Role of feed-in tariff policy in promoting solar photovoltaic investments in Malaysia: A system dynamics approach

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Abstract

Solar photovoltaic has shown a significant rise in terms of worldwide installation. One of the main reason is due to the introduction of the feed-in tariff (FiT) policy by the governments. This paper aims to evaluate FiT policy in promoting solar photovoltaic (PV) investments in Malaysia by using a dynamic systems approach. The assessment model captures the complexities arising from the interaction of FiT rate dynamics, construction delays, and investors' and technology learning dynamics in an integrated framework. The model provides total operational PV capacity, amount of finances needed to support the policy, and the cost of environmental savings, as output. Computer simulations, based on twelve scenarios, were used as a means to study the model behaviour. For the most favourable scenario, a total capacity of about 16 GW PV by 2050 can be expected, while for the least favourable scenario, expectations would be only about 10 GW. On the expenditure side, the most favourable scenario can cost up to Malaysia Ringgit (MYR) 15 billion, whereas, for the least favourable ones, the cost can be as low as MYR2 billion. The maximum cost of CO_2 abatement can vary from MYR 0.05 per kg to the lowest value of MYR 0.02 per kg.

Keywords feed-in tariff, System dynamics, Solar PV, Cybernetics

1. Introduction

The global demand for electricity is on a rise. In 2001, electricity generation was 15,640.7TWh, which grew to 22,668 TWh in 2012 [1,2]. A rise in population and economic prosperity are attributed to be the main drivers behind the increase in demand [3]. According to the International Energy Agency (IEA), around 68% of the world's electricity production is from fossil fuels. Coal is the most widely used fossil fuel for power generation, followed by hydropower; supplying around 40.4% and 16.2% of the world's electricity needs in 2012, respectively [2]. There are two major concerns over the use of fossil fuels for electricity generation: finite resources and environmental degradation. It is estimated that coal will last 164 more years, oil 200 years, natural gas 65 years , and not fossil, but non-renewable, nuclear resources will be available for the coming 70 years [4]. The second concern regards harmful emissions like CO_x, NO_x and SO_x from using fossil fuels based electricity generation. These emissions are also believed to be contributing to global climatic change [5]. Therefore, one of the top priorities of countries around the world is to divert their electricity generation from non-renewable to renewable sources. This diversification will achieve sustainability in production as well as combat climate change.

Likewise, the Government of Malaysia (GoM) is keen to diversify the fuel-mix for power generation. Various steps had been taken in the past to promote renewable sources for electricity production. The 10th Malaysia Plan (2011-2015), being the most recent, targeted 985MW of renewable generation capacity [6]. According to this plan, the solar photovoltaic (PV) capacity is targeted to be raised to 65MW [7]. This seems to be an arduous task, as the solar PV technology is expensive and is still treated as novice technology [8].

To overcome the financial barrier for a large scale adoption of the solar PV technology, GoM opted for feed-in tariff (FiT) policy, saying, " FiT is the most effective RE policy mechanism in promoting and sustaining renewable energy growth" [9]. However, FiT subsidies place a financial burden on governments, which may restrict policy continuance under difficult economic conditions. This situation can thus adversely affect public confidence in these support mechanisms. Therefore, it becomes imperative for policymakers to fully assess the consequences of their intended policies before implementing them. Thus, the objective of this study is to develop a simulation model which will evaluate the FiT policy for the solar PV systems deployment in Malaysia.

2. An overview of FiT policy

In an anticipation to increase the renewable capacity investments, around 65 countries and 27 states around the world have introduced the FiT support scheme [10]. This list includes Germany, Spain, and Ontario (Canada), from the developed world, to Taiwan and Turkey, from the developing world [11-15]. The aim of the FiT policy is to offset the high investment cost of renewable energy technologies. FiT is believed to be a more effective support mechanism as compared to renewable portfolio standard [16].

The FiT policy has two basic characteristics: guaranteed fixed prices and long contractual period for any technology using renewable fuel for electricity generation. These FiT prices are characterized per kWh of electricity (energy) produced, which has to be paid to an independent power producer by a system operator, or a utility company, to whose grid energy is exported. These prices vary for different technologies, range of capacities and length of contracts [17]. The FiT policy mandates the utility companies to provide grid access to independent producers, thus ensuring financial reliability [15]. The risk mitigation, either financial or technical, or both, is an important feature for any policy design for renewable technology deployment [18]. The FiT policy effectively lowers the perceived risk for investors, thus stimulating various segments of society for scaling up of renewable technology for electricity production [19]. However, some drawbacks have also been identified. The foremost reservation concerns FiT inhibiting a healthy market competition by giving preferential treatment to certain technologies; other reservations include, financial burden on taxpayers and propensity to lock–in to a specific technology [20,21]. To overcome these impediments policy-makers are compelled to limit the time and size of FiT policy; enabling local markets to flourish as well as embracing no extra financial burden [22].

