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Optimizing Solar Thermal Energy Systems for Integration in Industrial Processes: A Case Study of Mewaholeo Industries Sdn Bhd Oil Palm Refinery in Malaysia

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Abstrak

Bahan bakar fosil berkontribusi pada pemanasan global dan perubahan iklim. Energi surya, sumber energi terbarukan dan aman, merupakan alternatif yang menjanjikan. Energi termal surya (STE) dapat digunakan di berbagai sektor untuk menghasilkan energi termal atau listrik dari matahari. Di Malaysia, listrik lebih murah, sehingga kurang menarik untuk beralih ke energi terbarukan. Studi ini bertujuan untuk mengeksplorasi potensi sistem panas termal surya dalam proses industri di Malaysia, dengan fokus pada kilang kelapa sawit Mewaholeo Industries Sdn Bhd. Tantangan utama adalah investasi modal yang tinggi dan efisiensi sistem termal surya yang bervariasi, yang bergantung pada spesifikasi teknis dan faktor lingkungan. Untuk menentukan spesifikasi optimal untuk pemasangan sistem termal surya, penelitian ini akan memeriksa aliran proses, mengusulkan desain sistem termal surya, mengumpulkan data, dan mengintegrasikan energi termal surya. Tipe kolektor terbaik, jumlah kolektor, dan desain termal surya akan dianalisis menggunakan alat Excel bernama Solar Heat Industry Process (SHIP) untuk evaluasi kinerja dan finansial.

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Abstract

Fossil fuels contribute to global warming and climate change. Solar energy, a renewable and safe energy source, is a promising alternative. Solar thermal energy (STE) can be used in various sectors to produce thermal or electrical energy from the sun. In Malaysia, electricity is cheaper, making it less appealing to switch to renewable energy. This study aims to explore the potential of solar thermal heat systems in industrial processes in Malaysia, focusing on the oil palm refinery Mewaholeo Industries Sdn Bhd. The main challenge is the high capital investment and varying efficiencies of solar thermal systems, which depend on technical specifications and environmental factors. To determine the optimal specifications for solar thermal system installation, this study will examine the process flow, propose a solar thermal system design, collect data, and integrate solar thermal energy. The best collector type, number of collectors, and solar thermal design will be analyzed using an Excel tool called Solar Heat Industry Process (SHIP) for performance and financial evaluation.

INTRODUCTION

One of the main contributors to global warming and climate change is the use of fossil fuels, such as coal and oil to generate electricity. Energy demand continues to grow, and the fossil fuel consumption will most likely increase, resulting in a further increase in CO_2 emissions. Governments around the world have since taken steps to tackle this issue by promoting the introduction of renewable energy (RE) through different national program [1]. Although renewable and alternative energy offer great potential to replace fossil fuel reliance, progress has been slow in most developed countries in getting it into the mainstream [2]. Governments and businesses around the world are constantly looking for ways to reduce their operations' greenhouse emissions, with a significant emphasis on the use and deployment of sustainable renewable energy systems [3].

Iceland, Sweden, and Costa Rica are the top three countries that use renewable energy to sustain their economies rather than non- renewables. These countries can implement a renewable energy very well. Renewable sources of energy include wind, hydro, solar, biomass, geothermal energy, and tidal energy, among other things. Every renewable energy has its own benefits and drawbacks and a global preference for consumption. Between 2019 and 2024, renewable power will grow by 50%, led by solar photovoltaics. This 1 200 GW rise is equal to today 's total US installed power capacity. In figure 1.2, it shows that Solar PV alone accounts for nearly 60 percent of the projected rise, with one-quarter of onshore wind. Renewable capacity growth could be 26 per cent (1 500 GW) higher than in the main forecast of the study in the accelerated case of Renewables 2019. The accelerated case needs policymakers to address three major challenges such as, policy and regulatory uncertainty, high investment risks in developed countries, and wind and solar energy integration in some countries. Solar PV is the single largest source of capacity for additional expansion followed by onshore wind and hydropower.

Solar energy has many benefits over other options and is the most promising backup energy. Solar energy is a safe and renewable source of energy originating from the sun that can be directly used to produce electricity [4]. With some remarkable developments in the recent past the solar energy sector is rapidly developing. Reviews published recently concentrate widely on RE integration research and the enhancement of grid criteria with control methods. Other aspects recently published include effect and status of RE in Malaysia , public opinion-influenced policies, sustainable ideas for RE development, climate change mitigation in Malaysia and feasibility studies on solar use in Malaysia [5].

Solar thermal energy (STE) is a type of renewable energy and technology that can be used in manufacturing, residential and commercial sectors to harness solar energy to produce thermal or electrical energy. Solar thermal technology mechanism is by collecting the heat energy from the sun and using it for heating and electricity output. By comparison, this solar thermal is different from photovoltaic solar panels which directly convert the radiation from the sun into electricity.

There are two major types of solar thermal systems which are active and passive systems used in energy production. Active systems require moving components such as pumps to move heat carrying fluids while passive systems do not have mechanical components and rely on design features to absorb heat (e.g. greenhouses) only. Solar thermal technologies can be categorized by applications of low, medium, or high temperature defined as follows:

a. Usually systems with low temperatures (less than 100° C) use solar thermal energy for hot water. Many active systems consist of a flat plate collector mounted on the roof, from which liquid circulates. The collector receives heat from the air, and it is transported by the liquid to the desired destination, such as a home heating device. Intelligent building design practices include passive heating systems which reduce the need for heating or cooling systems by better capturing or reflecting solar energy.
b. Medium-temperature applications (ranges from 100° C to 250° C) are not popular. An example of this would be a solar oven, which uses a specially shaped reflector to concentrate the rays of the sun on a central pot. Similar systems could be used but are not widely used for industrial processes.
c. Solar thermal systems with high-temperature (more than 250° C) use mirror groups to focus solar energy on a central collector. These concentrated solar power (CSP) systems can reach temperatures that are high enough to produce steam, which then turns a turbine and drives a generator to generate electrical power.

