Journal of Energy and Safety Technology

JEST

RESEARCH ARTICLE Open

A Techno-Economic Analysis of Parabolic Trough Collector (PTC) and Solar Power Tower (SPT) as Solar Energy in Malaysia

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Article History

Received: June 08, 2021 Received in revised form: November 17, 2021 Accepted: November 18, 2021 Published Online: December 25, 2021

Abstract

Malaysia receives an annual average of 2200 hours of solar radiation, making her abundant renewable resources to generate electricity. Thus, a good planning is required to manage the resources efficiently and to utilize the abundant resources fully. Concentrating solar power (CSP) technology is a possible approach to manage renewable resources in Malaysia. Using a techno-economic analysis, the researchers, engineers, industries, or government agencies will be able to identify contributing and discouraging factors of building the CSP technology. This paper presents a techno-economic analysis of two CSP technology: parabolic trough collector (PTC) and solar power tower (SPT), for potential implementation in Malaysia. This paper provides information on two CSP technologies to researchers and industries prior to the planning and design stages. The techno-economic analysis begins with identifying potential locations based on the direct normal irradiation (DNI). Kuah, Kuantan, Miri and Labuan are identified as the potential locations using the RETScreen Expert software. Labuan could be the most promising PTC and SPT technology project because it has the highest DNI received annually. Next, the techno-economic analysis uses two reference projects, ANDASOL-1 and PS-10 systems in Spain, as references for all locations. The techno-economic analysis consists of annual electricity generation, unit cost of electricity, net Present Value (NPV), benefit-to-cost ratio (B/C), internal rate of return (IRR), and payback period calculated in Microsoft Excel. Finally, a sensitivity analysis is conducted to measure the impact of uncertainties of one or more input variables, leading to uncertainties on the output variables. Two sensitive factors are the annual electricity generation and the initial cost, affecting the construction, installation, and implementation of PTC or SPT technology.

Keywords: Concentrating solar power (CSP); parabolic trough collector (PTC); solar power tower (SPT); solar radiation; techno-economic analysis.

1.0 INTRODUCTION

Energy consumption in Malaysia keeps increasing as the population has reached 32 million. According to the Energy Commission (EC), energy consumption has been doubled in ten years from 1997 to 2017 [1]. The total energy consumption in 1997 was 26,167 kilotonnes of oil equivalent (ktoe), and the value increased to 62,489 ktoe in 2017. Sectors used high energy consumption is transportation (38.5 percent), industrial (28.0 percent), non-energy use (20.0 percent), residential and commercial (12.5 percent), and agriculture (1.0 percent) [1]. Energy consumption is expected to increase to meet the demands of the Malaysian population.

The increasing energy demand and consumption is one factor leading to many renewable energy production technologies as an alternative to conventional energy production. Renewable energy has positive effects on economic globalization, particularly the per capita income, per capita carbon dioxide emissions and the real price of oil. At a higher level, economic globalization can become one of the mechanisms promoting renewable energy to the world to raise awareness of this matter to people worldwide. Countries with higher economic performance are capable of demanding more renewable energy, allocating financial budgets, and spending money to overcome the problem of non-renewable energy [2].

According to the International Energy Agency (IEA), energy production is a significant contributor to carbon dioxide emissions (CO_2), which keep increasing from 1990 to 2019 [3]. However, the CO_2 emissions produced from coal reduced by 200 million tonnes (Mt) in 2019 compared with CO_2 emissions in 2018. The global energy-related sector emission of CO_2 flattened at 33 gigatonnes (Gt) in 2019. Factors leading to the flattened CO_2 emission are i) the role expansion of renewable sources, which mainly involved wind and solar photovoltaic, ii) higher nuclear power output, and iii) fuel switching from coal to natural gas. CO_2 emissions from the global power sector in 2019 were also showed a reduction by 170 Mt, which is the biggest fall taking since the late 1980s [3]. Based on the CO_2 emissions trends, it can be concluded that the power sector led the transition of conventional energy production into renewable and clean energy.

