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Optimized Prosumer Tariff Setting Framework On Solar Photovoltaic (Pv) Using Linear Programming

Noriza Mohd Saad[1*], Izzaamirah Ishak[2], Mohd Zamri Laton[3]

[1]Faculty of Business Management, Universiti Teknologi MARA, Kelantan, Malaysia.

[2]College of Energy Economics and Social Sciences,, Universiti Tenaga Nasional (UNITEN), Malaysia.

[3]Market Operations Division, Sustainable Energy Development Authority (SEDA) Malaysia.

Abstract:

This paper discusses the optimization effect of service costs given in the prosumer tariff on quota ability and installation costs among prosumer categories, in Malaysia. This topic is quite important as it can affect the future take-up rate of potential prosumers that can support the policymaker prepare to deliver future quota allocation dependent on maximum permissible demand. Technically, cost disbursement needs a more accurate and justifiable process leading to the need to update the tariff design methodology as solar PV technologies have achieved socket parity in Malaysia. Overall, the findings suggest that the prosumer tariff is actually quite competitive.

Keywords: Solar Prosumer, Linear Programming, Installed Capacity, Installation Costs, Tariff.

1. Introduction

A prosumer is a customer capable of producing and consuming energy. They are energy producers and consumers themselves, resulting in a two-way or bi-directional flow of energy. Prosumers have the benefit of being able to share or sell excess energy produced by solar PV sources to the Tenaga NasionalBerhad (TNB) grid using the NEM system managed by the Sustainable Energy Development Authority (SEDA) of Malaysia. A prosumer can achieve economic advantages by optimizing self-consumption as well as generate green investment by excess energy. A key goal is to find the optimal energy flows of storage charge/discharge and load consumption. This occurs when the optimal size and configuration of generators and storage systems are determined by considering the prices of energy purchased from or sold to the grid [1].

In Malaysia, the Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC, now known as KeTSA stand for The Ministry of Energy and Natural Resources), has introduced few solar PV initiatives to encourage Malaysia's Renewable Energy (RE), one of the significant initiatives is by introducing the NEM system in November 2016. On 12th July 2018, the PV industry highlighted the essential alteration of NEM from the existing net billing to true net energy metering (TNEM) for promised the return of investment of solar PV. Starting from 1st January 2019, the NEM was enhanced by espousing the TNEM concept, and this will allow excess solar PV-generated energy to be exported back to the grid on a "one-on-one" offset basis. This means that every 1kWh exported to the grid will be offset against 1kWh consumed from the grid instead of the Displaced Cost. The quota allocation for NEM is 500 MW up to the year 2020. This quota was provided for both categories, domestic/residential and non-domestic. In detail, these categories are Residential, Commercial, Industrial, and Agriculture, whereby the new NEM scheme is only applicable to Peninsular Malaysia, and applicants must be registered TNB customers. NEM is executed by the KeTSA, regulated under the Energy Commission (EC) and SEDA Malaysia as the implementing agency.
Since the revised NEM (NEM 2.0) is up to the year 2020, there are many considerations to review the system as well as to revise the solar PV prosumer tariff structure by analyzing the segregation of the KWh/ KWp tariff is either optimize or under/over-optimize, fairness to both parties involved and cost-reflective to the utility provider. The lack of policy areas, especially on energy prosumer tariff structure analysis, motivates this study to be conducted.

Concerning the definition of NEM, the main electricity utility provider in Peninsular of Malaysia, TNB defined the NEM as a mechanism for the customer to use their solar energy produced for self-consumption. Then, if any excess energy generated will be exported to the TNB grid, it will be turned to credit that may be used to offset part of the electricity bill [2]. Like the SEDA, they derived the concept of NEM as the energy generated from the installed solar PV system for self-consume, and if any excess energy will be exported to the TNB grid on a "one-on-one" offset basis. This scheme applies to all TNB customers include domestic, commercial, industrial, and agricultural sectors. The PV systems can be installed at available rooftops or car porch within their premises.