In the case of solar thermal technology, solar energy is used to satisfy the demands of the various end users in the various industries, such as construction, industry and the domestic sector [6]. In industrial applications, it represents a range of applications ranging from low to high temperatures. The category of HVAC needs a significant allocation of total energy demand to satisfy heat ventilation and air conditioning requirements [5].

Malaysia is experiencing hot and humid weather due to its geographic location, with a decent amount of rainfall all year round. It receives an abundance of solar radiation during the year, with an average solar radiation mean of 4.7 - 6.5 kWh/m^2 in most places [7]. Applications involving solar energy therefore also gained popularity in Malaysia due to favourable climate conditions in the region.

Minister Yeo Bee Yin had implemented the Net Energy Metering (NEM) scheme in Malaysia, the Ministry of Energy, Science, Technology, Environment and Climate Change, with a view to growing Malaysia's renewable energy mix from 2% to 20% by 2030. Following the trend of global demand for solar panel technology and local interest in renewable energy, this study will thus assist with research data on solar system optimization in terms of cost to any location provided that the technological and environmental data are recognised as capital expenditure for such a larger target is not inexpensive [8].

Conventional fossil fuels like oil, gas, and coal has growing environmental issues such as the carbon emission from their activities. It was important to discover a new green and renewable energy source to replace the current method of obtaining energy through combustion of fossil fuel which generates tons of CO_2 emissions, which is the main culprit of greenhouse warming. Solar thermal energy could be used as a substitute for fossil fuel because it could be produced in an environmentally friendly way that almost did not damage our climate [9]. The challenger relies on the implementation of solar thermal heat systems in manufacturing processes and the use of solar thermal heat applications based on energy production, usage, and climatic conditions in Malaysia.

In Malaysia in particular, electricity is much cheaper, so it is not as attractive as other countries to switch to renewable energy. However, there is huge potential to harvest solar energy for industrial heating demand, below than 100 °C. Complex case of solar optimization model by understanding and considering all environmental data and costs per used technical specification had not been investigated in any research in Malaysia [10]. The challenger relies on the implementation of solar thermal heat systems in industrial processes and the use of solar thermal heat applications based on energy demand, consumption, and climatic conditions in Malaysia. Lack of detailed model design optimization results in implemented oversized installation system which ultimately costs more than it should [19]. Therefore, in Malaysia, solar thermal potentials had to be studied and the optimum conditions had to be determined for installing the solar thermal system in industrial processes.

LITERATURE REVIEW

Solar Irradiance

Irradiance or insolation is specified as power per area received; watt per square meter (W m^{-2}) is the unit. Irradiation is the energy obtained per area; joule per square meter (J m^{-2}) is unit. The International Society for Solar Energy recommends symbols H. A widely used unit of industrial electrical energy metering is watt-hour (Wh).

Solar energy is becoming increasingly popular as a source of renewable energy and has different thermal as well as photovoltaic applications since the Earth receives a huge amount of energy in the form of solar radiation. Solar conversion systems however differ from other energy conversion systems because the amount of energy available on Earth is not easily regulated, it is a variable that depends on several factors, including the following [11].

The latitude band between 23.5 ° N (the Tropic of Cancer) and 23.5 ° S (the Capricorn Tropic) is called the tropics. As an example, figure 1 indicates that energy from the sun passes through more atmosphere, depicted by the length of the black lines, farther away from the equator, at high latitudes, and is distributed over a wider region on the earth, shown by the size of the ovals. Closer to the equator, and at low latitudes, less ambient energy must flow from the sun.

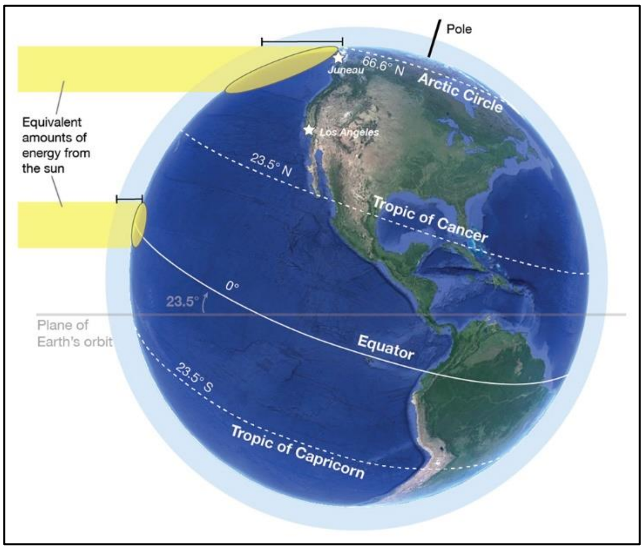

Figure 1. The same amount of sunlight hitting different latitudes of Earth's surface (Map data: SIO, NOAA, U.S. Navy, NGA, GEBCO, US Dept. of State Geographer; Image: Landsat).

Therefore, understanding the essence of solar insulation, its spectral distribution, its variation due to seasonal and atmospheric conditions, and its measurement for horizontal and tilted surfaces is very important before a country can implement solar energy techniques properly. Figure 2 indicates that soil and ocean can consume just 51 per cent of solar energy.

