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System Dynamic Approach for Long-Term Solar Thermal Installed Capacity for Malaysian Industries

Anis Sabirin Baharom*, Nofri Yenita Dahlan
Universiti Teknologi MARA (UiTM), Electrical Engineering Faculty, Shah Alam, Selangor Darul Ehsan, 40450, Malaysia
*Corresponding author, e-mail: anis@unisel.edu.my

Abstract

This paper presents a novel System Dynamics model for solar thermal installed capacity for Malaysian Industries. The objective of this paper is to foresee the influences of technical acceptance and willingness of the Malaysian industries to install the solar thermal system to replace the current system for heating process. Results revealed the Malaysian industries interest level on solar thermal is low. Therefore to increase the interest, Malaysian industries need more booster supports from the government to increase the investment in new technology, which will advantage the company and Malaysia in long-term. Not only industries, the policy makers will also benefit from the outcome, to tailor the framework for solar thermal in developing the solar thermal policy for industries in Malaysia.

Keywords: *solar thermal, system dynamics, solar thermal installation, renewable energy industries*

1. Introduction

In 2014, total final energy demand in Malaysia was 52,209 kilotonne of oil equivalent (ktoe) (1). From the total energy demand in 2014, 25.21% was consumed by industrial sector which is equivalent to 13,162 ktoe. In Malaysia's industrial sector alone, 38.54% of this energy demand was used for electricity, meanwhile, the balance i.e. 61.46% was used for heating purposes.

In Malaysia, there are a large number of industrial sectors that use heating for their industrial process such as 1) electrical and electronic industry, 2) chemical and petroleum industry, 3) wood industry, 4) textile industry 5) food, beverages and tobacco industry and etc. (2). The heating processes include bleaching, dyeing, washing, fixing, pressing, pre-heating water, and distillation (3). In January 2017, it was reported that Malaysia's industrial production index increased 3.5% compared to the same month in 2016. This figure was contributed by 4.6% manufacturing, 1.1% mining and 1.1% electric (4). The production trend in industries has foreseen an increase in the future. This indicates that more energy will be required for the heating process in industries.

Malaysia is located near the equator and has hot and humid climate conditions. In average, Malaysia receives 4,000 Wh/m2 to 5,000 Wh/m2 of daily solar radiation with the duration of sunshine in the range of 4 to 8 hours in a day.

Looking at these figures, a significant energy from the fuel can be reduced if some portions of the heating use in industries are replaced by Renewable Energy (RE). Malaysia has an enormous potential in using solar thermal technology as RE source for the heating process in industries. This paper studies the potential of solar thermal in Malaysia's industries using System Dynamic model and factors influence solely on technology acceptance by the Malaysian Industries towards the solar thermal implementation. The result has shown that the Malaysia government need to take an initiative to increase the willingness of the Malaysian industries to invest in the solar thermal technology and controlled the local market price for the system.

The temperature of heat demand can be categorized into three; low, medium and high. These demands in industries are generally used for the process with low temperature (30%), medium (27%) and high (43%). In Malaysia, most of the industrial energy demand is contributed by chemical, followed by food, beverages and tobacco industries (5), which mainly operates at medium and low-temperature process heat. For example, the chemical industry uses low heat for boiling (95^oC – 105^oC) and medium heat for distilling process (110^oC - 300^oC). These

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indicate low and medium temperature solar process heats are suitable for industrials sector in Malaysia. Most solar thermal application in Malaysia today is for domestic hot water systems. Although the domestic sector offers an enormous potential demand for the solar thermal application, the industrials sector should not be left out due to its potential as discussed above.

2. Research Method

There are many methods available in renewable energy studies for example the author (6) used agent application for monitoring the involvement of behaviour changes. In opposite, the author (7) use different technique which manipulate policy scenario to simulate the action plan for energy efficiency. Most of the renewable energy studies used MATLAB/SIMULINK software in the research.The author (8) has used Matlab/Simulink for his photovoltaic proposed design (8). Meanwhile (9) also used Matlab/Simulink for simulating the proposed grid connected photovoltaic system. This research involved complex problems therefore System Dynamics simulation technique been used.