The production and consumption of renewable energy are one of the Sustainable Development Goals (SDGs) developed by the Department of Economic and Social Affairs of the United Nations. Goal 7 ensures accessibility to affordable, reliable, sustainable and modern energy for all people by the year 2030. The access to energy is different among countries as different countries have different resources based on the climate and any other factors [4]. Countries with high energy consumption will require to double their effort in meeting the goal to fulfill the demands of energy.

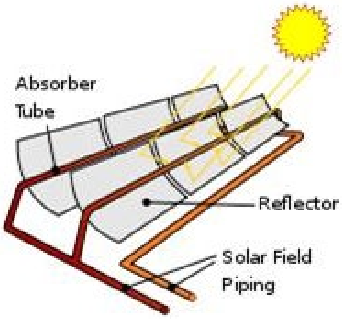
Renewable energy is a possible alternative to replace non-renewable resources, which are expected to deplete in future. Renewable energy also has a great potential in ensuring the continuous supply of energy resources. Solar is one of the renewable energy, which works by converting sunlight to usable energy for buildings. Many countries have adopted solar technology, such as the United States, Germany, France, the United Kingdom, Italy, India, China, Japan, South Korea, and Australia, to accommodate the energy demand.

A renewable energy planning and decision-making framework is needed to manage the abundant resources effectively. The planning should include both identifying and removing barriers and obstacles that prevent the use of the resources. Two models are often used in the planning: benefit, opportunity, cost, risk (BOCR), and analytic network process (ANP). The BOCR can identify the potential benefits, opportunities, costs, and risks of options related to renewable energy alternatives. The ANP, on the other hand, enables the concurrent assessment of quantitative and qualitative criteria through the decision-making process. The analysis of renewable energy should consider crucial aspects, particularly the mutual weight of strategic criteria such as technology, economy, energy vulnerability, security, global effects, and human well-being. The role of the infrastructures, policies and administrative structures facilitating the development must also be considered in the renewable energy analysis [5].

There are two different technologies to harness solar energy, which are solar thermal and solar photovoltaic. This paper focuses on solar thermal technology, which is concentrating solar power (CSP). CSP technology can generate electric power with a series of mirrors by concentrating sunlight. Next, the concentrated solar heat is transferred to electricity. The technology has four types, which are solar power tower (SPT), parabolic dish, parabolic trough collector (PTC), and Linear-Fresnel reflector (LFR).

A brief introduction to each CSP technology is provided in this paper. A parabolic trough collector is a linear concentrating system made of long, parabolic-shaped mirrors, and a receiver tube placed along the focal axis of the parabola [6]. Solana generating station in Gila Bend, Arizona is the world's largest parabolic trough plant, which having a 280 MW gross capacity and 6 hours of thermal storage using molten salt. Solar power tower uses heliostats, which work as reflectors that rotate about both the azimuth and elevation axes, to reflect sunlight onto a central receiver. Two examples of solar power towers are i) the Ivanpah Solar Electric Generating System consists of three direct-steam power towers and more than 170,000 heliostats (each 15 m^2) with a gross capacity of 390 MW_e and ii) the Crescent Dunes Solar Energy Project in Tonopah, Nevada has a capacity of 110-MW_e with ten hours of thermal storage. A linear-Fresnel reflector captures the sun's energy with large mirrors that reflect and focus the sunlight onto a linear receiver tube. The receiver contains a fluid that is heated by the sunlight. Finally, a dish/engine system uses a parabolic dish of mirrors to direct and concentrate sunlight onto a central engine two major parts of the system are the solar concentrator and the power conversion unit [6]. Kuravi et al. [7] review different thermal energy storage concepts available in the literature that are being or can be used for CSP plants – parabolic trough, solar tower, linear Fresnel, and dish-Stirling.

Figure 1 shows two CSP technologies studied in this paper. Future policy outlooks must be considered during the planning stage to install and implement the CSP technology. The outlooks are the hybrid technology implementation, regional renewable energy policy development, regulatory reform in feed-in-tariff (FiT), and the long-term sustainable renewable energy system development [8], [9].