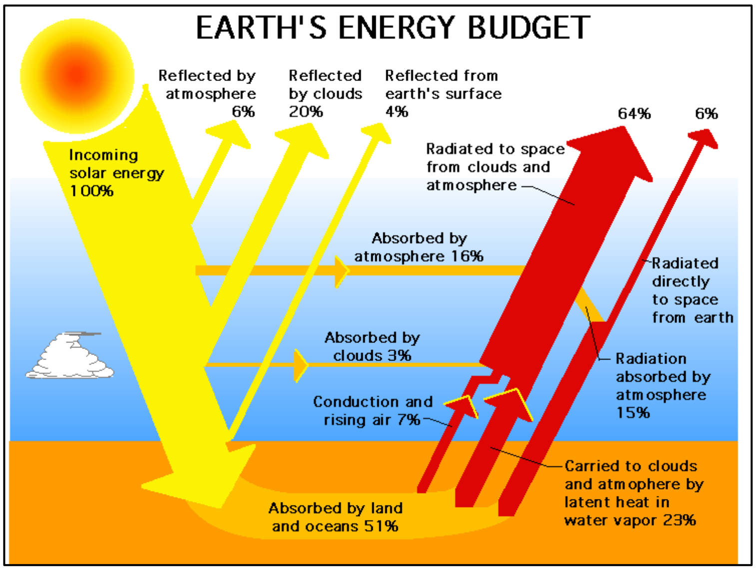

Figure 2. Earth's solar energy budget (National Aeronautics and Space Administration, NASA).

Solar Thermal Collectors

Solar thermal collectors are instruments that are used to transform solar radiation into thermal energy and move it to a storage unit for subsequent use [12]. Natural or forced circulation can be characteristic of the system. Typically, solar thermal systems are used to produce hot water or zone heating, but they can also be used for various purposes. For example, solar air heater collectors use air as the fluid for heat transfer. The hot air produced can be used as working fluid in a motor, for domestic heating or for some industrial applications such as drying products [13] .The theoretical limit of a solar thermal panel's energy efficiency is represented by the amount of solar radiation it can absorb and intercept [14]. Figure 3 offers description of the solar systems, distinguishing between non-concentrating and concentrated systems.

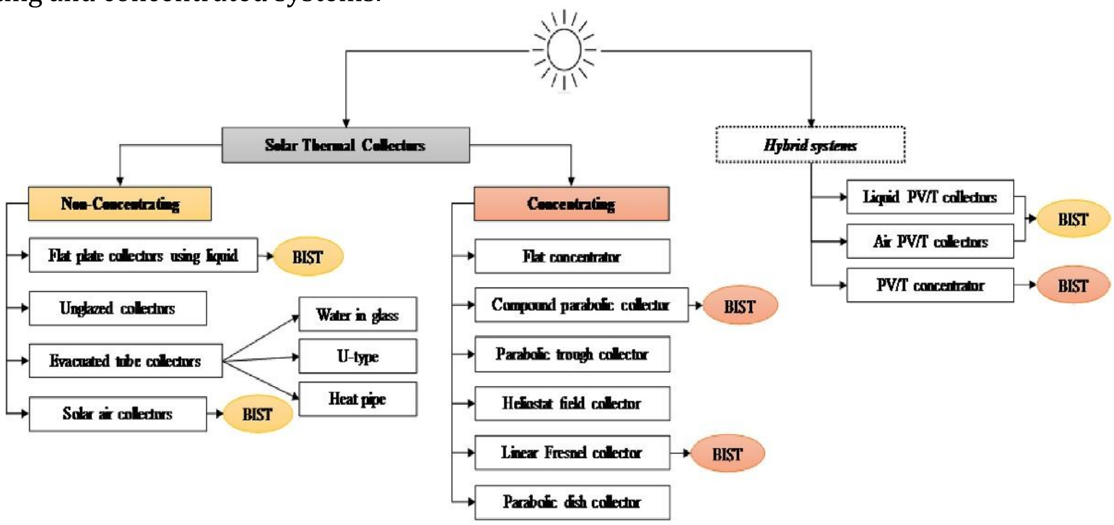

Figure 3. Solar systems classification (Source: [14]**)**

Application of Solar Thermal in Industrial Sector

We get the energy obtained from solar irradiation from heat transfer, is called solar thermal energy. Solar thermal energy will, like other renewable energy systems, replace fossil fuels in industrial systems. The energy conversion systems employ a variety of solar thermal collectors along with concentrators that accumulate and distribute solar radiation to be used in commercial or industrial plants for processing heat generation. The most important consideration in choosing the type of solar collector in industry is that solar energy may not be available in the device for 24 h supplying process heat. Additional process heating systems should be fitted with either phase change materials (PCM) or molten salts.

Electricity accounts for about 17 percent of the global final energy demand for low-temperature heat applications, while high-temperature industrial process heat accounts for 10 percent [15]. Solar energy has a long history of use in the residential construction market. The industrial and manufacturing sectors are well suited to solar thermal technology and its implementation due only to the volume of energy needed for integrated process heating systems. For example, for processes such as different types of drying, cleaning, washing, water heating, pasteurization, and sterilization and so many food processing applications, the main heat requirement is for. The required temperature level for these industrial processes is similar for almost all applications below 250 °C .

The study of industrial processes cannot be standardized or classified due to conditions that differ too widely, for example, in plants for the purification of food production or for bottle cleaning. Several unit operations operating in different processes and sectors of industry are shown below.

a. Water Heating
b. Drying Processes
c. Preheating Processes
d. Steam Heating Processes
e. Pasteurization and sterilization Processes
f. Washing Processes

METHODOLOGY

There were total of 4 phases involved. The first phase was the process flow familiarization. The process could be split into seven major unit operations which are homogenizer, crystallizer, stabilizer, hopper, high pressure filter, melting tank and olein tank.

The second phase was to propose the solar thermal system design, the third phase was the data collection based on a case study given. The heating demand and process condition would be identified. The current heating utility has been recognized and the existing type of fuel for heating would also be considered in this study.

The fourth phase was solar thermal integration by using Solar Heat Industry Process (SHIP) design and analysis tool application. Based on the data analysed in first to third phases, the potential of solar thermal system replacing the current utility system would be evaluated and a suitable solar thermal system was designed for the process usage [16].