Prior research suggests that the FiT policy can have varied outcomes in different countries in terms of installed PV capacities [18]. The reason for this variation is attributed to the unique design characteristics of the FiT policy in a particular country [23]. To evaluate the FiT policy, a number of researchers have adopted various methodological approaches in developing their assessment models. For example, Jenner et al. [23] used the econometric approach to evaluate the success of the FiT policy in 26 European Union countries, whereas Kim and Lee [24] used the stochastic-optimization approach to assess the effectiveness of Ontario's FiT policy. The static Monte Carlo simulation was employed to assess the uptake of wind power by Walters and Walsh [25], while a dynamic simulation package called, Green-X, was used by Walker [26] to evaluate the effect of FiT in attaining 2% of renewable technology share in UK. On the other hand, Muhammad-Sukki et al. [27] used an accounting approach to assess the impact of revised FiT rates for solar PV deployment in UK. Along with quantitative approaches, Verbruggen and Lauber [28] used a qualitative approach to asses FiT and Tradable Green Certificate scheme for renewable technology deployment. Furthermore, on the methodological side, models using a dynamic, nonlinear, feedback approach of system dynamics; similar modeling approach used in this study, focussed on modelling renewable target capacity [29,30], and assessing the renewable technology cost development [31].However, only one model by Hsu [32] presented a combined FiT and subsidies assessment using system dynamics approach.

3. Malaysian electricity sector

Being a fast developing country, with an aspiration to be in a higher income group of countries, Malaysia's electricity demand is sharply increasing. The peak demand in 2000 was 10,639MW, which rose to 17,883MW in 2012 [33]; this corresponds to an annual rise of peak demand of 5.2%. This shows that large generation capacity expansions were made in order to meet the growing peak demand. In 2000, the total electricity demanded was 61,168 GWh, which jumped to 116,353 GWh in 2012, corresponding to an annual growth rate of 6.9% [33]. It is estimated that Malaysia would require 234TWh by 2030[10] while in short run, by 2022, 151TWh [32- 35], which seems to be a great challenge for the country. The development of peak demand and average electricity consumption, for the period 1997-2012 is shown in Fig.1.

The Malaysian electricity generation is dependent on five main types of fuels: oil, coal, natural gas, hydro and others (biomass, biogas and solar). This fuel-mix for electricity generation presented in Figure 2 shows that the share of oil/diesel for power production is decreasing, while the gap created is being filled-up by natural gas; currently, gas based production dominates the share of fuel-mix. Nevertheless, since 2000 the share of coal in fuel-mix is also on the rise.

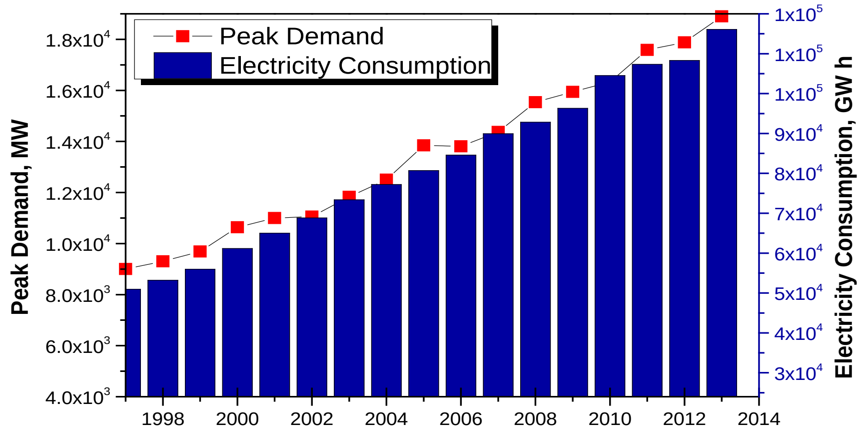

Fig. 1. Annual peak demand and electricity consumption. Adapted from [ref?]

On the renewable side, hydropower share is decreasing, as opposed to biomass share, which is rising sluggishly. In 2010, 94% of electricity was produced from fossil fuels, whereas hydropower plants provided only 5.6% of the total electricity produced [7, 31]. It is estimated that the Malaysian oil reserves would only last for 18-20 years, while natural gas production can only be sustained for the coming 35-36 years [6]. The supply for coal, on the other hand, is maintained by imports from Indonesia, Australia, and South Africa [36]. Thus, in order to meet the rising power demand, whilst cutting the reliance on the fossil fuels, Malaysia needs to changeover to renewable sources for electricity generation. Putting off this transition may lead to serious power shortages.