The remainder of the paper is organized as follows—next, discussion on past studies on costs of installation related to the tariff issues and take-up rate. Next, it further explains the data and methodology used. Then, proceed with linear optimization results analysis. Lastly, this paper concludes and highlights policy recommendations.

2. Literature review

Photovoltaic (PV) power is one of the fastest-expanding forms of renewable energy sources. With PV generation available for anywhere from single residences to large industrial plants, the technology has improved tremendously over the years. Initiatives to stimulate the development of solar power have been adopted by several countries [3]. According to [4], the global installed capacity of renewable energy technologies is growing rapidly. The ability of renewable technologies to enable a rapid transition to a low carbon energy 3 system is highly dependent on the energy that must be 'consumed' during their life-cycle. PV installation capacity is also associated with cost reductions because when installation capacity is increased, technological improvements and scale economies increase for PV panels. When first produced, photovoltaic systems had short lifetimes. Through development, the technology lifecycle of photovoltaic systems has increased to 20–25 years [5]. As claimed by [6], the cost of energy produced by the SPV power plant decreased significantly in recent years due to a sharp fall in the PV module prices, improved performance (efficiency), and PV modules' reliability reduced initial investment.

Since it becomes a green investment, the prosumer's optimized tariff offer should be at par at least. The mechanism of analyzing the potential return generated considering the costs involved besides self-consumption should be investigated. Many studies, for instance, [7],[8],[9],[10],[11], reported that linear programming (LP) is the most effective technique in order to find the best fit of decision for cost optimization. Furthermore, this LP is quite complex and uncertain concerning the dynamic data pattern that requires the decision-makers and planners to face increased pressure to respond more effectively to several energy-related issues and conflicts [12] and need to associate with economic, environmental, and regulatory implications. The goal of any LP algorithm is to find the optimum solution to a given problem. The problem is formulated by an objective function, which needs to be minimised or maximised under a set of limits and constraints. This tool processes various input parameters and constraints associated with feasible renewables and returns a mix of renewable technology plant sizes required to comply with building and planning regulations at the minimum installed capital cost [13].

Furthermore, the LP formulation offers many attractive features, including the capability to present a huge number of variables and equations, ease of solution, ease in obtaining sensitivity analysis, i.e., shadow prices, and the sensitivity of the (optimal) alternatives to changes in costs/benefits of units, as well as parametric analysis. An energy optimization model's objective function is to reduce costs, subject to certain energy demand constraints, or to optimise the welfare function, subject to limited resources, including financial, environmental, and geological factors. It is possible to identify more than one objective function, in which case one may look for "efficient" or Pareto-optimal solutions. Two objective functions pose virtually no issues, and if the model is not too broad, three objective functions can be treated, but four or more are impractical, if not impossible[9]. Thus, a dynamic linear programming model developed by Kavrakoglu, 1987 for the national planning of energy systems is deeply considered in optimizing the tariff offers to NEM 2.0 prosumer in this study.

3. Data and Methodology

This study uses secondary data. The data mainly gathered from SEDA and TNB Retail by signing a Non-Disclosure Agreement (NDA) on the raw data provided. Therefore, we only shared the results to explain the objective of the study since all the raw data provided to us is highly confidential. Next, all the data was sorted, screened, and matched. For missing data are then omitted, for instance, from a commercial category based on voltage and agriculture category. Therefore, the total usable observation data under NEM 2.0 are 3071 consisting of 4 main customer categories, i.e., domestic, industrial, commercial, and agriculture, from January 2019 until October 2020. However, there is only 2000 customer under observation data provided by TNB Retail, which refers to those who have energy export or import or excess energy with the full capacity amount and account user for the study period.