2.1. System Dynamics

System Dynamics is a tool that can be used to identify the solution for structural and policy-oriented problems (10). It uses a feedback concept to structure the complex system by circular causality and looping the information feedback. In complex problems, each component may influence another component, therefore, the system dynamics have the ability to monitor over time the behavior of the system and able to identify the intervention from making things (problems) worse (11).

It also accentuates the continuous view to see the dynamic pattern underlying them. Most of the authors have used the five basic System Dynamic modeling processes which consist of conceptualization, formulation, testing, and implementation. Meanwhile, others have extended it by detailing each process. For example, the author of (12) suggests the conceptualization process be problem articulation and dynamic hypothesis. Application of System Dynamic for various policy studies includes in (13) which uses System Dynamic to analyze potential sustainable management policies for a shallow freshwater lake ecosystem. Meanwhile, the authors of (14) use System Dynamic to study the impact of subsidy policies on recycling and remanufacturing industries in China.

In the field of energy research, System Dynamic has been used for many years for forecasting, strategic planning, assessing policy options, negotiating, shaping, defending and swaying policy (15). The authors in (16) use System Dynamic to analyze the impact of carbon tax on installed capacity of photovoltaic and electricity cost. In Malaysia, the authors in (17) use System Dynamic to study the impact of feed-in tariff on solar photovoltaic investment. A study in (16) focuses on investigating the role of RE policies on Finland energy security. Meanwhile, the authors of (18) use System Dynamic to study a long-term biodiesel behavior in planning effective strategies for the Latvia Transport policy. A similar study focusing on biodiesel policy was also carried out by (19) for Columbian biodiesel market. Sensitivity analyses were performed to validate the model.

None of the literature above presents a study on solar thermal heating for industries using System Dynamic model. Therefore, this paper presents a solar thermal installed capacity model in Malaysia using System Dynamic considering four factors: 1) area of installation, 2) system market price, 3) technical acceptance and 4) industry willingness. The solar thermal-System Dynamic model is developed using Vensim PLE Plus.

2.2. System Dynamics Methodology

In the beginning of the studies (Figure 1), the objective, to find the solar thermal installed capacity was identified. Then, boundaries of studies were set to 2 main factors, industries willingness and technology acceptance. Causal loop diagram (CLD) and stock and low model was developed. The purpose of having CLD is to map the relationship between each component and to develop interactions. Through CLD, the system structure and behavior are much easier to visualize. The solar thermal CLD consists of several sub-models. Those sub-models are an area, market price, market sales, technical acceptance and industrial willingness to install the system. Meanwhile the stock and flow diagram is a model that will be used in System Dynamics.

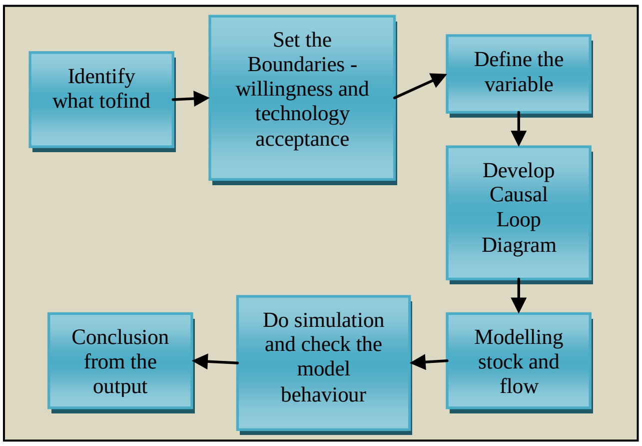

Figure 1. Methodology for Solar Thermal Installed Capacity

To make life easy, the cause tree can be used. The Causes tree is a simple way to read the system dynamic model in a small group. The tree represents the cause and effect. The cause of the problem is located at the tail of the arrow and the head of the arrow is the variable that will be affected over time. Figure 2 shows the overall causes tree that represents the elements contribute to the causes and influence the behavior of the solar thermal installed capacity (STIC) in industries in Malaysia. The study considers five components in developing the STIC model which are the sub-models in CLD as described above.