Solar Heat Industry Process

Solar thermal technologies capture the heat energy from the sun and use it for heating process [17]. The basic process of solar heat application involves the harnessing solar energy by the collector loop, charging and storage of the solar thermal energy, discharge loop, and heat integration point with conventional process heat supply. In Solar Thermal Integration phase, the method will be based on the application of SHIP design and analysis tool which was developed by AEE INTEC - Institute for Sustainable Technologies. Solar Heat in Industrial Process (SHIP) Design and Analysis Tool is used to design and analyze solar heat in industrial process plants. This tool demonstrates simulation of annual energy gains that consists of the annual heat output (MWh/a) of the solar thermal system designed and final energy that can be saved [18]. Elements such as process load, collector sizing and design, storage volume, heat exchanger in solar thermal system, process heat exchanger and stagnation, yearly analysis of heat balance of solar heat delivery could be calculated via this tool once the required input parameters inserted. Furthermore, the economic analysis could be performed as well by using this tool in order to obtain the total cost saved, final energy saving, and payback period of the solar thermal system designed.

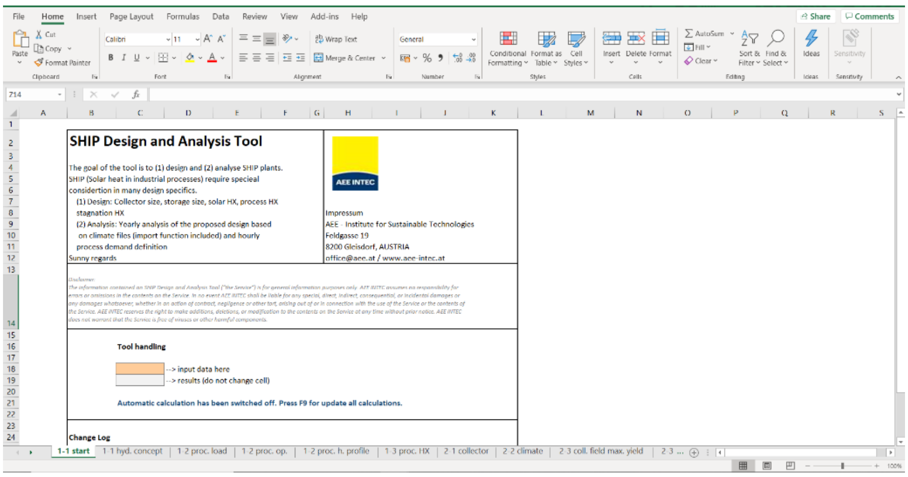

Figure 4. Solar Heat Industry Process (SHIP)

Several input parameters were required in this simulation to run the SHIP analysis, which included the energy load profile or energy demand of the palm oil industry, the solar thermal system component, the collector type, the climate condition, the area available for collector installation, the volume of heat storage and the cost of capital.

Energy Load Profile or Energy Demand

Calculating the demand for solar thermal energy was the first step in the design of solar thermal energy. It was necessary to identify the current energy consumption of the palm oil industry to generate the appropriate quantity of solar energy that could replace the current source of energy. The value would correspondingly be derived from the case study.

The Component in Solar Thermal System

The piping, flow rate of hot fluid and cold fluid, fluid properties and desired temperature of each stream are part of the solar thermal system component. This heat exchanger data in the solar thermal system was required for the application of the SHIP tool. To replace the present utility system, a solar thermal system would be designed.

Collectors Type

Technologies used in solar thermal collectors are used to collect heat by absorbing sunlight. For different temperatures, different collectors are designed. The choice of solar thermal collectors is based on temperatures below the design temperature:

Table 1. Type of collectors for specific design temperature

Type	Design Temperature
Standard flat plate collectors	20-80 °C
Advance flat plate collector (vacuum filled, multiple covers, etc.)	60-120 °C
Evacuated tubular collector	60-120 °C
Parabolic collectors	120-250 °C
Fresnel Collectors	120-250 °C

There are distinct collector efficiency coefficients for each collector. This coefficient parameter is required to determine the efficiency curve of the solar thermal collector (n), which is based on the formulas below:

$$n_{coll} = c_0 - c_1 \cdot \frac{T_{m,coll} - T_a - c_2}{G} \cdot \frac{(T_{m,coll} - T_a)^2}{G} \quad (1)$$

c_0= Maximum Efficiency
c_1= Linear heat loss coefficient [W/(K^{2}m^2)]
c_2= Quadratic heat loss coefficient [W/(K^{2}m^2)]
$T_{m,coll}$= Mean collector temperature
T_a= Ambient Temperature

Climate Condition

Climate is the daily weather condition measured over long periods of time by evaluating variation of temperature, humidity, atmospheric pressure, wind, precipitation, and other meteorological variables in each region. The simulation required the solar average radiation data for that certain area in the SHIP tool. Data on climate conditions, such as annual in-plane irradiance (kWh/m2.a) and mean ambient temperature (°C), can be obtained from the European Union's 'Hourly Radiation Data' Information System via the link http://re.jrc.ec.europa.eu/pvg tools/en/tools.html#HR. With this information system, the amount of radiance and ambient temperature will be provided daily, depending on the location in Malaysia.

Area Available for the Installment of Collector

The area for the collector would be determined by the maximum energy the solar energy could generate. Theoretically, the greater the area, the more it is possible to install the absorber and to absorb and convert more solar radiation into other energy. Besides, to avoid shading problems, the space between each absorber had to be calculated. The method of calculating the collector field size is based on the highest daily radiation that leads to the maximum specific solar output. The aperture area and number of rows are calculated based on the maximum daily collector yield and the availability of space. If space is available, it is possible to determine the optimum inclination and orientation of a single solar thermal collector.

