PV, and potential investor trust.

2) FiT payment

The FiT payment module describes the average FiT price demanded by PV developers in Indonesia. This is shown in Fig. 4. The FiT price requested is based on the electricity produced and purchased by PT PLN. The amount of self-generated electricity production is affected by the large efficiency figure of the PV module, namely the percentage of the capacity factor owned by the PV developer, currently the average PV capacity factor in Indonesia is 18%.

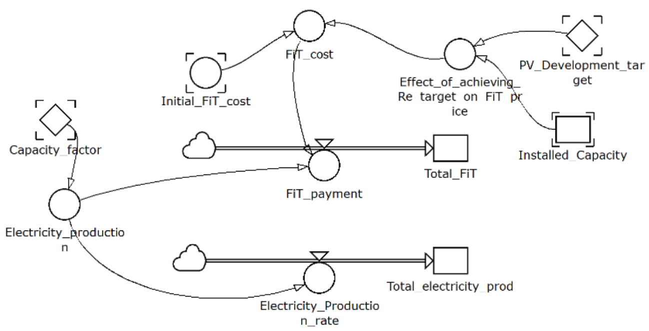

Fig. 4. Sub-model of FiT payment.

1) Budget

The budget module describes the availability of government budget for the development of EBT power plants.

The relationship between the components is explained in Fig. 5. PV policy is one of the policies that requires large investment by the government to attract Indonesian investors, so this module explains how the government's ability to pay FiT price requests has continued to grow along with the development of PV capacity approaching the RUPTL target in 2028.

The Feed-in Tariff that the government must pay to increase the national electricity supply is measured first by knowing the average FiT price. Furthermore, the obligation of annual FiT payments that must be made by the government must then be added to the renewable energy debt generated in the previous year. The renewable energy budget is smaller than the size of the renewable energy debt. The difference in the number of payments and the availability of the budget will become the procurement of renewable energy debt in the following year.