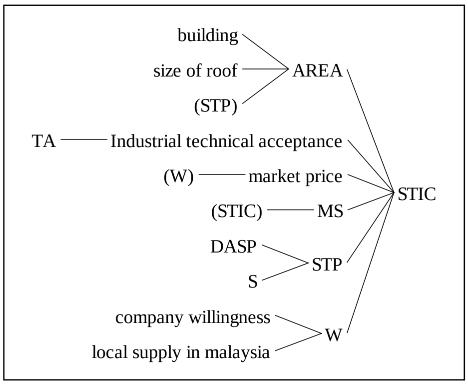

Figure 2. Causes tree diagram for solar thermal installed capacity in industries

The dynamic equation used for the STIC is considered as level type and based on few conditions such as technical acceptance of the companies, market sale together with the area and solar thermal potential available, the market price of the system and finally the willingness of the company to install the system. The unit for STIC is kW/m2 .

$$\mathrm{STIC(t)} = \int \mathrm{STIC(t-1)} + e\left(\frac{(\text{Industrial technical acceptance(t)} + \mathrm{W(t)})}{\mathrm{AREAt} + (\mathrm{STPt}) * \left(\frac{\mathrm{MS(t)}}{(\text{market} * \text{pricet})}\right)}\right) \quad (1)$$

Figure 3 shows the causes tree for the area in the STIC model. The area sub-model is influenced by three factors: 1) number of the building where the roof top is suitable for the solar thermal installation, 2) the size of the roof top and 3) solar thermal potential (STP).

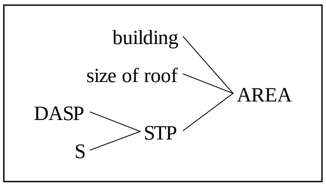

Figure 3. Causes tree diagram for area sub-model

The STP is influenced by the daily average of solar radiation potential (DASP) and the duration of thesunshine receives (S). The area (the gross collector area) was set by referring the default value which set by IEA SHC (20), 0.7kWth/ m2

$$\text{Area} = \frac{(size\ of\ roof * building * STP)}{700} \quad (2)$$

Figure 4 shows the market price sub-model. The market price is influenced by 1) local supply in Malaysia, 2) market sales trending and 3) the industry willingness to install the solar thermal system.

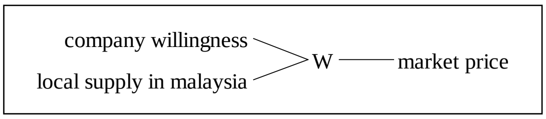

Figure 4. Causes tree diagram for market price sub-model

The market sales sub-model is the most complex sub-model because it is influenced by other 4 sub-models i.e. 1) area, 2) STP, 3) technical acceptance (TA) and 4) the industry willingness. The Causes tree diagram for market sales sub-model is shown in Figure 5.

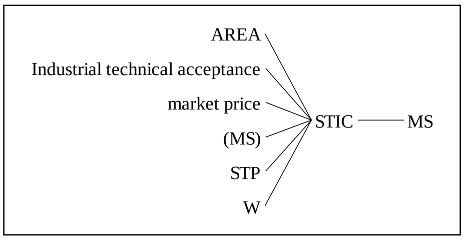

Figure 5. Causes tree diagram for market sales sub-model

The technical acceptance (TA) sub-model is developed considering the 1) company needs according to industrial types, 2) other technical and cost influence, 3) exposure, 4) availability of solar thermal local supply and 5) awareness on technology supply in Malaysia. Local supply and technology supply availability are considered because both will give impact on the cost of investment. Besides local supply, the necessity of heaving the system to reduce the operation cost of the industries also has an impact on the investment decision. The knowledge on the solar thermal system, the exposure of the system, the application of the system in the industries and the overall cost of the system also play role in decision to install the system. These factors are crucial in modeling industrial acceptance for investing in solar thermal. The TA sub-model causes tree diagram is shown in Figure 6.