Regarding the study's methodology, linear programming (LP, also called linear optimization) is used to achieve the best outcome (such as maximum profit or minimum cost) in a mathematical model whose requirements are represented by linear relationships. Since the model framework is to find the best tariff currently offered to the prosumer, the objective function is to minimize service costs; the deterministic and non-deterministic constraints should be considered (see figure 2). Due to disperse observations, twenty-one (21) bins are assigned for all categories, domestic, commercial, and industry. The highest customers are located at 900 kWh bin with 362 number of customers. However, the least number of customers located at 300,000 kWh bin with 10 customers only. All the bins aggregation is presented in the histogram, as shown in figure 1.

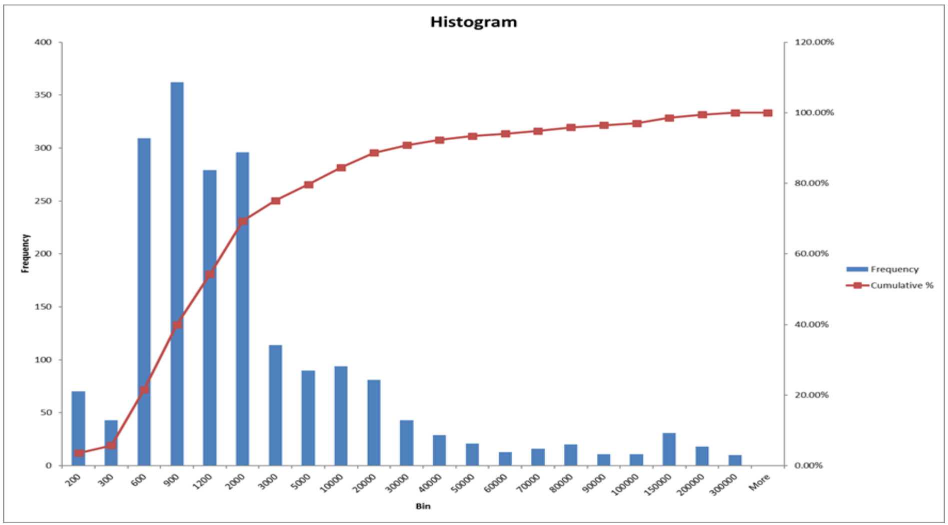

Figure 1: Bin Development for All Pooled Customer

Particularly, prosumers of tariff categories are modeled at the aggregate level, and deterministic variables are set up (see fig. 2). Data on the installation costs summarized using linear regression by each tariff category. With respect to the data on cumulative installed capacity sorted by period and summarized using linear regression by each tariff category. The import and export energy data to the grid were aggregated using histograms by each tariff category, whereby 9 bins per tariff major category developed. Based on aggregated data, then this study generates random future customer records based on tariff category distribution based on TNB tariff structure 2014, which is the latest version according to time horizon, the number of records can be defined upfront, data sorted by time period, cumulative installed capacity calculated as well as installation capacity and cost estimated. For each record set, decide whether the customer will sign up or not based on the attractiveness of tariff and installation costs. Then, the scenarios analysis developed, which embedded the following elements;

(1) Methods to calculate the export in Malaysian Ringgit (MYR) include the impact to prosumers' take up rate, (2) System Marginal Price (SMP) sold through NEDA,

(3) Quota determination for next 5 years,

(4) incentive based regulation (IBR) tariff revision every 3 years, tariff may go up, PV cost goes down, hence take up and,

(5) Lower installation cost in the future.