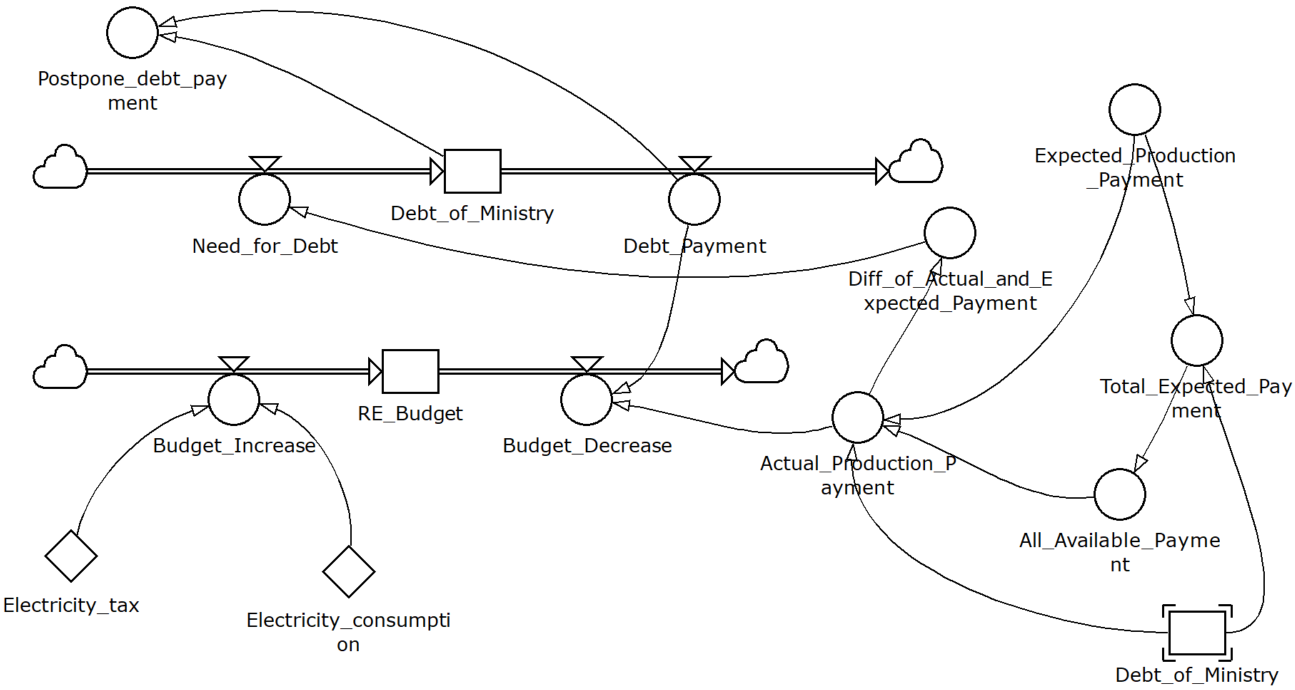

Fig. 5. Sub-model of budget.

The size of the budget can determine the government's ability to bear the cost of investing in new renewable energy. The budget provided by the government is indicated to be less than the amount of FiT payment debt submitted by PV developers each year. In this sub-model, the authors find out how long the government has the potential to delay payment of Feed-in Tariff electricity production debts by comparing debt payments and also the accumulated debt each year. Although the delay period for the debt owned by the Ministry of Energy and Mineral Resources was quite high at the beginning, in the following years the debt delay decreased drastically with a repayment period of 1.92 to 2.06 years.

2) Environmental

The fourth sub-model can be seen in Fig. 6. The environmental module describes the contribution of PV capacity to reducing CO_2 emissions. The electricity emission factor is a constant that shows the average weight of CO_2 generated per kWh of electricity (kgCO_2/kWh). The emission factor figure is obtained from the average CO_2 emission produced by fossil fuel power plants. In the system simulation, the accumulated CO_2 emission reduction from the use of a solar PV system is the sum of the annual CO_2 emissions [1]. The reduction in annual CO_2 emissions is directly proportional to the annual installation capacity, PV system capacity factor and electricity emission factor (kgCO_2/kWh) [1].

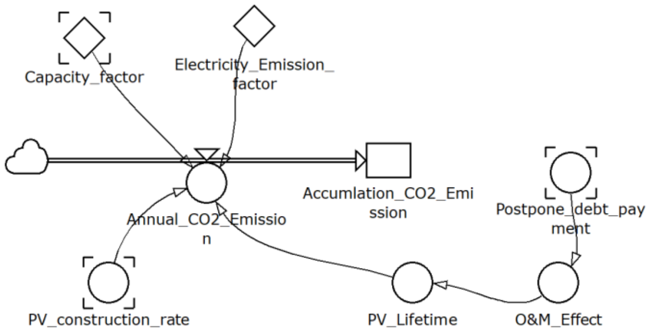

Fig. 6. Sub-model of environmental.

The annual reduction in CO_2 emissions contributed by each PV installation is directly proportional to the annual installation capacity, PV system capacity factor and electricity emission factor (kgCO_2/kWh).

C. Model Validation

1) Integration error test

In this study, testing was carried out by running the model at three-time steps: 1.5 years, 1 year and 0.5 years. The validation test results show that there is no significant change in the simulation results when the time step is changed, so the model can be considered valid.

2) Extreme condition

In this case, an extreme test scenario is given by entering the number 1 year in the remuneration period constant variable which normally has a number of 20 years. The input is then examined for its output in 3 auxiliary variables: project ROI, Investment Tendency, and PV Construction Level. The three outputs produce reasonable simulation results, so that this model can be considered valid.

3) Structure evaluation

This type of validation test aims to check whether the model structure is consistent with the description of the causal loop diagram. The model has a structure that is relevant to the concept of the problem as outlined in the causal loop diagram, so that it can be considered that the model is valid.

D. Policy Scenario Results

1) Result of base model with FiT policy

After the vital factors to increase PV capacity can influence the increased tendency to invest, it is obtained through a simulation that the target of increasing installed PV capacity based on the 2019–2028 RUPTL, will be achieved precisely in 2028. The increase can be seen in the graph in Fig. 7.