(a) parabolic trough collector (PTC)

(b) solar power tower (SPT) known as PS-10

Figure 1. CSP technologies, (a) parabolic trough collector (PTC) and (b) solar power tower (SPT).

Malaysia is a tropical country and located in the Equatorial region, receiving average solar radiation between 4000 to 5000 Whr/m within 4 to 8 hours per day. The atmospheric condition of equatorial regions is always cloudy, leading to a lower proportion of direct solar radiation to Malaysia. Such characteristics are considered when determining the most optimum solar energy system [10]. Malaysia's weather is suitable for implementing CSP technology to expand the use of solar energy in the community. A few factors should be considered in the planning of implementing the CSP technology. Cost, the amount of solar radiation received at a specific location, energy vulnerability, security, global effects and human well-being throughout the process of initiation up until completion of the plan must be evaluated thoroughly in the feasibility study.

Agyekum and Velkin [11] study the techno-economic performance of solar tower (ST) and parabolic trough (PT) at two different locations in Ghana – Navrongo and Tamale – using the System Advisor Model (SAM) software. A 100-MW power plant is simulated for each technology at Tamale and Navrongo, where the solar insolation is high. Based on the simulation results, the solar tower will be the best technology to be adopted for both sites since it has the highest annual power generation output of 424 GWh and 393 GWh as against the 211 GWh and 190 GWh for the PTC for the Navrongo and Tamale sites, respectively.

Aly and teams [12] investigate the techno-economic feasibility of PTC and SPT technologies in Tanzania. They modelled and compared both the CSP technologies in two sites – Dodoma and Sulunga – using the System Advisor Model, which is developed by the U.S. National Renewable Energy Laboratory. The study introduces an approach applicable to investigating the techno-economic feasibility of CSP technology in Tanzania by addressing the effects of the high financial uncertainties. The investigation contributes to the existing knowledge in techno-economic of CSP technologies by introducing one of the earliest case studies in one of the world's least developed countries [12].

Cavallaro [13] employs a multi-criteria method to make a preliminary assessment of CSP technologies. The work demonstrates that a multi-criteria analysis can provide a technical-scientific decision-making support tool to justify its choices clearly and consistently.

This paper presents an analysis of two types of CSP technology and its economic impacts for potential implementation in Malaysia. The analysis could provide an overview of parabolic trough collector (PTC) and solar power tower (SPT) prior to the installation and implementation in Malaysia. This paper will also identify and determine a good location for implementing the CSP technologies.

2.0 SOLAR RADIATION IN MALAYSIA

Perlis, Kedah (partly), Kelantan, Melaka (partly), and several other places in the eastern part of Malaysia receive the most solar radiation. Sarawak and Southern Peninsular Malaysia are, on the other hand, receive the lowest solar radiation. On average, Malaysia receives about 6 hours of solar radiation daily and 2200 hours in a year [6].

Figure 2 present the global horizontal irradiation (GHI) in Malaysia. The global horizontal irradiation (GHI) is the total amount of shortwave terrestrial irradiance received by a surface horizontal to the ground. GHI could be considered an electricity generation parameter to decide a suitable location for building and installing CSP technology in Malaysia. Based on **Figure 2**, northern states of Peninsular Malaysia and several parts of East Malaysia can provide high sun radiation to the CSP technology. Further research should be conducted to evaluate the potential location in Malaysia and its economic impacts on the community.