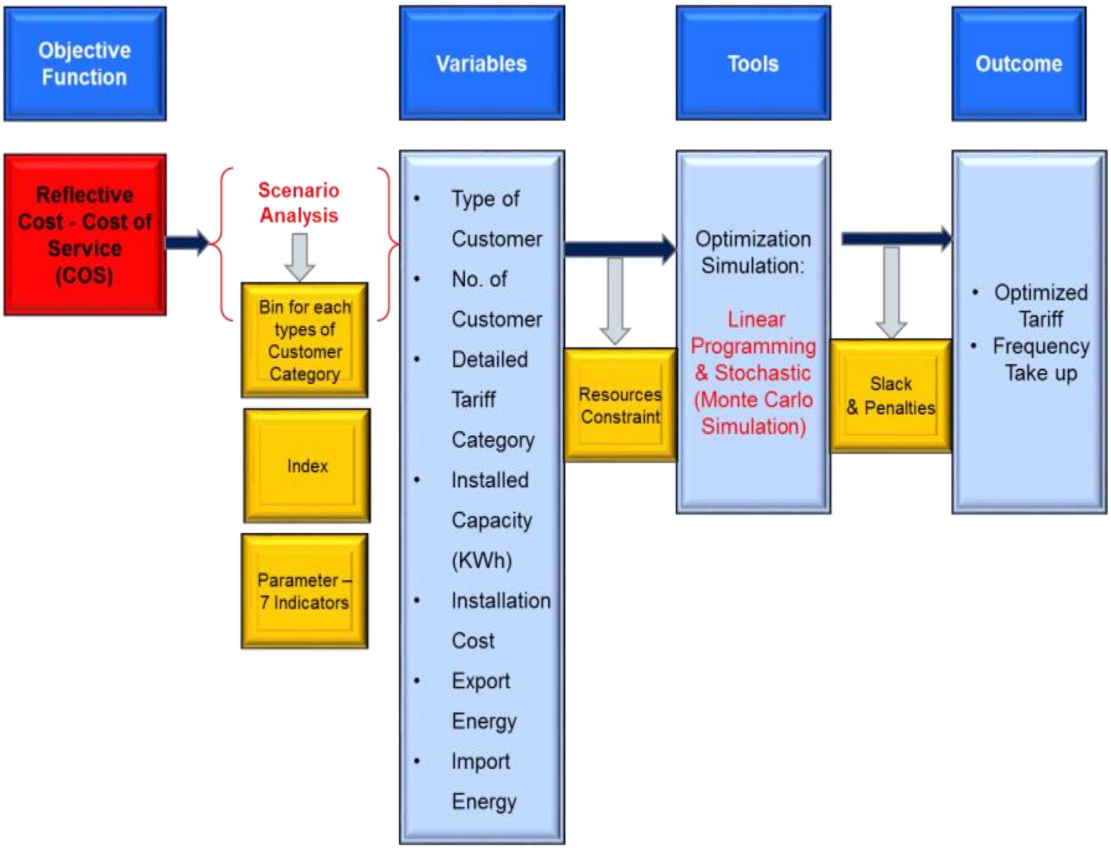

Figure 2: The Optimized Prosumer Tariff Setting Framework

4. Results and Discussion

4.1 Descriptive Statistics

According to fig. 3 & 4 of installation cost per kW and cumulative installed capacity KWh from January 2019 until October 2020 for all categories, it shows lower R^2 at 1.42% but it is a fit time series model. Thus, it indicates that this model would predicts well in future values. Along the chart, there is a bunch of application come before the incentive of implementing NEM has been lifted at the end of 2020.