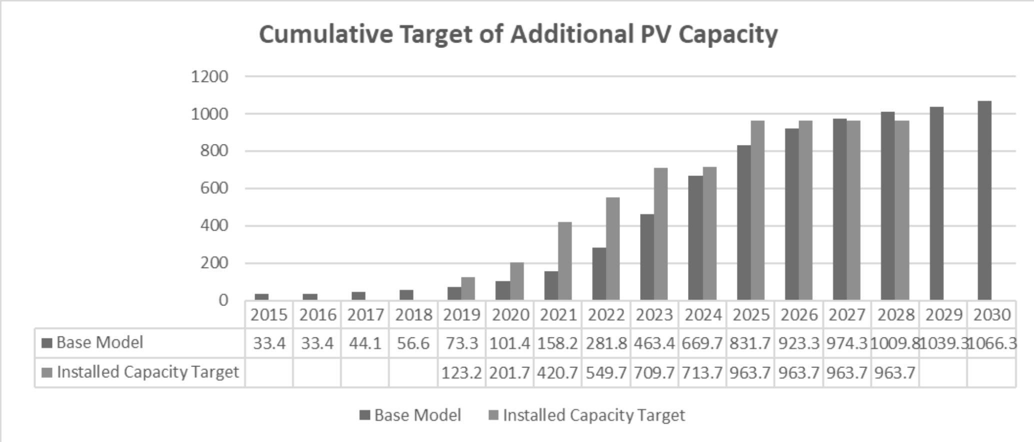

Fig. 7. Simulation result—Cumulative installed PV vs target PV installed in 2028.

2) Household rooftop PV policy and subsidy policy for PV developers

The subsidy policy has a more significant effect on PV capacity development in Indonesia than the Rooftop PLTS policy. The impact can be seen in the graph in Fig. 8. This is indicated by the relatively slow adoption factor of the Rooftop PV market and also the contribution of rooftop PV capacity which is quite small for each household that installs it, so that the development of PV capacity from rooftop PV policies is not significant enough.

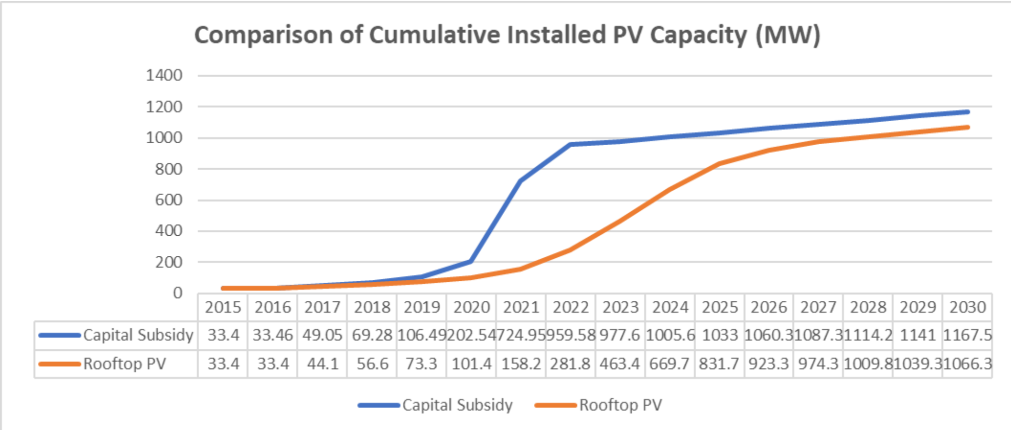

Fig. 8. Cumulative comparison of PV capacity installed on PV Rooftop and capital subsidies.

VI. Conclusion

This research successfully showed the impact of supporting policies on the reach of PV installation capacity targets in Indonesia in accordance with the RUPTL. It was obtained that with the Feed-in Tariff policy, the cumulative PV capacity target of 968.7 MW in 2028 can be achieved on time. Then, when the policy scenario is included in the model, it is also obtained that the capital subsidy policy has a significant impact than PV rooftop policy. This is proven by the faster 2028 RUPTL target reached in 2025. Renewable energy support policy is a policy that requires a large investment cost provided by the government. Therefore, it is necessary to provide an adequate renewable energy budget so that all supporting policies can produce a positive impact without delay in payment of feed in tariff debt to developers. Then, it is also recommended that the renewable energy tax policy can be an additional income for the renewable energy budget in Indonesia.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

R. Ardi: Conceptualization, analysis, supervision, securing funding; V. Alvin: Data collection, model development, writing original draft; Y.E. Purwanto: Writing final manuscript; all authors had approved the final version.