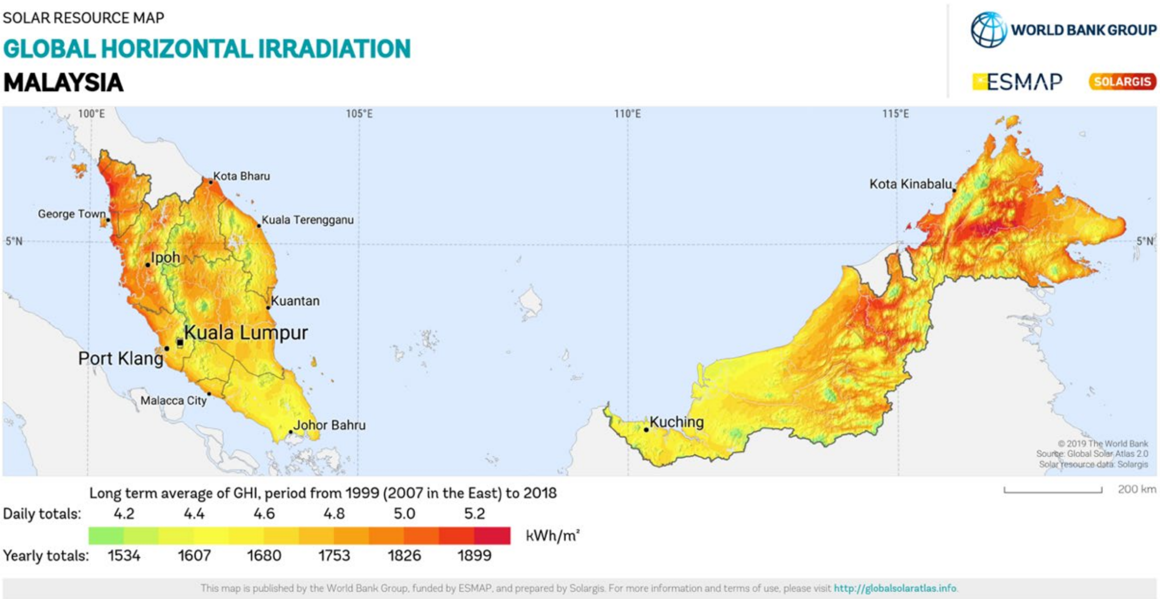


Figure 2. Global horizontal irradiation (GHI) in Malaysia. (©2019 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis)

According to the Malaysian Energy Commission (EC), the comparison of fuel production in 1997 and 2017 in **Figure 3** shows an increment in the energy production from renewable energy resources. The trends portray the country is in transition to renewable energy, and it could have positive changes in renewable energy development in Malaysia. The technologies converting the resources into energy are being developed from time to time to produce more clean energy for the country and nature.

The energy demand from various sectors in Malaysia will keep rising as the population increases over time. The renewable energy resource should be fully utilized to meet the consumer's demand for now and in the future. However, if no development of technologies, the generation of energy might be lower than the demand, resulting in many problems for all sectors.

Islam and his colleagues studied electricity generation from various renewable energy sources from 2012 to 2018 in Malaysia [8]. Based on the study, solar PV is the highest renewable energy source from 2015 to 2018, making it the suitable source for generating electricity annually in Malaysia. More research is required to develop more technologies to manage the sources efficiently. It could be an economic treasure for the country and beneficial to the consumer and nature.

Solar radiation is the resource that being observed as the most abundant, and it leaves other sources far behind.

Malaysian government and researchers should be proactive in ensuring renewable energy resources are appropriately utilized. Many people are aware of the use of renewable energy, and they are moving to new choices that are more eco-friendly, clean energy, and efficient.

Levelized cost of energy (LCOE) is an essential metric in deciding the execution of a project. Different energy-producing technologies, such as wind, solar, and nuclear power sources, can be compared using LCOE to determine either a project will be profitable or not. The calculation of LCOE reflects a per-unit cost of electricity generated. The comparison can include unequal life spans, differing capital costs, size of the projects, and the differing risk associated with each project for different technologies. The risk of each project is an implication of the specific discount rate used for each power-generating asset. The calculation of LCOE reflects a per-unit cost of electricity generated.