As a rule, to choose the correct inclination and orientation of the collectors, the collector should be facing the equator, which means the collector facing north in the southern hemisphere and the collector facing south in the northern hemisphere. In addition, care should be taken that at any time of the year the collectors are not shaded, either by trees, buildings, or other collectors. When the collector is always oriented perpendicular to the sun, the largest yield is obtained. To prevent overshadowing, Figure 5 shows the variables influencing the minimum row distance D between the collectors.

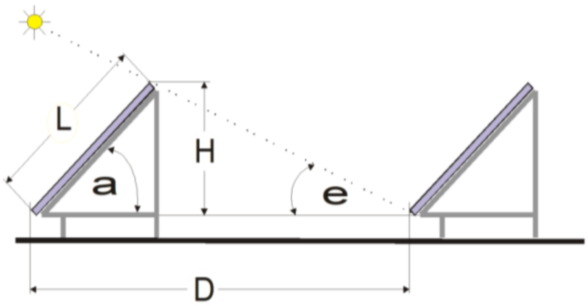

Figure 5. Variables influencing the distance, D between the collectors

RESULTS AND DISCUSSION

In an oil palm refinery known as Mewaholeo Industries Sdn Bhd, the case study was conducted (MHI). The company was founded in the 1950s and became one of the largest companies in the field of edible oils and fats, with a total refining capacity of 3.5 million MT annually. MHI has diversified its business for over 60 years by offering other consumer products such as rice, soap, and dairy products to its portfolio. Today, in their daily lives, more than a billion people in over 100 countries use Mewaholeo products. The aim of the case study was to assess the performance of existing systems and identify the potential for energy savings and identify and analysed the solar thermal integration, and assess economic performance based on the scenario analysis.

Location of Solar Collector

The place for the installation of the solar collector has been identified. The roof of the plant was chosen to deploy the solar collector, as there was no existing flat area on the ground. This arrangement, however, was relatively challenging as there would be a limited area for solar collector placement. A satellite image overview of the roofing area was captured using Google Earth and showed that 3,996 m^2 was the calculated applicable area for the solar collector.

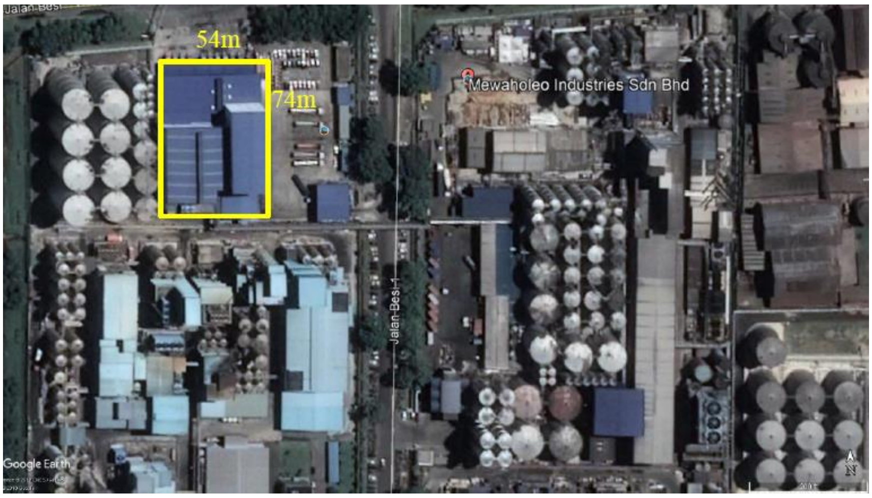

Figure 6. Overview of CBS Plant Site

On the other hand, there are 2 hot water tanks located at the MHI Plant. The volume size for each of the well-insulated hot water tanks were 40 m³. These tanks were found to be appropriate to convert as hot water storage system for the solar thermal system. However, it would be more reliable if the tanks had larger storage.

Climate Data

Irradiation and ambient temperature parameters were included in the required climate data from the SHIP tool software. These irradiation values were used to determine the maximum daily energy yield, while the efficiency of the solar thermal collector was calculated using ambient temperature data. The most appropriate solar collector in this case study was identified based on the calculated efficiency. The climate data was generated and extracted via the following link from the European Union Hourly Radiation Data Information System: http://re.jrc.ec.europa.eu/pvg tools/en/tools.html#HR. The information was based on the climate of 2016 and sorted in the table below:

Table 2. Climate Data of Pasir Gudang, Johor

Yearly in-plane irradiance (kWh/m^{2}a)	1810.98
Average Temperature (°C)	27.32
Slope (°)	10
Azimuth (°)	-24
Max Daily Yield (Wh/m^{2}d)	7357.88

Chosen Collectors

There were eight types of solar collectors chosen from the following link: http://www.solarkeymark.nl/DBF/ 4 of which were type flat plate collector (FPC) while the remaining four were type evacuated tube collector (ETC). In the table below, collector parameters such as efficiency coefficients, length, width, aperture, and gross area have been listed. The efficiency of each collector varied according to the temperature difference between the circulating fluid and ambient temperature.

Definition of Solar Thermal Collectors	Collector efficiency coefficient			Length	Width	Aperture Area	Gross Area
	C0	C1	C2	L	W	A_ap	A_gr
	-	[W/(K∘m²)]	[W/(K∘m²)]	[m]	[m]	[m²]	[m²]
STE-2.0C-AO-F (FPC)	0.74	4.93	0.014	2	1	1.87	2
K2PLUS (FPC)	0.76	2.23	0.012	2	1.2	2.25	2.4
M4-200 (FPC)	0.76	3.89	0.013	2.076	0.98	1.87	2.04
FMAX_2.72(FPC)	0.77	3.16	0.012	2.16	1.26	2.7	2.72
CC-HPV-S12 (ETC)	0.54	1.21	0.004	1.917	1.35	2.16	2.59
Prisma Pro 8 (ETC)	0.54	1.21	0.004	1.917	0.91	1.41	1.74
Eurotherm Solar CPC 16R (ETC)	0.54	1.21	0.004	1.917	1.79	2.91	3.43
EtaSun Pro @ VPK20 (ETC)	0.46	1.26	0.006	1.983	2.3	2.81	4.57

Figure 7. Chosen Collector Details

Solar Thermal System Design

The below figure showed Solar Thermal Design 1 which was maintaining the hot water in the tank at 65 °C. Thus, the heat demand for the solar thermal collector included the heat to increase the hot water return to 65 °C and the heat loss of the tank. Based on this design, the solar thermal system needed to generate 0.85 kg/s of hot water at 95°C from 65°C.