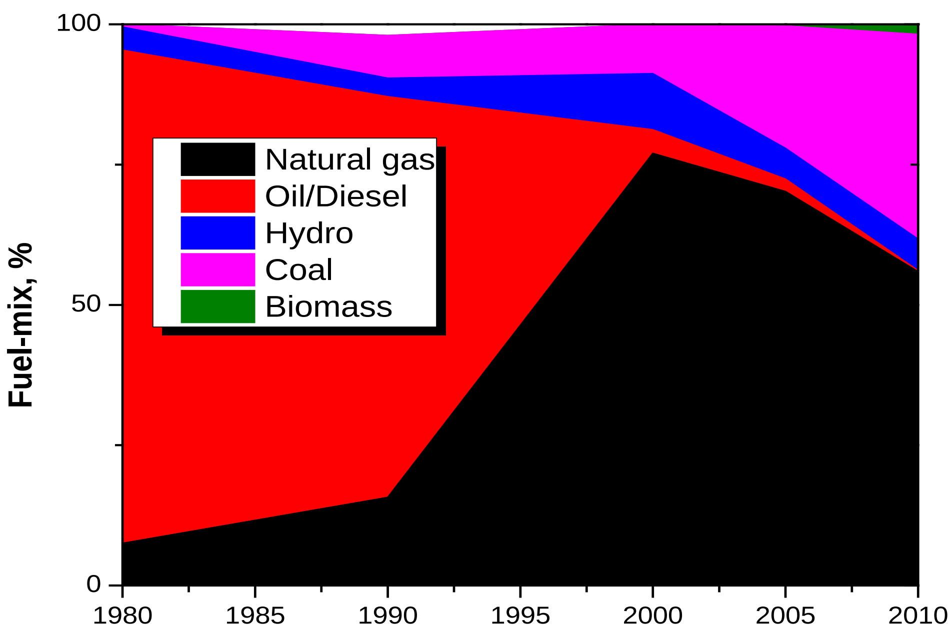

Fig. 2. Fuel-mix for electricity generation in Malaysia [36]

4. Salient characteristics Malaysia's FiT policy

The Malaysian FiT policy differentiates between various renewable technologies available for electricity generation. This attribute of the policy is same as practiced in other countries. The benefit of this feature lies in promoting, simultaneously, market shares of all indigenous renewable sources. The Malaysian FiT rates vary by size of installations: smaller capacities have higher FiT rates as compared to larger ones. This feature benefits in bringing diversity to the type of investors. Small and large utility scale investors can take advantage of the FiT scheme. Heterogeneous investors help in avoiding any monopolistic market being developed. Finally, the annual degression[1] in the FiT rates is known to investors. Knowing the degression rates ex-ante not only lowers investors' perception of a potential capital risk, but it also increases investments in research and development (R&D) of technology. Furthermore, investors' risk perception is also lowered by long duration of contracts. In Malaysia, contract period for solar PV and small hydro system is 21 years while that of biomass and biogas is 16 years only [37]. The most prominent characteristic of the Malaysian FIT policy is that it places no extra financial burden on the government; the FiT fund is being financed by electricity consumers themselves. It was estimated that the FiT policy will raise the monthly electricity bill by approximately 1% but consumers having less than 300 kWh per month usage will not be affected [9]. These features are close to those presented by the National Renewable Energy Laboratory, USA, for a successful implementation of FiT policy [35]. However, from January 2014 onwards, to ensure continuance of FiT policy Ministry of Energy, Green Technology and Water adjusted the electricity tariff that resulted in monthly electricity bills consumers to rise to 1.6% from 1% [38].

5. FiT policy model development

5.1. System dynamics methodology: Rationale

System dynamics (SD) modelling and simulation methodology has been used in this study due to its characteristic of incorporating time varying behaviour of complex systems. Other modeling approaches disregard multiple indirect, nonlinear, and feedback relationships arising from the interaction among system components in energy sector [39]. For example: the higher the financial benefits, the greater the pressure on the government to provide the funds. Moreover, the feedback capability of SD is of special interest to policy-makers. SD provides a platform to policy-makers in which they can simulate possible scenarios for different policies. The results of these policy experiments can significantly improve their decisions. Thus, the SD approach is deemed appropriate for the current study.

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[1] An annual degression rate is the annual decrease in FiT rate applied to a renewable energy technology. The decrease rate is decided by the government by taking into account a number of factors including the decrease in a specific technology cost and the cumulative installation of the technology.

5.2. Methodology

This study adopts a three layer methodology for model development. The first layer is a high level representation of the FiT assessment model, named mental model. The second level is a mathematical model, and the third level is a computer simulation model. Each of the model's level is described in sub-sections below.

5.2.1.Mental Model

A mental model depicts the structural construct of a system under enquiry. However, it is not possible to analyse the problem from a universally holistic framework. Therefore, a mental model renders a model boundary [40]. The causal loop diagram for the study is shown in Fig. 3. A total of six feedback loops have been identified. They are labeled as R1, R2, R3, C1, C2, and C3; the first three loops are reinforcing, whereas the last three are controlling or balancing loops. The reinforcing loops have an increasing effect, while the balancing loops have a limiting effect on the system. The interactions of these two types of loops generate the model behaviour or dynamics of the system.