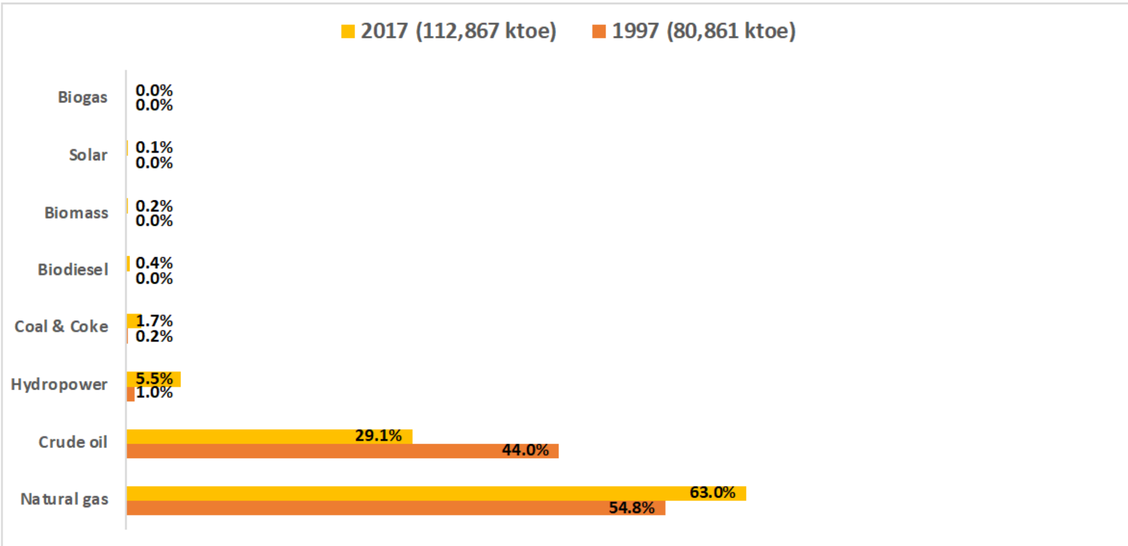


Figure 3. Malaysia's primary production by fuel type in 1997 and 2017 (Adapted from Energy Commission [1]).

Table 1 shows a list of LCOE for different types of power plants [3]. Solar thermal power plants govern the highest LCOE due to the high initial cost at USD 0.165 per kWh. The LCOE for a solar PV power plant is four times lower than the solar thermal. The cost of energy is one of the vital factors to determine profit from the project.

Table 1. LCOE of different types of power plant

Type of Power Plant	LCOE, US$/kWh
Wind onshore	0.037
Geothermal	0.037
Solar PV	0.038
Hydro	0.039
Combined-cycle (CC) Natural Gas	0.043
CC with Carbon Capture and Sequestration (CCS)	0.075
Biomass	0.092
Nuclear	0.093
Wind offshore	0.106
Coal with CCS	0.120 – 0.130
Solar Thermal	0.165

3.0 METHODOLOGY

The research has three phases, which are types of CSP technologies, parameters selection, and techno-economic analysis. These three phases are explained in details in Sections 3.1 to 3.3.

3.1 Types of CSP technologies

Two types of CSP technologies, Parabolic Trough Collector (PTC) and Solar Power Tower (SPT), are selected based on the suitability of weather conditions in Malaysia. This research used data available from other researchers. Purohit and Purohit [14] and Ravelli et al. [15] have published data for parabolic trough collector and solar power tower. Both ANDASOL-1 is a project of parabolic trough collector, and PS-10 is a project of solar power tower conducted in Spain. The two projects are used as a reference in this research for techno-economic analysis of PTC and SPT in Malaysia.

Table 2 shows the characteristics of both ANDASOL-1 and PS-10 projects. The electricity generated by the system is estimated based on the DNI at the selected locations in Malaysia. The cost of the whole project in Malaysia is assumed to be the same as in both projects in Spain [16]. The research is conducted based on parameters of both ANDASOL-1 and PS-10 as listed in Table 2. ANDASOL-1 has a higher investment cost compared to PS-10. However, the capacity of the plant built in ANDASOL-1 is much greater than in PS-10.

Table 2. Characteristics of the ANDASOL-1 and PS-10 [9].