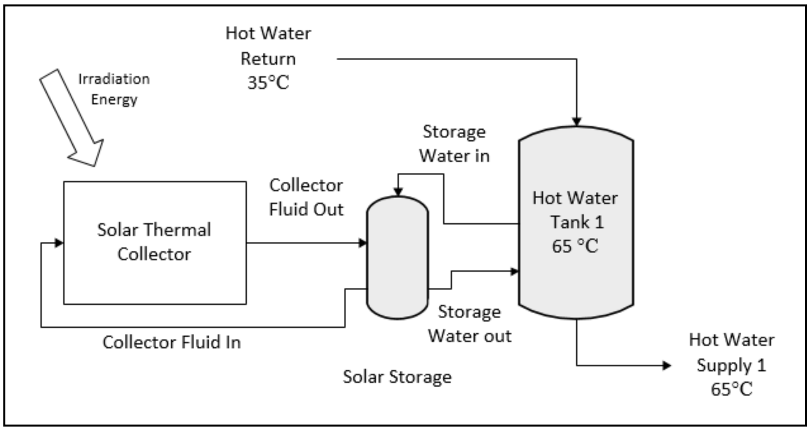

Figure 8. Solar Thermal System Design

Determination of the Best Solar Thermal Collector

There are 8 collectors has been chosen, and from those collectors, we would find the optimum collectors based on the efficiency curves and economic part. The collector field data will also be determined, such as number of collectors, number of rows, gross area, aperture area, and utilization ratio. The figure below will show the efficiency curve between the 8 collectors.

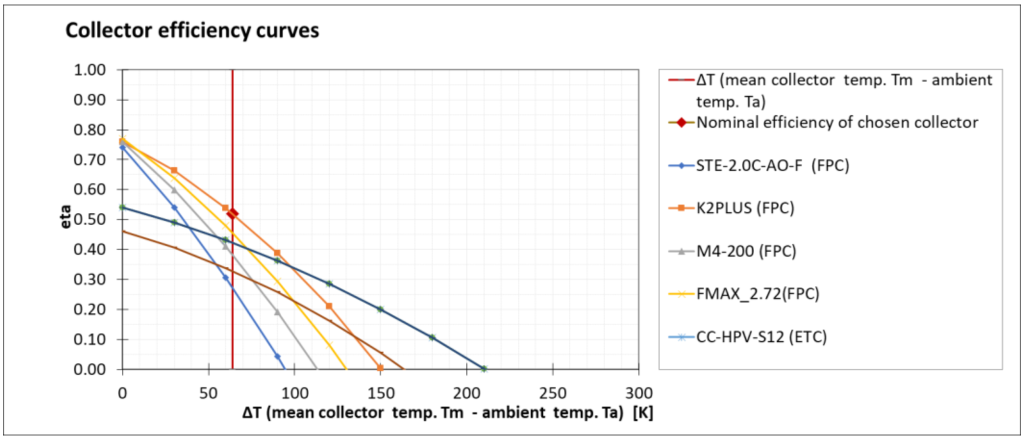

Figure 9. Efficiency for Solar Thermal Collectors vs Temperature Difference

At the ΔT ambient temperature of 30K, it showed that the K2 Plus flat plate collector (FPC) has the highest collector efficiency. Determination of the best solar thermal collector would also need to identify based on the economical part. The parameters that needed were LCOH (Levelized cost of heat), solar fraction, annual energy savings, and payback period. The figures below show the graph of LCOH vs solar fraction and annual energy savings vs payback period for each design.