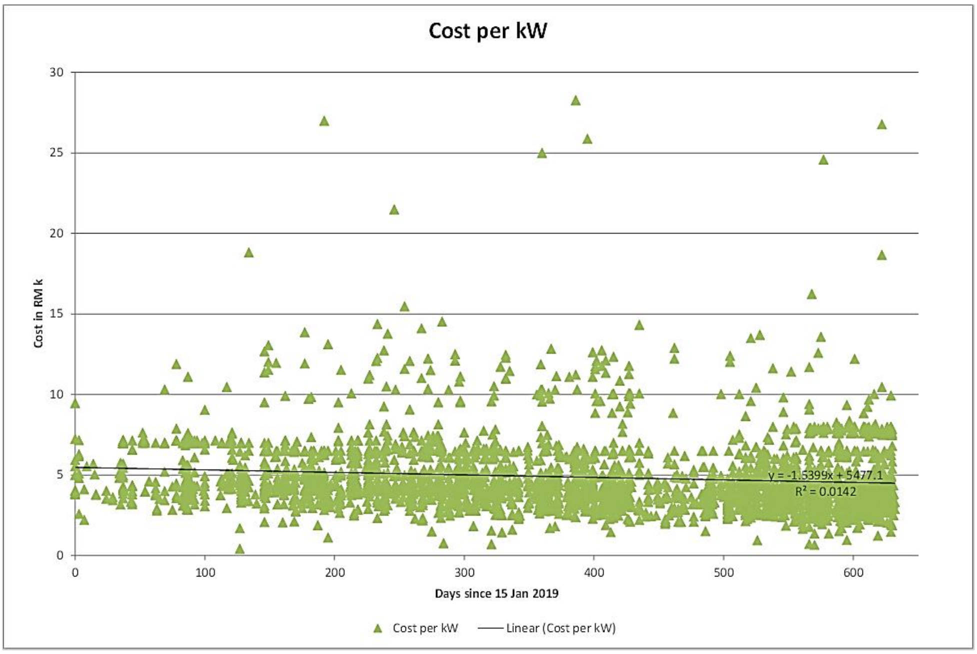

Figure 3: The Total Installation Cost based on Category

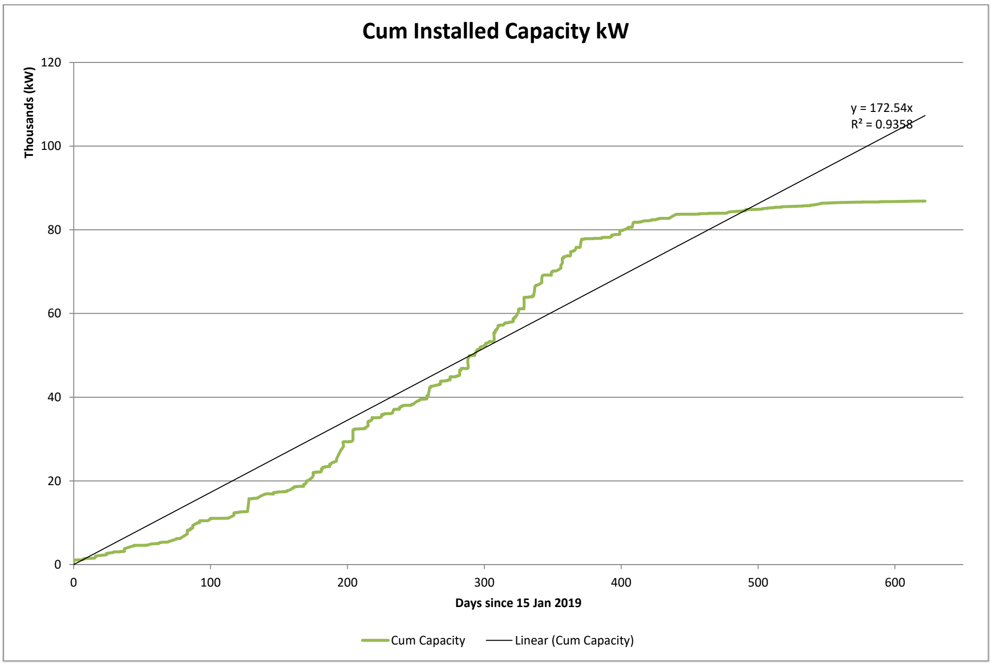

Figure 4: The Total Installed Capacity (KWh) based on Category

Table 1. Summary of Linear Equation Model Installation Cost per kW

Category	Linear Equation Model	R^2
Pooled	$Y = -1.5399x + 5477.1$	1.42%
Domestic	$Y = -1.0014x + 5921.9$	0.59%
Commercial	$Y = -2.4503x + 5007.3$	5.77%

Industry	$Y = 1.3226x + 3939.9$	3.19%
Agriculture	$Y = -1.7136x + 4257.3$	3.96%

From the Table 1, shows commercial category lead the R^2 at 5.77%. It indicates the installation cost per kW is high for commercial industry. Moreover, the installed capacity from January 2019 to October 2020 would be portrait in the table 1.