Reinforcing loop R1

Starting with *the willingness to invest in PV* this variable influences the *PV capacity under planning* through *the PV start rate*. As the willingness to invest increases, the *PV capacity under planning* increases. With a certain rate of success, the *PV capacity under planning* affects the *PV capacity under construction;* the higher the number of successful projects, the more the capacity under construction. After a fixed delay, the construction time, under construction capacity, goes into operation. The *PV operational capacity* growth influences the experience in using the PV system. This learning results in lowering the cost, modeled as a *cost of PV system*. The cost reduction, in turn, influences the *willingness to invest in PV*, which impacts the *PV start rate*, thus closing a reinforcing loop.

Reinforcing loop R2

This loop shares some of the variables as R1. The difference takes off from the *PV operational capacity* influencing the *PV capacity retirements*. Higher PV retirements require more adjustments to be made to the PV capacity. These adjustments are depicted by a variable, *PV capacity adjustments*, which then influence the *PV start rate.*

Reinforcing loop R3

This loop is based on the assumption that the retired PV capacity is brought back into the system. However, no provision is made to identify that replacing the PV capacity is of higher efficiency.

Controlling loop C1

This loop acts as a limit to cost reduction effect of a PV system. It makes uses of saturation of learning in reducing the cost of a PV system. The cost reduction cannot be dropped to zero, which, in itself, is an unrealistic assumption

Controlling loop C2

This loop consists of similar variables to that in R1 loop. Instead of the *PV operation capacity* affecting the *PV capacity retirements*, another variable, the *PV capacity gap*, is influenced. The *PV capacity gap* is the difference between the *government target* and the *PV operational capacity*. This gap variable then affects the *PV capacity adjustment*. Thereafter, C2 follows the path of the R1 loop.

Controlling loop C3

This loop consists of two variables, the *PV operational capacity* and the *PV capacity retirements*. As the operational capacity grows, there is going to be more capacity that will be retiring after their useful life. As more capacity retires, the total operational capacity is reduced. The interaction of these two variables forms a controlling loop.

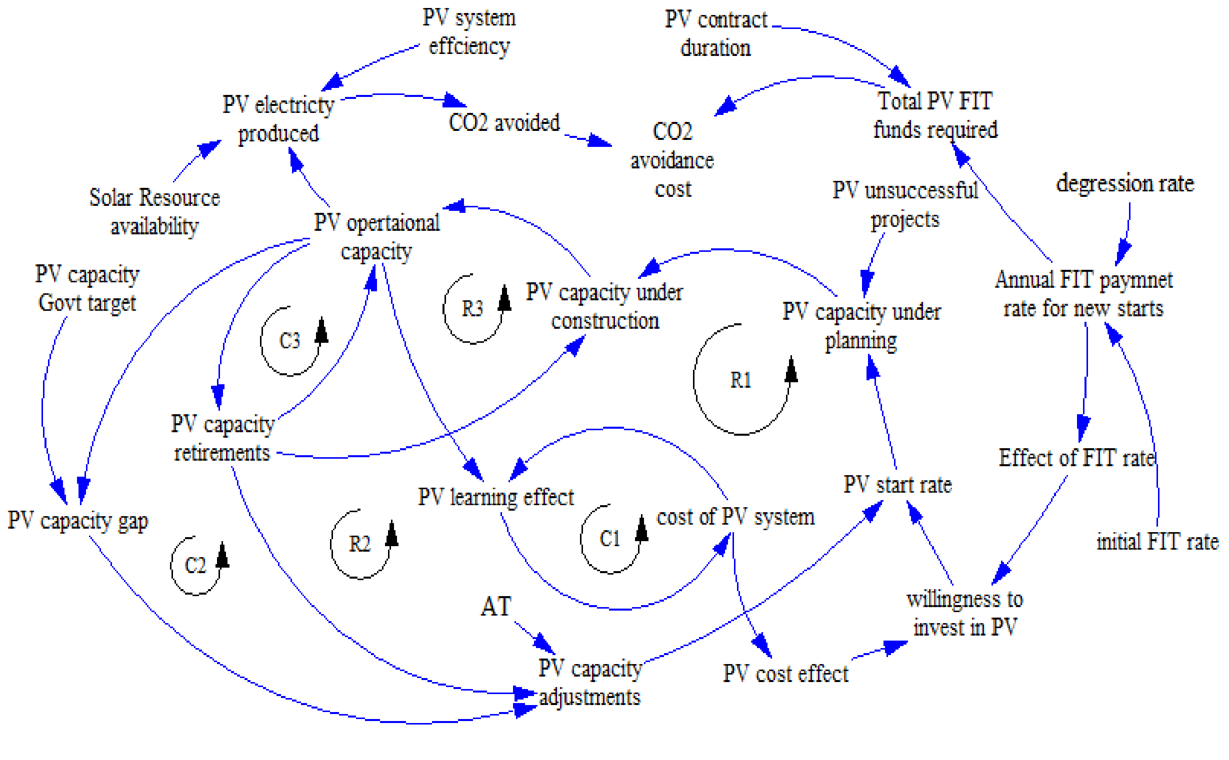

Fig. 3. A causal loop representation of FIT assessment model

5.2.2.Mathematical Model

The mathematical model developed in this study consists of differential equations and algebraic relationships. The structural relationships are the same as the mental model explained above. The differential equations are written for stock variables. In the current study seven stock variables have been modeled. The differential equation for a stock, the *PV operational capacity* (PVOpCap, in kW), is given in equation (1).