Design features	ANDASOL-1	PS-10
Location	Granada, Spain	Seville, Spain
Nominal Electricalpower (capacity of plant), (MW)	49.9	11.02
Annual DNI (kWh/m^2)	1750	1860
Investment cost (Euro)	311 million	35 million
Receiver technology	Parabolic trough	Power tower
Receiver geometry	510,120 m^2	Cavity 180 degree, 4 panels 5.40 x 12.00 m
Thermal storagetechnology	Molten-salt (60% $NaNO_3$ and 40%KNO_3)	Water-steam
Thermal storage capacity	6.5 hours reserve	20 MWh, 50 Min @ 50% rate
Capacity factor (%)	41	23
Ground area (ha)	20	55
Annual electricity production (GWh)	179	23

3.2 Parameters selection and equation

The research evaluates the feasibility of CSP technologies at a potential location in Malaysia using data from PTC and SPT [14],[15]. Direct normal irradiance value (DNI) and capacity factor (CF) are two parameters used in deciding the potential location for implementing PTC or SPT. The output power calculation and the cost are calculated using the current data of electricity and the data from the RETScreen® Expert.

Financial parameters are required to determine whether the technologies are feasible or not in particular locations. Thus, the research estimates the financial using

i) Annual electricity generation

ii) Unit cost of electricity

iii) Net Present Value (NPV)

iv) Benefit to Cost ratio (B/C)

v) Internal Rate of Return (IRR)

vi) Payback period

3.2.1 Annual Electricity Generation

The annual electricity generation by a CSP system, AEG_{CSP} can be estimated in Equation (1).

$$AEG_{CSP} = (365\ x\ 24)\ x\ CF_{CSP}\ x\ P_{CSP} \quad (1)$$

where CF_{CSP} is the capacity factor

P_{CSP} is the capacity

3.2.2 Unit cost of electricity

The unit cost of electricity, UCE_{CSP}, can be generated by a CSP system, which is calculated as the total annual cost to the total annual electricity generation. Equation (2) shows the calculation for the UCE_{CSP} in RM/kWh.

$$UCE_{CSP} = \frac{C_{CSP}\ CRF + \zeta C_{CSP}}{AEG_{CSP}} \quad (2)$$

where C_{CSP} is the capital cost,

ζ is the annual repair and maintenance cost as a fraction of the capital cost of the CSP system, and

CRF is the capital recovery factor estimated in Equation (3).

$$CRF = \frac{d(1+d)^{t_{CSP}}}{(1+d)^{t_{CSP}} - 1} \quad (3)$$

where *d* is the discount rate, and

t_{CSP} is the useful lifetime

3.2.3 Net Present Value (NPV)

Net Present Value (NPV) can be calculated using Equation (4).

$$\text{NPV} = \sum_{i}^{t_{CSP}} \frac{B_i - C_i}{(1+d)^i} - C_{CSP} \quad (4)$$

where B_i represents the annual benefit accrued to the investor in a way of selling the electricity generated, and C_i is equal to ζC_{CSP}, which is the annual operation and maintenance cost of the CSP system

B_i can be obtained using Equation (5)

$$B_i = 8760\ x\ CF_{CSP}\ x\ P_{CSP}\ x\ P_e \quad (5)$$

where P_e is the purchase price of electricity delivered by the CSP system.

3.2.4 Benefit to Cost ratio (B/C)

Benefit to cost ratio is an important aspect in estimating the profits that can be obtained from the project of installing CSP technologies. The benefit to cost ratio (B/C) is shown in Equation (6).

$$\left(\frac{B}{C}\right)_{CSP} = \frac{1}{C_{CSP}}\ x\ \sum_{i}^{t_{CSP}} \frac{B_i - C_i}{(1+d)^i} \quad (6)$$

3.2.5 Internal Rate of Return (IRR)

The Internal Rate of return (IRR) is calculated by equating the NPV to zero (Equation 7).

$$NPV = 0 \quad (7)$$

3.2.6 Payback period

The payback period is defined as the ratio of capital cost of the system to the annual net revenue of the system as shown in Equation 8. The payback period is a parameter considered in the project to ensure that the capital will earn the profit in a short period of time. The longer the payback period, the lower the feasibility of a project.

$$Payback\ period\ (years) = \frac{Capital\ cost}{Annual\ revenue - Operation\ \&\ maintenance\ cost} \quad (8)$$

3.3 Techno-Economic Analysis

To perform the techno-economy analysis, It can be started with identifing potential locations in Malaysia. More steps are provided in Figure 4. Each step is explained in Sections 3.3.1 to 3.3.6.