Table 2. Summary of Linear Equation Model in Installed Capacity kW

Category	Linear Equation Model	R^2
Pooled	$Y = 172.54x$	93.58%
Domestic	$Y = 15.165x$	95.87%
Commercial	$Y = 43.768x$	95.27%
Industry	$Y = 118.38x$	90.55%
Agriculture		-

As we can see, the capacity installed has increased from time to time until October 2020. In summary, the linear equation model in installed capacity kW in Table 2 for every category with a high value of R2, respectively. This implies that installation costs variations are explained for more than 90 percent confidence level towards installed capacity among solar PV prosumer in Malaysia. It also shows the time series model is for every category to predict well the future values. However, there is no input for the agriculture category due to a lack of information.

Table 3. Result of LP on Frequency of Prosumer, Import and Export in Detailed Category

Detailed Category	**Freq**	**Avg Imp kWh**	**Std Imp kWh**	**Avg Exp kWh**	**Std Exp kWh**	**E/I Ratio**
Domestic_200	62	81.22	66.20	63.10	60.34	77.69%
Domestic_300	37	253.78	30.23	199.24	67.32	78.51%
Domestic_600	275	469.69	81.93	309.98	121.36	66.00%
Domestic_900	328	751.75	86.66	407.30	201.33	54.18%
Domestic_1200	242	1,027.54	84.34	481.44	268.56	46.85%
Domestic_2000	244	1,490.79	231.17	590.59	389.96	39.62%
Domestic_3000	82	2,378.62	267.89	727.22	572.16	30.57%
Domestic_5000	36	3,711.6595	473.90	651.46	832.73	17.55%

Domestic_high	11	6,239.06	1,048.81	723.73	764.72	11.60%
Commer_B_LV_200	8	127.07	56.27	120.82	56.70	95.08%
Commer_B_LV_1000	87	653.59	217.11	454.83	274.57	69.59%
Commer_B_LV_3000	100	1,725.26	519.97	972.84	697.13	56.39%
Commer_B_LV_5000	49	3,901.76	545.32	1,957.33	1,491.67	50.17%
Commer_B_LV_10000	63	7,060.59	1,500.54	2,344.29	2,198.45	33.20%
Commer_B_LV_50000	101	21,331.20	9,992.13	2,778.12	5,227.06	13.02%
Comme_B_LV_100000	20	74,030.12	12,582.09	3,275.77	3,833.88	4.42%
Comme_B_LV_200000	7	126,817.67	28,140.60	214.95	374.61	0.17%
Commer_B_LV_high	1	298,716.67	-	103.33		0.03%
Industry_D_LV_200						
Industry_D_LV_2000	6	1,117.67	666.04	856.89	603.29	76.67%
Industry_D_LV_5000	6	3,612.56	895.45	2,130.44	1,340.51	58.97%
Industry_D_LV_10000	20	7,609.00	1,068.43	2,418.38	2,517.73	31.78%
Industry_D_LV_25000	29	17,016.49	4,286.71	4,674.37	5,237.55	27.47%
Industry_D_LV_50000	41	35,346.41	7,944.09	11,441.25	13,561.80	32.37%
Industry_D_LV_100000	50	73,160.84	14,262.30	12,958.95	22,368.00	17.71%
Industry_D_LV_200000	40	143,977.43	28,021.62	11,752.69	17,167.50	8.16%
Industry_D_LV_high	9	227,946.74	24,759.78	17,901.78	28,318.26	7.85%