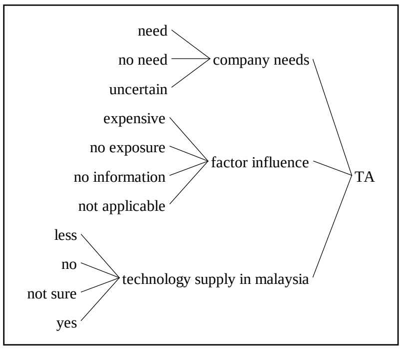

Figure 6. The causes tree diagram for technical acceptance sub-model

Finally, the willingness sub-model causes tree diagram is shown in Figure 7. The willingness sub-model is influenced by 1) the industry types and 2) local solar thermal technology supply in Malaysia.

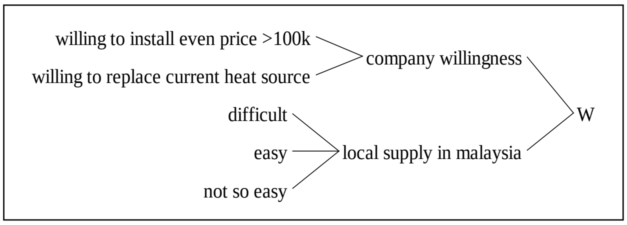

Figure 7. The causes tree diagram for industries willingness

Figure 8 shows the CLD of the solar thermal installed capacity model that combined all the five sub-models explained earlier. As a preliminary study, the model does not include incentives or subsidies as influence factors for the implementation of solar thermal in industry.