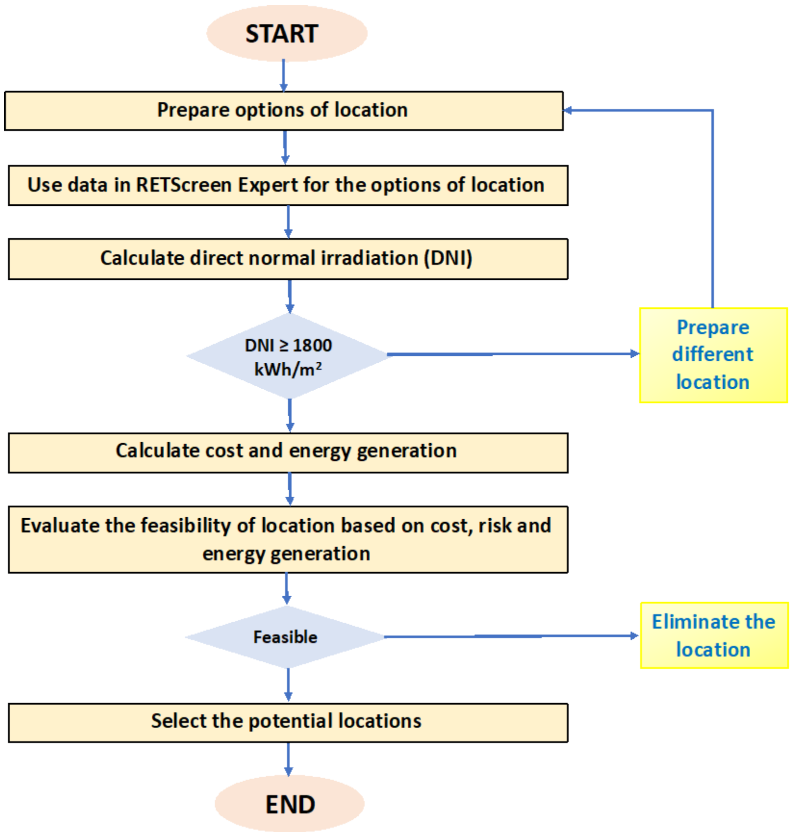


Figure 4. The flowchart for analyzing techno-economic of PTC and SPT technologies in Malaysia.

The direct normal irradiation (DNI) is used in the techno-economic analysis to find places with DNI of at least 1800 kWh/m^2 or more for the CSP technology to be built. The World Bank Group prepared the DNI for many countries, including Malaysia. **Figure 5** shows that the annual DNI in Malaysia ranges between 1314 to 1461 kWh/m^2. The average value of DNI could be considered an indicator in selecting and deciding potential locations for building the CSP technologies. Based on the DNI, the Northern part of Malaysia and many locations in Sabah are the potential locations. The techno-economic analysis employs the direct normal irradiation together with the daily solar radiation.