The *PV operational capacity* is increased by *PV construction completion rate* (r_{Comp}, in kW/year) and decreased by *PV retirement rate* (r_{Ret}, in kW/year), while PVOpCap(0) is the initial capacity. This is mathematically represented as:

$$PVOpCap_t = INTEGRAL\ (r_{Comp} - r_{Ret})dt + PVOpCap(0) \qquad (1)$$

The other stock equations follow the same format, but with their specific variables. On the other hand, the flow equations, using the PV *capacity retirements, as* an example, are given in equation (2).

$$r_{Ret} = PVOpCap / t_{life} \qquad (2)$$

where t_{life} is the operational life of a solar PV panel, in years.

All the flow variables used in the model have the similar construct as equation (2). Once mathematical equations are settled, a computer simulation model is constructed.

5.2.3.Computer simulation model

The computer simulation model consists of the differential equations and algebraic relations being coded in a software package called, iThink®, version 9.0.3, for simulations. Along with stock and flow variables, auxiliary variables are used to convert mental model logic comprehensively into a simulation model. A portion of the quantitative model used in this project is shown in Fig. 4. The stocks of planning, construction and operational PV capacity are used. This structure is similar to the one suggested by Akhwanzada and Tahar [41], for capital infrastructures but with an improvement. The improved structure distinguishes *FiT contract capacity* from *PV Operational Capacity*. This is important in two ways; firstly *FiT contract capacity* is utilised for calculating financial requirements of FiT policy, secondly, *FiT contract capacity* information is used to find the amount of electricity generated by solar PV during the contractual period, and subsequent CO_2 savings that can be made. The improved structure is presented by a stock variable labelled *FiT contract capacity,* in Fig. 4, below. In order to observe the dynamic behavior of the model certain parameters are needed. These parameters have a fixed numeric value throughout the simulation run. Parameters and their values are provided in Table 1.