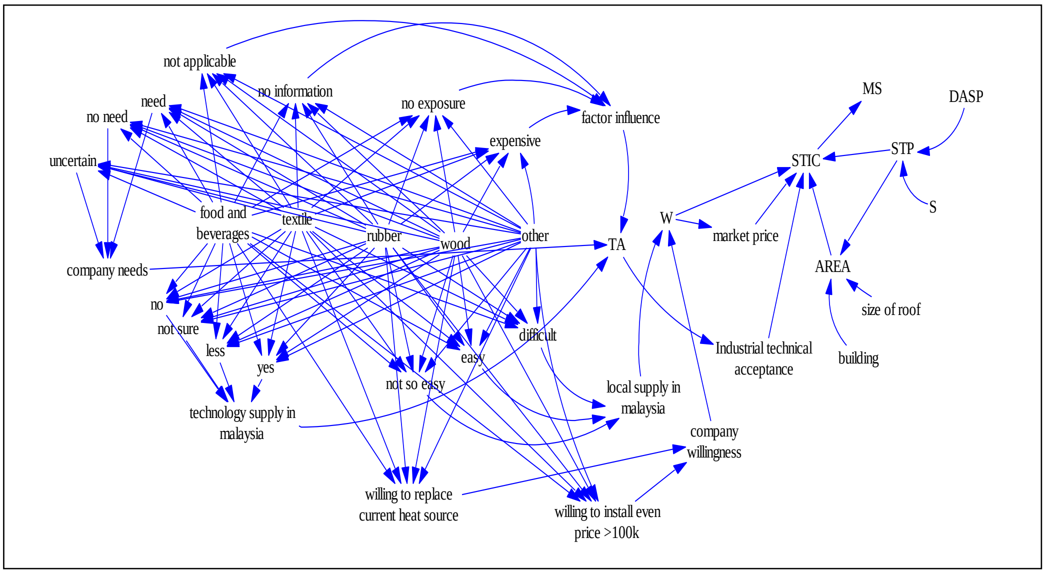

Figure 8. Causal Loop Diagram for Solar Thermal Installation Capacity

2.3. Test Data

The data used for the simulation was taken from a survey conducted by Scientific and Industrial Research Institute of Malaysia SIRIM in 2013. The industry sectors involved in the survey was categorized into five: 1) Food and beverages, 2) Textile, 3) Wood, 4) Rubber and 5) Others. Seventy industries were selected to participate in the survey and only fifty companies were responded.

The solar energy data was obtained from the Malaysian Meteorological Department Malaysia's (MET). Malaysia daily average solar energy is in the range of 4,000-5,000 Wh/m^2. In this model, the average of sunshine used was 4-5 hours. Rainy season is considered as a minor disruption since it is only happening towards the end of the year, therefore did not consider in the model.

For technical data, the solar thermal collector is assumed produces 0.7 kW/m^2 of energy per meter square. It is also assumed that the building roof top surface that available for solar thermal installation is 7 MW per 10,000 m^2.

The average size of the roof top is 2,000m^2. The number of the building available is 40,500. The amount of a number of the building was based on 90% of the building that can be considered for solar thermal installation. This is because 10% of the buildings do not have roofing capability for construction to carry addition weight of the solar thermal system installation. The data from the survey carried out by SIRIM is shown in table 1-4.

The availability scenario of local supplies in Malaysia (Table 1) was divided into 3 categories i.e. 1) difficult to get the local supply, 2) easy to get the local supply and 3) not so easy to get the local supply. The table below shows the percentage of response collected for local supply in Malaysia.

Table 1. Solar Thermal System Provided By Local Supplies In Malaysia
Source: Sirim (2013)

Type of Industries	Solar Thermal System Provided By Local Supplies		
	Easy (%)	Not so easy (%)	Difficult (%)
Food and beverages	17	17	57
textile	25	0	50
Wood	0	100	0
Rubber	100	0	0
Others	44	33	33

Table 2. Company Need
Source Sirim (2013)

Type of Industries	Company Needs		
	Yes (%)	Not sure (%)	No (%)
Food and beverages	57	0	30
Textile	50	25	25
Wood	100	0	0
Rubber	100	0	0
Others	33	11	50

Table 3. Factor Influence
Source Sirim (2013)

Type of Industries	Factor Influence			
	No exposure (%)	No information (%)	Expensive (%)	Not applicable
Food & beverages	61	4	22	4
Textile	25	0	25	0
Wood	0	0	100	0
Rubber	0	0	0	100
Others	28	21	33	22

Table 4. Technology Supply In Malaysia Source Sirim (2013)

Type of Industries	Technology Supply in Malaysia			
	No supply (%)	Less Supply (%)	Not Sure (%)	Yes (%)
Food and beverages	13	22	48	9
Textile	0	25	50	0
Wood	0	100	0	0
Rubber	0	100	0	0
Others	17	44	28	6

Few assumptions were made in order to predict the output. The conditions for technical acceptance were made as equation below

1. (Company needs>= 75) then decision = (Company needs)
2. (74>=(company needs + factor influence)>= 50) then decision= (Company needs *factor influence)
3. (74>=(Company needs + technology supply in Malaysia)<=50) then decision= (Company needs *technology supply in Malaysia)
4. (Company needs +factor influence+ technology supply in Malaysia+ local supply in Malaysia<=50) then decision= (Company needs * factor influence * technology supply in Malaysia)