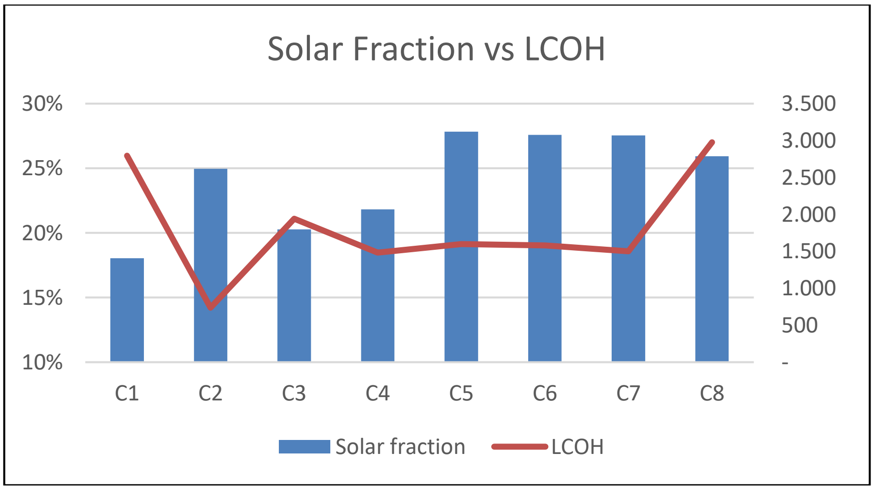

Figure 10. Scenario 1 – Solar Fraction vs LCOH

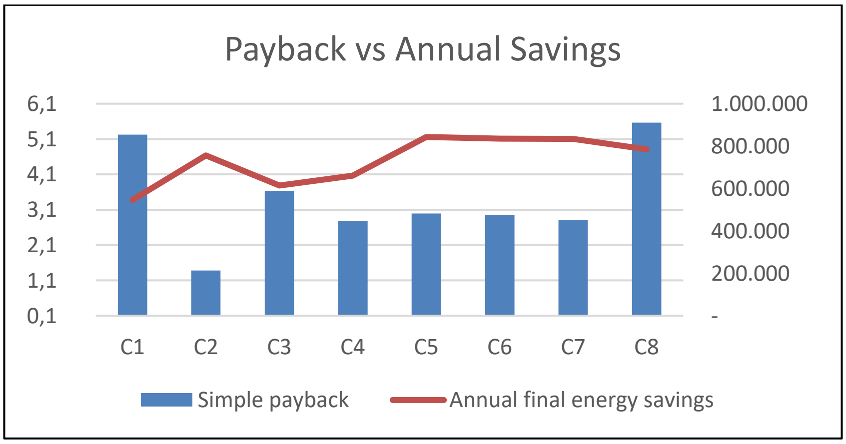

Figure 11. Scenario 1 – Payback Period vs Annual Energy Savings

From the figures above, C1 until C8 represent the collector type based on table 4.2. It can be seen for both designs, the C2 (K2 Plus) would be chosen, because it has higher savings and shortest payback period. The collector field design has also been generated based on the chosen collector above. The details are shown below.

a. Collectors/row = 40
b. Rows = 7
c. No. of Collectors = 280
d. Gross Area = 672
e. Aperture Area = 630
f. Utilization Ratio = 0.17

Determination of Collector Numbers per Row

After the best type of collectors has been chosen, the number of collectors per row should be determined to identify and analyzed the effect of number of collectors per row. And, to find the best collector field design in term of economic feasibility. The figures below show the same graph as scenario 1 or stage 1, but with a different numbers of collector per row from the selected collectors (K2 Plus).

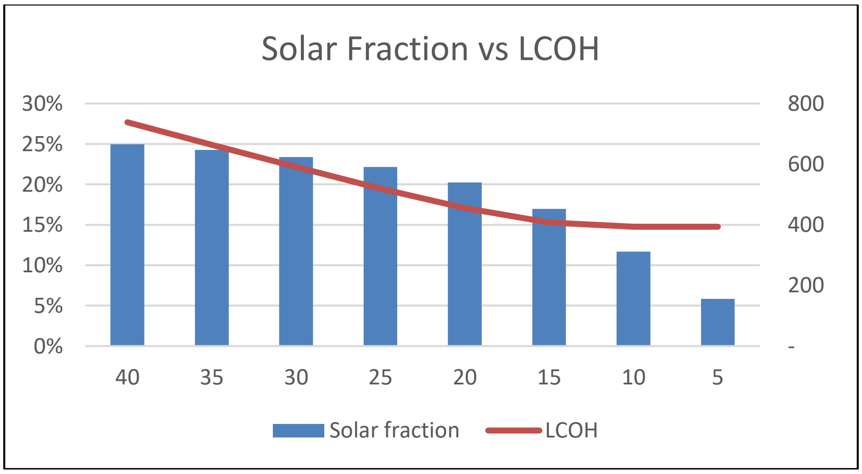

Figure 12. Scenario 2 – Solar Fraction vs LCOH

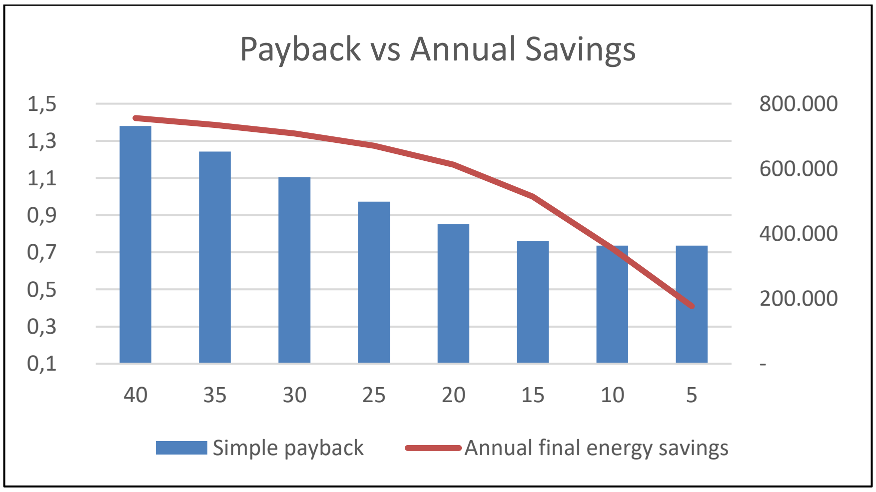

Figure 13. Scenario 2 – Payback Period vs Annual Energy Savings

From the figures above, the horizontal axis represented the number of collectors per row. The number of collectors that was chosen was 25 collectors per row. The number was chosen because of the payback period lower than the original design in scenario 1. There is little difference between 25 collectors and 40 collectors (original design) annual savings. The details are shown below.

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a. Collectors/row = 25
b. Row = 7
c. No. of Collectors = 175
d. Gross Area = 420
e. Aperture Area = 394
f. Utilization Ratio = 0.11

CONCLUSION

After careful analysis, the following important points have been concluded: Firstly, the FPC K2-Plus will be chosen as the solar thermal collector. Secondly, there will be 25 collectors per row, resulting in a total of 175 collectors. Thirdly, the selected design and collectors have been deemed economically feasible. This is supported by the projected energy savings of 200 MWh per annum and an estimated energy cost saving of RM 670,725 per annum. Furthermore, the payback period for this investment is anticipated to be only one year.

A case study on the potential of solar thermal energy in other industrial sectors such as food & beverages, chemicals, pulp & paper, iron & steel, rubber & plastic and so on is recommended for future study. The selected heating demand temperature of this industry could correspondingly range from 80 ° C to 450 ° C.