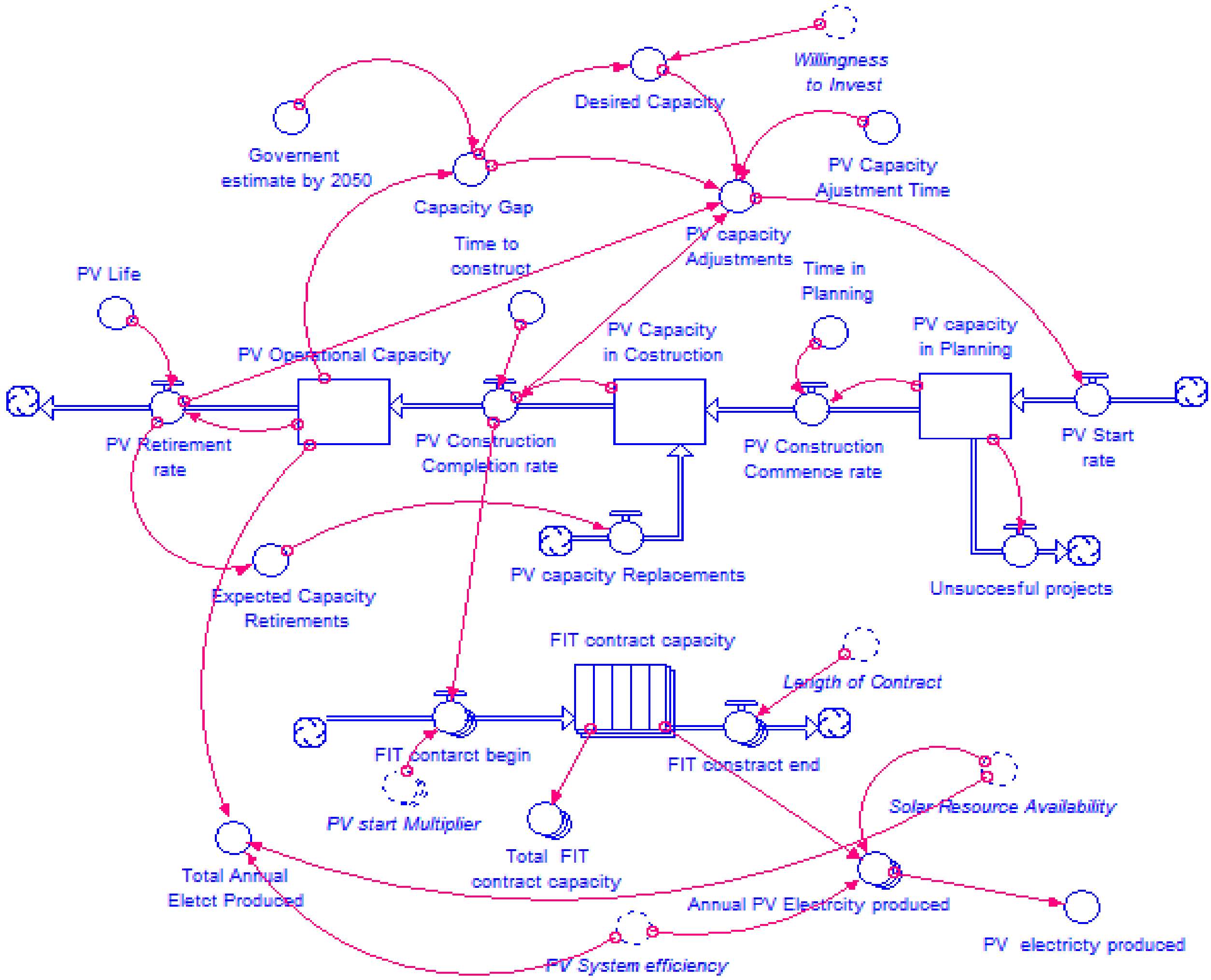

Fig. 4. Computer simulation model for solar PV capacity construction

Table 1. Parameters used in model with values

Parameter	**Value**	**Reference**
Initial number of PV system	1 MW	[41]
Initial cost of PV system	MYR* 19,210/ kW	[41]
Learning rate in PV system	10%	[18]
Operational life of a PV system	30 years	[24]
CO_2 emission factor	0.69kg of CO_2/ kWh	[42]
Solar irradiation	1170 kWh/kWp	[35]

* Malaysian Ringgit is the currency in Malaysia. 1 Malaysia Ringgit is approximately USD 3.30.

6. Simulation results and analysis

6.1. Model Validation

The validation process is critical for building confidence in a model's output. For policy analysis models, like the one developed in this study, the validation process, as outlined by Quadrat-Ullah and Seong [43] was followed. Of the five validity tests, the boundary accuracy and structural verification were confirmed by causal feedback diagram in Fig. 4, whereas the parameter verification was done from data provided in Table 2. The dimensional consistency test can be verified from equation 3.

$$PVOpCap_t \{this\ year\} = PVOpCap \{previous\ year\} + dt * (r_{Comp} - r_{Ret}) \{during\ the\ year\}$$
$$[kW] = [kW] + year * (kW/year - kW/year) \quad (3)$$

The right and left hand side of equation 3 are balanced, having the same units of kW on both hand sides of the equation 3. Hence, the differential equation is dimensionally consistent. Finally, the extreme conditions test is performed to check, whether or not, the equations make sense when subjected to extreme conditions. For this particular test, two parameters, *Length of Contract* and *Time to construct*, were used. The extreme condition test (ECT) for the former parameter was set to zero, while for the latter, a very high value of 1000000 was used. As seen in Fig. 5, with minimal possible length of contract, no FiT payments are made, while for an infinitely large construction delay, Fig. 6 shows no new PV capacity additions; rather a steady decay is observed. Both the outputs are rational, thus validating the model under extreme conditions.