Meanwhile, the assumptions made for company willingness as shown by equation

1. If company willingness <=10 then decision = no installation (0 kwth)
2. If 10 < company willingness <=30 then decision = install 1 0 kwth
3. If 30 < company willingness <=40 then decision = install 30kWth
4. If 40 < company willingness <=50 then decision = install 50kWth
5. If 50 < company willingness <=70 then decision = install 100kWth
6. If 70 < company willingness <=90 then decision = install 300kWth
7. If 90 < company willingness <=100 then decision = install 500kWth

To project the STIC, the assumptions for the market price was made based on the data collected by International Renewable Energy Agency (IRENA) for investment cost per kW made by the countries worldwide for the solar thermal Industrial process.(21). The countries chosen as reference were China, India, and Vietnam. This is because these countries have more similarity in term of its geography and social life. The price used is for the Evacuated Tube Collector (ETC) collector type. The price in Euro/ kW and it has been converted to Malaysian currency based on the 1st April 2017 currency exchange which 1 EUR is equal to RM 4.72652.

3. Result and Analysis

3.1. Results

Overall (

Figure 9 &

Figure 10) the STIC pattern is slow in progress. It is mainly controlled by the market price and the industries willingness to install the solar thermal system. The STIC reacted when there are changes in the market price (fall).

On the other hand, the industries willingness (to replace or to install for the price more than 100k) is low. It is below than 35%. This explains why the progress of installation is slow and does not give an impact from the changes of market price over the time as shown in Figure 11.