From the results presented in Table 3, there are 1945 of prosumers data. The highest number of prosumers is 328, capped at 900 kWh/kW in the domestic category, with a 407.30 kWh average exported to the grid. Thus, it gives 54.18% of the export-to-import ratio of energy. However, the prosumer at 300 kWh/kW domestics' category enjoyed the highest ratio of the export-to-import grid at 78.51%, with 199.54 kWh/kW average exported energy grid. The commercial low voltage category successfully generated energy back into the grid by 95.08%, with only 8 prosumers recorded. It is the highest ratio of the export-to-import grid for all categories. The highest number of frequencies is cap at 50,000 kWh/kW with 101 prosumers but only 13.01% of export-to-import ratio. The highest export-to-import ratio is 76.67% that capped for low voltage 2000 kWh/kW with 6 prosumers for the industrial category. However, the highest prosumer is low voltage 100,000 kWh/kW category with 50 frequencies. The highest average export to the grid is 17,901.78 kWh/kW, and the highest energy usage is 227,946.74 kWh/kW.

Table 4 : An Analysis on Linear Programming

Parameter	Value
Rate of new prosumers take-up	30%
Days after 15 Jan 2019	800 days

The researcher considers this parameter in this LP Model. There are 30% of new prosumers will taking-up in this new-cycle program NEM. New frequency of customer, new export rate (kWh), new import and export (kWh and MYR) has been created in the Table 5. From the Table 5, we can conclude that 2572 customer from domestic and 637 from others category. The details of the table shown below:

Table 5: New customer take up for next cycle of NEM

Detailed Category	Tariff	kWh	Min Charge	Sales	N Freq	N Import	N Import RM	N Export	N Export RM
Domestic_200	0.218	81.22	3	5,203.18	395		6,994.10	63.10	5,433.54
Domestic_300	0.334	253.78	3	439.93	11	53.78	677.19	199.24	546.40
Domestic_600	0.516	469.69	3	9,574.51	83	169.69	13,658.50	309.98	10,768.74
Domestic_900	0.546	751.75	3	32,780.01	98	151.75	30,836.28	407.30	21,042.25
Domestic_1200	0.571	1,027.54	3	49,364.97	73	127.54	34,195.07	481.44	19,303.98
Domestic_2000	0.571	1,490.79	3	96,554.76	73	590.79	53,504.80	590.59	24,617.51
Domestic_3000	0.571	2,378.62	3	67,620.94	25	1,478.62	30,997.27	727.22	10,381.13
Domestic_5000	0.571	3,711.65	3	58,646.46	11	2,811.65	22,011.59	651.46	4,091.84
Domestic_high	0.5	6,239.0	3	33,340.51	3	5,339.0	10,332.	723.73	1,239.7

	71	6				6	61		4
Com_B_LV_200	0.435	127.07	7.2	21.75	2		110.55	120.82	105.12
Com_B_LV_1000	0.509	653.59	7.2	7,522.02	26	453.59	8,264.77	454.83	6,016.81
Com_B_LV_3000	0.509	1,725.26	7.2	36,817.84	30	1,525.26	25,900.64	972.84	14,855.29
Com_B_LV_5000	0.509	3,901.76	7.2	47,770.67	15	3,701.76	29,567.90	1,957.33	14,944.23
Com_B_LV_10000	0.509	7,060.59	7.2	150,305.07	19	6,860.59	68,001.77	2,344.29	22,671.66
Com_B_LV_50000	0.509	21,331.20	7.2	952,300.96	30	21,131.20	325,283.49	2,778.12	42,421.82
Com_B_LV_100000	0.509	74,030.12	7.2	719,983.28	6	73,830.12	225,999.18	3,275.77	10,004.19
Com_B_LV_200000	0.509	126,817.67	7.2	450,981.87	2	126,617.67	129,070.78	214.95	218.82
Com_B_LV_high	0.509	298,716.67	7.2	151,979.39	0	-	-	-	-
Ind_D_LV_200	0.38		7.2	-	0		-	-	-
Ind_D_LV_2000	0.441	1,117.67	7.2	616.82	2	917.67	961.38	856.89	755.78
Ind_D_LV_5000	0.441	3,612.56	7.2	3,848.47	2	3,412.56	3,161.87	2,130.44	1,879.05
Ind_D_LV_10000	0.441	7,609.00	7.2	45,537.24	6	7,409.00	20,060.21	2,418.38	6,399.04
Ind_D_LV_25000	0.441	17,016.49	7.2	157,489.62	9	16,816.49	67,428.67	4,674.37	18,552.58
Ind_D_LV_50000	0.441	35,346.41	7.2	431,728.97	12	35,146.41	186,906.78	11,441.25	60,547.08
Ind_D_LV_100000	0.441	73,160.84	7.2	1,326,841.67	15	72,960.84	483,775.98	12,958.95	85,723.47
Ind_D_LV_200	0.4	143,977	7.2	2,331,956	12	143,777	761,782	11,752.	62,195.