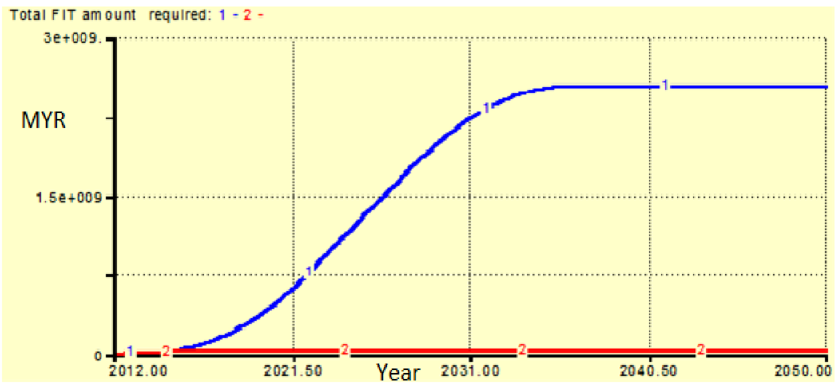

Fig. 5. ECT, FiT payments

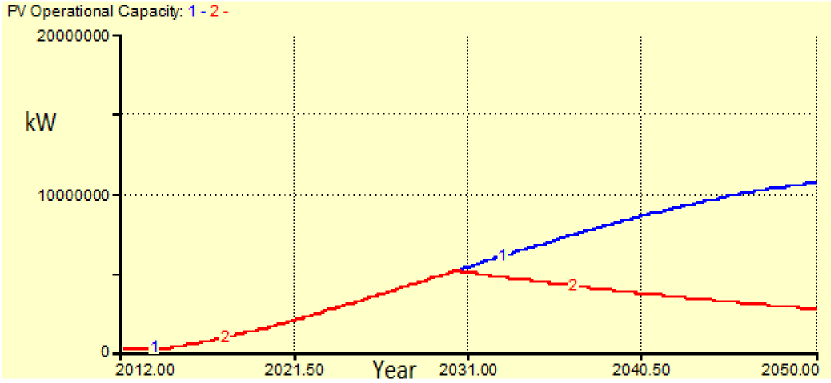

Fig. 6. ECT, Operational capacity

6.2. Scenarios setting

SD models are best utilized when they are not considered for a single path projection, rather as a means to improve understanding and learning about the system. Therefore, to judge the usefulness of the FiT assessment model developed in this study, the scenario analysis approach was considered. However, there is a limit to the scenario analysis; not every possible change that may take in the future can be considered; instead, parameters that are considered to be most pertinent to the model are considered. Therefore, in this study twelve scenarios are evaluated. Each scenario is a combination of different FiT rates, degression rates, and lengths of contract. Table 2 ssummarises the scenario settings.

Table 2. Scenario description

Scenario	**Sc1**	**Sc2**	**Sc3**	**Sc4**	**Sc5**	**Sc6**	**Sc7**	**Sc8**	**Sc9**	**Sc10**	**Sc11**	**Sc12**
FIT rate, MYR/kWh	1.23	1.23	1.23	1.23	1.23	1.23	0.85	0.85	0.85	0.85	0.85	0.85
Degression rate, %	7	8	9	7	8	9	7	8	9	7	8	9
Contract duration, years	21	21	21	14	14	14	21	21	21	14	14	14

6.3. Scenarios results and analysis

In this section, results from twelve scenarios considered for the FiT policy assessment model are discussed. The results for total PV operational capacity are shown in Figure 7. The lines 1, 2, 3 correspond to Sc1, Sc2, and Sc3, while lines 4, 5, 6 correspond to Sc7, Sc8 and Sc9, respectively. On inspection, scenarios Sc1, Sc2, and Sc3 showed similar dynamics: initially slow, followed by a rapid growth, and finally leveling towards the end of a simulation run. This trend resembles an S-shaped growth pattern, which is quite common in the adoption of new technologies [44], primarily due to delays, feedback and nonlinearities in the system. However, the observed dynamics of this FiT assessment model is unlike Hsu [32], which showed an exponential growth. The most likely reason for this difference can be attributed to shorter time horizons considered by Hsu [32], which seem to have failed in divulging the effect of any delayed actions within the system.

Among Sc1, S2 and Sc3 a difference in the PV operational capacity is observed towards the end of the simulation. Sc1 attained a maximum capacity of 16.273 MW, which is approximately 3.7% more than Sc2 and a staggering 8% more than Sc3. For scenarios Sc7, Sc8, and Sc9 quite different dynamics are observed in comparison to Sc1, Sc2 and Sc3. The former three scenarios exhibit a quite strong S-shape dynamics, while the latter three preset a weak one. Sc7, Sc8, and Sc9 dynamics reveal that a lower rate of FiT lacks the ability to attract investors; the gap between the final PV operation capacities is much lower than the former scenarios. The average difference between them is around 5MW. It is also observed that there is not much difference in PV operation capacity at the end of the simulation runs for each of scenarios 7, 8 and 9. As seen from Figure 7, the simulation dynamics of these scenarios (7, 8 and 9) seem to be overlapping each other. The percentage difference of the PV operational capacity between Sc7 and Sc8 is 0.4%, only 0.37% between Sc8 and Sc9, while 0.7% between Sc7 and Sc9.

It was observed that scenarios 4, 5, and 6 provide the same dynamics as scenarios 1, 2, and 3; similar behaviour is observed for scenarios 10, 11, and 12, which fall on scenarios 7, 8 and 9. To explore the reason for these dynamics it is found that these scenarios differ only in the *length of contract,* which relates to total FiT payments, not to total PV operational capacity. For example, in Sc1 the total FiT payments is MYR 14.944 billion, while in Sc4 it is only MYR 9.963 billion, though both the scenarios have the same total PV operational capacity as well as the FiT contract capacity. The FIT payments for different scenarios are provided in Table 3.

Electricity production from solar PV off-sets the need of production from fossil fuels, thus saving CO_2 emissions. The FiT policy can also be seen as an environmental protection policy. As mentioned earlier, Malaysia's FiT fund is not a government spending. Rather, the FiT policy can be seen as money the government would be saving in case it had to run a parallel environmental protection policy. In this context, the model's output shows that for scenarios 1-6, with the FIT rate of MYR 1.23 per kWh, the cost of policy reduces from MYR 0.05 kg-CO_2 to MYR 0.03 kg-$CO_{2,}$ whereas for scenarios 7-12, having a FiT rate of MYR 0.85 per kWh cost of policy varies from the highest of MYR 0.03 per kg-CO_2 to the lowest of MYR 0.02 kg-CO_2. It can be inferred from the results that initially the government can benefit from the FiT policy as an environmental protection policy, but after the year 2025 it would lose its effectiveness as the benefits levels off.