Various types of solar collectors such as Evacuated Tube Collectors, Advance Plate Collectors, CPC Collectors, Small/Large Parabolic Troughs, Fresnel Collectors, High Vacuum Flat Plate Collectors and Advanced Evacuated Tube Collectors would therefore be required in the industrial process for different design temperature ranges.

Optimization tool or software also recommended for the future study. Software such as GAMS, LINDO, or MatLab is an example of optimization software that can solve linear and mixed integer model.

REFERENCES

[1] IEA, “Southeast Asia Energy Outlook 2017,” 2017.

[2] M. Malahayati, “Achieving renewable energies utilization target in South-East Asia: Progress, challenges, and recommendations,” *The Electricity Journal*, vol. 33, no. 5, p. 106736, 2020, doi: https://doi.org/10.1016/j.tej.2020.106736.

[3] E. A. Abdelaziz, R. Saidur, and S. Mekhilef, “A review on energy saving strategies in industrial sector,” *Renewable and Sustainable Energy Reviews*, vol. 15, no. 1, pp. 150–168, 2011, doi: https://doi.org/10.1016/j.rser.2010.09.003.

[4] R. Saidur, “A review on electrical motors energy use and energy savings,” *Renewable and Sustainable Energy Reviews*, vol. 14, no. 3, pp. 877–898, 2010, doi: https://doi.org/10.1016/j.rser.2009.10.018.

[5] M. Vaka, R. Walvekar, A. K. Rasheed, and M. Khalid, “A review on Malaysia’s solar energy pathway towards carbon-neutral Malaysia beyond Covid’19 pandemic,” *J Clean Prod*, vol. 273, p. 122834, 2020, doi: https://doi.org/10.1016/j.jclepro.2020.122834.

[6] S. Y. Heng, Y. Asako, T. Suwa, L. K. Tan, N. B. Sharifmuddin, and J. O. Kamadinata, “Performance of a small-scale solar cogeneration system in the equatorial zone of Malaysia,” *Energy Convers Manag*, vol. 184, pp. 127–138, 2019, doi: https://doi.org/10.1016/j.enconman.2019.01.059.

[7] J. O. Petinrin and M. Shaaban, “Renewable energy for continuous energy sustainability in Malaysia,” *Renewable and Sustainable Energy Reviews*, vol. 50, pp. 967–981, 2015, doi: https://doi.org/10.1016/j.rser.2015.04.146.

[8] L. Kumar, M. Hasanuzzaman, and N. A. Rahim, “Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review,” *Energy Convers Manag*, vol. 195, pp. 885–908, 2019, doi: https://doi.org/10.1016/j.enconman.2019.05.081.

[9] A. Kylili, P. A. Fokaides, A. Ioannides, and S. Kalogirou, “Environmental assessment of solar thermal systems for the industrial sector,” *J Clean Prod*, vol. 176, pp. 99–109, 2018, doi: https://doi.org/10.1016/j.jclepro.2017.12.150.

[10] S. Mekhilef, A. Safari, W. E. S. Mustaffa, R. Saidur, R. Omar, and M. A. A. Younis, “Solar energy in Malaysia: Current state and prospects*,” Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 386–396, 2012, doi: https://doi.org/10.1016/j.rser.2011.08.003.

[11] H. P. Garg and G. Datta, "Fundamentals and characteristics of solar radiation," *Renew Energy*, vol. 3, no. 4, pp. 305–319, 1993, doi: https://doi.org/10.1016/0960-1481(93)90098-2.
[12] A. Kasaeian, G. Nouri, P. Ranjbaran, and D. Wen, "Solar collectors and photovoltaics as combined heat and power systems: A critical review," *Energy Convers Manag*, vol. 156, pp. 688–705, 2018, doi: https://doi.org/10.1016/j.enconman.2017.11.064.
[13] A. Fudholi and K. Sopian, "A review of solar air flat plate collector for drying application," *Renewable and Sustainable Energy Reviews*, vol. 102, pp. 333–345, 2019, doi: https://doi.org/10.1016/j.rser.2018.12.032.
[14] L. Evangelisti, R. De Lieto Vollaro, and F. Asdrubali, "Latest advances on solar thermal collectors: A comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 114, p. 109318, 2019, doi: https://doi.org/10.1016/j.rser.2019.109318.
[15] S. H. Farjana, N. Huda, M. A. P. Mahmud, and R. Saidur, "Solar process heat in industrial systems – A global review," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 2270–2286, 2018, doi: https://doi.org/10.1016/j.rser.2017.08.065.
[16] K. Hansen and B. Vad Mathiesen, "Comprehensive assessment of the role and potential for solar thermal in future energy systems," *Solar Energy*, vol. 169, pp. 144–152, 2018, doi: https://doi.org/10.1016/j.solener.2018.04.039.
[17] A. A. Navarro, L. Ramírez, P. Domínguez, M. Blanco, J. Polo, and E. Zarza, "Review and validation of Solar Thermal Electricity potential methodologies," *Energy Convers Manag*, vol. 126, pp. 42–50, 2016, doi: https://doi.org/10.1016/j.enconman.2016.07.070.
[18] İ. H. Yılmaz and A. Mwesigye, "Modeling, simulation and performance analysis of parabolic trough solar collectors: A comprehensive review," *Appl Energy*, vol. 225, pp. 135–174, 2018, doi: https://doi.org/10.1016/j.apenergy.2018.05.014.
[19] Ali Basrah Pulungan, & Rani Afriyanti. Studi Ekonomi Solar Panel Pada Penetas Telur Itik Menggunakan Homer Pro Energy. *Jurnal Teknik Elektro Indonesia*, 3(1). 2022. https://doi.org/https://doi.org/10.24036/jtein.v3i1.236