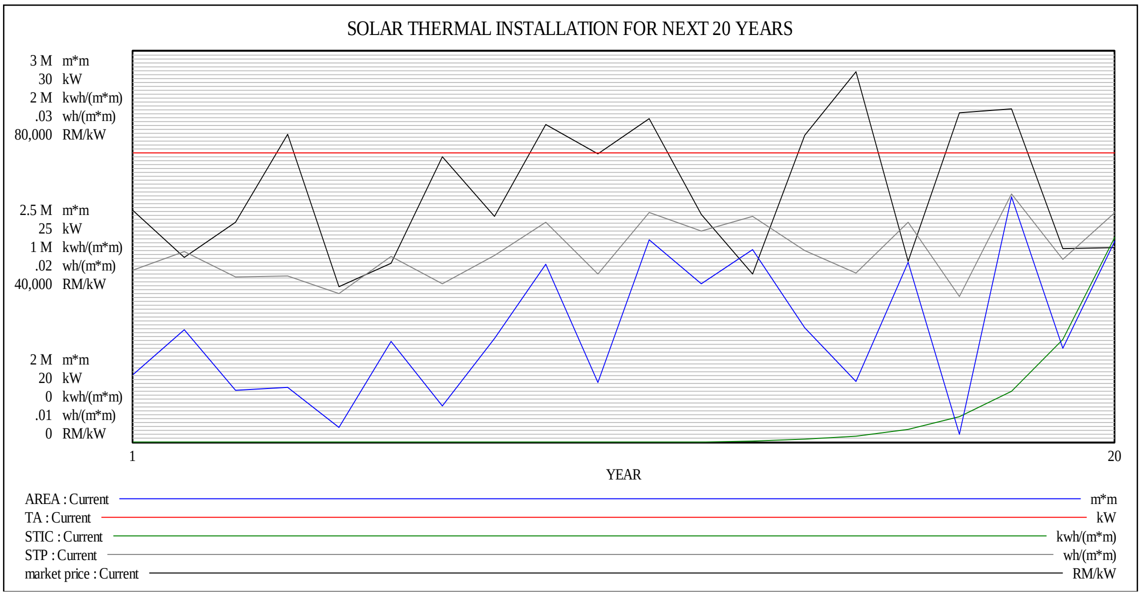

Figure 9. The Output of the Solar Thermal Installed Capacity for 20 Year

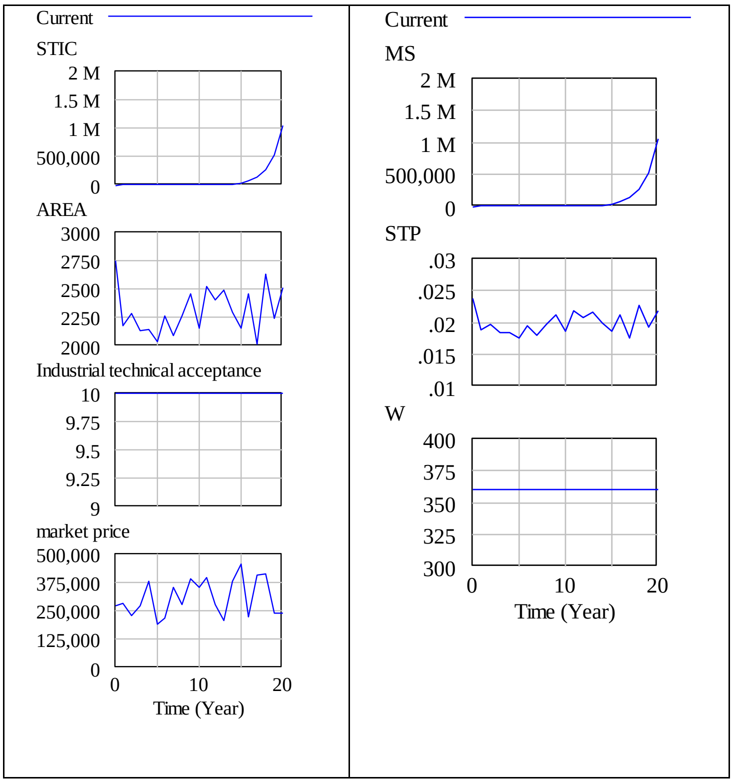

Figure 10. The Solar Thermal Installation and the Causes Component Output

Figure 11. The Industries Willingness to install the Solar Thermal

Figure 12. Relationship Between Solar Thermal Installed Capacity and Market Price

The market sales show the same pattern as STIC Figure 12 shows that the STIC does not sensitive to market sales pattern. The market sales pattern has almost a similar pattern as STIC which influenced by the market price and the industries willingness.

Table 5. Investment Cost Per Kw For Industrial Process Heat
Source Irena (2015)

Countries	Installed Capacity kW	Price EUR/kW	RM/kW
China	4025	248	1172.177
	441	272	1285.613
India	97-369	203	959.4836
Viet Nam	700	286	1351.785
	494	91	430.1133

Table 6. Solar Thermal Installation Projection for 20 Years

Time (Year)	STIC (kW/m2)	Time (Year)	STIC (kW/m2)
0	0	10	1023.05
1	1	11	2047.109
2	3.00001	12	4095.236
3	7.00007	13	8191.523
4	15.00022	14	16384.19
5	31.00057	15	32769.54
6	63.00167	16	65540.34
7	127.0043	17	131083.4
8	255.0098	18	262169.7
9	511.0227	19	524348.6
		20	1050192

3.2. Discussion

Solar Thermal is a new potential of renewable energy resources in industries in Malaysia. The government has taken initiatives introducing the application to the Malaysia industries. From the results obtained, obviously, shows the Solar Thermal Installed Capacity is not only depending on the market price but also depending on the decision made by the industries.

The model developed able to predict the macro (national) pattern of market sales and market price via industries installation capacity. Through the model, the policy maker would able to identify the most influenced factor or variable to be focused on in order to increase application of solar thermal in Malaysia.

4. Conclusion

For Malaysia, the government needs to tailor a program that will increase the level of confident for process industries to invest in solar thermal technologies since this technology has so much of benefits especially to ecology system. This technology will help to reduce CO^2. Therefore, the policy maker needs to develop a suitable policy and offers suitable incentives that would increase the willingness of industry in investing in the solar thermal application. For the next phase of studies, the model will be improved by considering more factors from the different point, for example, economic, managerial, ecological and technical where more variables such as collector prices, collector types and project cost will be included.

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