000	41	.43		.48		.43	.17	69	22
Ind_D_LV_hig h	0.4 41	227,946 .74	7.2	833,558.6 6	3	227,746 .74	301,536 .94	17,901. 78	23,684. 05

Table 5. Comparison of LP Model and Quota Allocation

Category	New Prosumers	Sum kWh	Quota Allocation
Domestic	2572	419,839.80	50,000,000
Commercial Industry Agriculture	637	5,740,836.59	450,000,000
Total kWh (new Prosumers)	3209	6,160,676.39	500,000,000

Total allocation provided by the Malaysian Energy Commission is 500 megawatts for all prosumer categories. However, there are about 0.4198 megawatts have been used in the domestic category with 2572 new prosumers and about 5.74 megawatts optimized by the other category, as shown in Table 5. The new prosumers for the other category are 637 only. It means there are 6.16 megawatts occupied, and 493.84 megawatts are export to the grid. Thus, the objective function for this model is MYR679,191.16.

Table 6. Comparison of LP Model and Quota Allocation

Aggregate Category	Avg IC (per kW)	IC2021	IC2022	IC2023	IC2024	IC2025
Domestic - Tariff A	5500	5390	5280	5170	5060	4950
Commercial - Tariff B	5200	5096	4992	4888	4784	4680
Commercial - Tariff C1	5000	4900	4800	4700	4600	4500
Commercial - Tariff C2	4800	4704	4608	4512	4416	4320
Industrial - Tariff D	4200	4116	4032	3948	3864	3780
Industrial - Tariff E1	3800	3724	3648	3572	3496	3420
Industrial - Tariff E2	3400	3332	3264	3196	3128	3060
Industrial - Tariff E3	3200	3136	3072	3008	2944	2880
Agriculture - Tariff H	4800	4704	4608	4512	4416	4320
Agriculture - Tariff H1	4500	4410	4320	4230	4140	4050
Agriculture - Tariff H2	4200	4116	4032	3948	3864	3780

Based on forecast scenario simulations, this study predicts the future installation cost as displays in Table 6. Overall, the installation cost shows decreasing rate trend from the year 2021 until the year

2025. It means the installation cost would be cheaper year to year while the installation capacity demand would be increasing. Thus, this decreasing installation cost trend would become an opportunity for potential prosumer to invest in their money in solar PV not only for self-consumption but also to generate revenue in green investment that our government fully supports.

Conclusion

Overall, the results postulated that the tariff structure currently offered is attractive enough looking by the take-up rate is increasing where most of the excess energy is charging at high life bands of tariffs. Due to decreasing the cost of installation for all prosumer category, it might be because of competition rivals, new technology innovation, inflation rate, market demand, and government incentives towards solar PV. On the one hand, the regulators can consider increasing the quota capacity at grid maximum demand. Besides, the existing incentives offered to commercial and industrial customers may also prolong and offer domestic customers too to make it solar PV business in the near future instead of for self-consumption. On the other hand, by considering the impact of grid capacity, the policymakers can probably impose install capacity charges to all prosumer categories at different rates.

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Ethical Declaration

The data are provided by SEDA by signing Non-Disclosure Agreement (NDA). Noted that, all the data are screening and not published in original version.

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