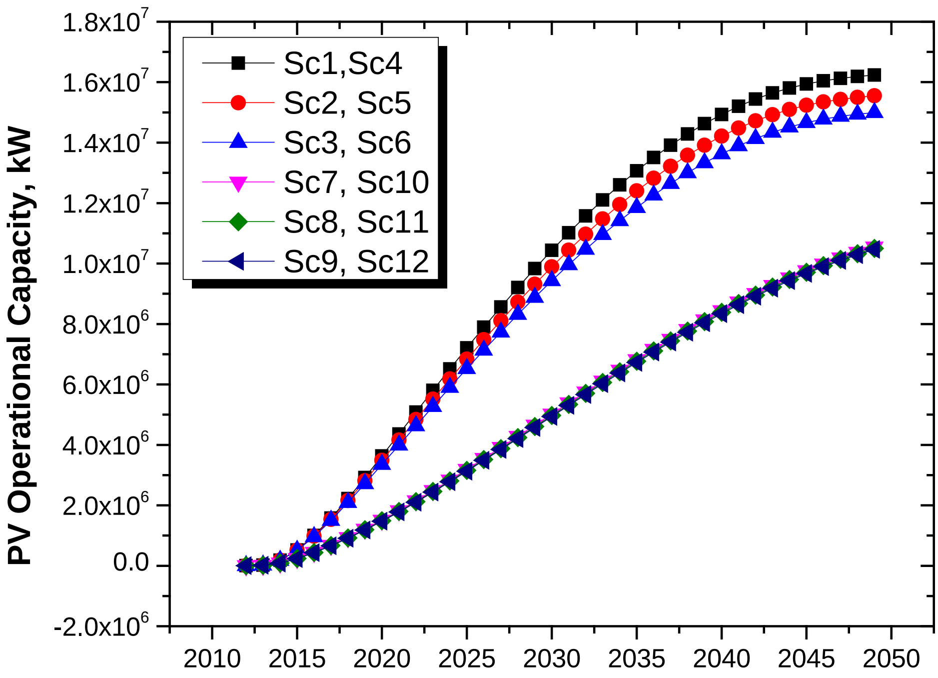

Fig. 7. Total PV operational capacity

Table 3. Output of the FiT assessment model

Scenario	**PV operational capacity,** MW	**FiT contract capacity,** MW	**Total cost of FiT policy,** billion MYR	**Cost of CO_2 avoidance policy,** MYR/kg-CO_2	
				Maximum	**Minimum**
Sc1	16.273	879.159	14.944	0.05	0.03
Sc2	15.686	825.395	13.519	0.05	0.03
Sc3	15.036	781.374	12.289	0.05	0.03
Sc4	16.273	879.159	9.963	0.05	0.03
Sc5	15.586	825.395	9.012	0.05	0.03
Sc6	15.036	781.374	8.193	0.05	0.03
Sc7	10.700	392.534	4.366	0.03	0.02
Sc8	10.657	388.574	4.078	0.03	0.02
Sc9	10.623	385.384	3.819	0.03	0.02
Sc10	10.700	392.534	2.911	0.03	0.02
Sc11	10.657	388.574	2.719	0.03	0.02
Sc12	10.623	385.384	2.546	0.03	0.02

7. Conclusion and remarks

Though Malaysia has a favourable climate for solar PV based electricity generation, the number of solar PV installations is quite minimal. To diversify the fuel-mix for electricity production, the government of Malaysia introduced the FiT policy to encourage the general public and business enterprises to invest in solar PV systems. The estimate is to have 9GW of solar PV installations by 2050. Hence, an FiT policy assessment model has been developed in this study. The model uses system dynamics simulations to explore the total solar PV capacity that could be operational, cost of the environmental protection policy, and the financial requirements to support the policy. A relatively longer time horizon (2012 to 2050) has been used so as not to ignore the effect of any delayed dynamics in the system. A total of twelve scenarios were evaluated based on varying FiT rates, degression rates, and contract duration. The computational results show that scenarios with higher FiT rates result in much higher PV capacity being installed and are also more sensitive to FiT degression rates as compared to scenarios having lower FiT rates. The length of the contract does not affect the PV capacity; rather in shorter contracts lesser payments are to be made. Apart from differences, there is similarity in all scenarios. All scenarios exhibit a constrained growth towards the end of the simulation run. This system behavior is very important for policy-makers, particularly demonstrating the limit to effectiveness of the FiT policy. If higher number of PV installments is desired, then changes to the system structure, as well as parameters, is to be made. The model output proficiently provides the timing for that decision, along with the graphical development of solar PV capacity. However, this study has its limitations. Foremost limitation is exclusion of other renewable technologies from the model. In addition, variable degression rates would be another aspect that could be explored. Future research should address these issues.

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