FUNDING

This study was partially funded by Universitas Indonesia through Hibah Publikasi Terindeks Internasional (PUTI) Q2, Number NKB-711/UN2.RST/HKP.05.00/2022.

REFERENCES

[1] C. W. Hsu, "Using a system dynamics model to assess the effects of capital subsidies and feed-in tariffs on solar PV installations," *Applied Energy*, vol. 100, pp. 205–217, 2012.

[2] S. F. Kennedy, "Indonesia's energy transition and its contradictions: Emerging geographies of energy and finance," *Energy Research and Social Science*, vol. 41, no. 4, pp. 230–237, 2018.

[3] IPCC. (2012). Managing the risks of extreme events and disasters to advance climate change adaptation. [Online]. Available: https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/

[4] M. Jänicke, "Dynamic governance of clean-energy markets: How technical innovation could accelerate climate policies," *Journal of Cleaner Production*, vol. 22, no. 1, pp. 50–59, 2012.

[5] H. M. Mousavian, G. H. Shakouri, A. N. Mashayekhi, and A. Kazemi, "Does the short-term boost of renewable energies guarantee their stable long-term growth? Assessment of the dynamics of feed-in tariff policy," *Renewable Energy*, vol. 159, pp. 1252–1268, 2020.

[6] K. H. Solangi, M. R. Islam, R. Saidur, N. A. Rahim, and H. Fayaz, "A review on global solar energy policy," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 4, pp. 2149–2163, 2011.

[7] R. Wand and F. Leuthold, "A review on global solar energy policy," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 4, pp. 2149–2163, 2011.

[8] IESR. (2020). Indonesia clean energy outlook. [Online]. pp. 1–54. Available: www.iesr.or.id

[9] S. W. Yudha, and B. Tjahjono, "Stakeholder mapping and analysis of the renewable energy industry in Indonesia," *Energies*, vol. 12, no. 4, pp. 1–19, 2019.

[10] A. Kollmuss and J. Fussler, "Overview of carbon offset programs: Similarities and differences," *Partnership for Market Readiness (PMR) Technical Note*, vol. 6, 2015.

[11] World Business Council for Sustainable Development, "The climate investment fund," *The Climate Investment Funds Business Guide*, 2010.

[12] A. Hidayatno, A. D. Setiawan, I. M. W. Supartha, A. O. Moeis, I. Rahman, and E. Widiono, "Investigating policies on improving household rooftop photovoltaics adoption in Indonesia," *Renewable Energy*, vol. 156, pp. 731–742, 2020.

[13] R. Kurniawan, Y. Sugiawan, and S. Managi, "Cleaner energy conversion and household emission decomposition analysis in Indonesia," *Journal of Cleaner Production*, vol. 201, pp. 334–342, 2018.

[14] M. E. Menconi, S. dell'Anna, A. Scarlato, and D. Grohmann, "Energy sovereignty in Italian inner areas: Off-grid renewable solutions for isolated systems and rural buildings," *Renewable Energy*, vol. 93, pp. 14–26, 2016,.

[15] National Research Council of The Academies. (2010). Hidden costs of energy. [Online]. Available: https://nap.nationalacademies.org/catalog/12794/hidden-costs-of-energy-unpriced-consequences-of-energy-production-and

[16] J. D. Sterman. (2002). Systems thinking and modeling for a complex world. [Online]. Available: https://www.researchgate.net/publication/44827001_Business_Dynamics_System_Thinking_and_Modeling_for_a_Complex_World

[17] J. W. Forrester, *Industrial Dynamics*, 1st ed. MIT Press, 1961.

[18] C. E. Kampmann and J. D. Sterman, "Do markets mitigate misperceptions of feedback?" *System Dynamics Review*, vol. 30, no. 3, 123–160, 2014.