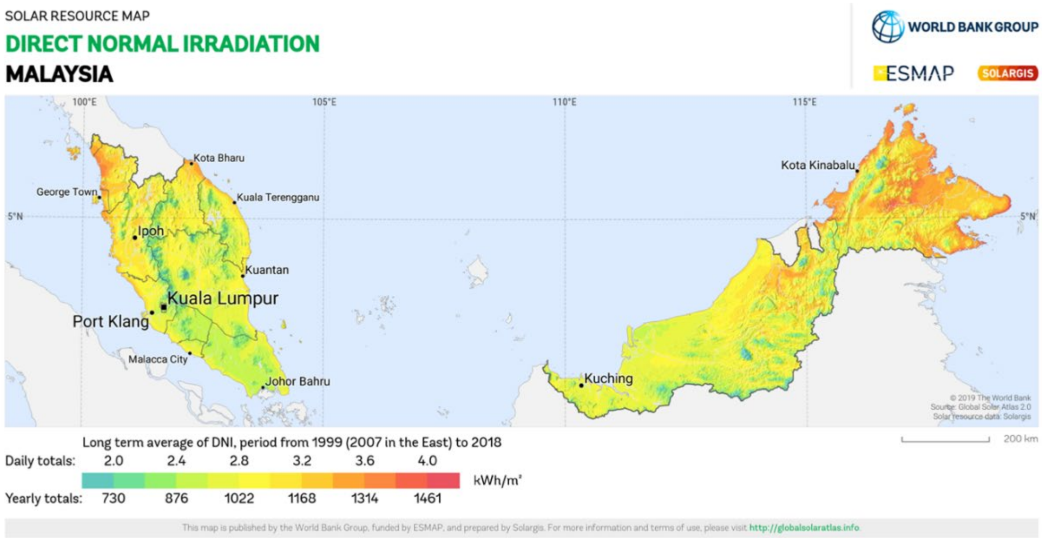


Figure 5. Direct normal irradiation (DNI) in Malaysia. (©2019 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis)

Selecting and deciding locations to install and implement either the PTC or SPT should be prioritized in the techno-economic analysis. Information or data such as energy usage, cost, emissions, financial benefits and risk associated with the project can be calculated after the location has been decided. The intensity of solar radiation at any location in Malaysia varies throughout the year. This variety is caused by many factors, i.e., solar hour angle, geographical angles, latitudes and longitudes, solar declination angle, and climate conditions, particularly the wind speed and humidity. The RETScreen Expert software is used to get the average daily solar radiation for calculating the direct normal irradiation (DNI) received by a location throughout the year.

3.3.3 Calculate Direct Normal Irradiation (DNI)

Twenty-three locations in Malaysia are identified in the RETScreen Expert software. The software generates the direct normal irradiation (DNI) for all locations to evaluate the potential locations for building the CSP technology. **Table 4** lists all locations with their DNI value. Many Northern regions of Malaysia receive higher amounts of solar radiation, which is greater than 1800 kWh/m^2 per year. The Southern regions receive the lowest solar radiation.

Not all locations in Malaysia are available in the RETScreen Expert software. This paper presents the analysis of locations with available data in the software. The DNI value for all the chosen locations is determined based on the average value of daily solar radiation gained from the software. Labuan is the location that received the most solar radiation at 2062 kWh/m^2 per year. Kuching is the location that received the lowest amount of solar radiation at 1529 kWh/m^2 per year. The average value of DNI for the locations in Malaysia is 1797 kWh/m^2 per day. Therefore, not all locations can be selected for implementing the CSP technologies. The amount of solar radiation is the crucial factor in deciding the location. The research selects 12 locations, from 23 locations, with a DNI value greater than 1800 kWh/m^2 per year for the techno-economic analysis.

Table 4. DNI value for various locations in Malaysia.

Location	DNI (kWh/m^2 per year)
Bayan Lepas	1810.40
Setiawan	1861.50
Kuah	1938.15
Kota Bharu	1803.10
Kuala Terengganu	1850.55
Kuantan	1894.35
Kuala Lipis	1766.60
Temerloh	1755.65

Ipoh	1730.10
Sungai Besar	1773.90
Seremban	1835.95
Melaka	1708.20
Batu Bahat	1689.95
Kluang	1679.00
Kuching	1529.35
Sri Aman	1715.50
Sibu	1755.65
Miri	1887.05
Bintulu	1843.25
Tawau	1788.50
Labuan	2062.25
Kota Kinabalu	1832.30
Sandakan	1828.65

3.3.4 Calculate Cost And Energy Generation

The DNI value for each location is then applied into Equations (1) to (3) to calculate the annual electricity generation and the unit cost of electricity. The capital costs use the project conducted in Spain (1 Euro = RM 4.88) as a reference, which gives RM 1,519 million and RM 170 million for ANDASOL-1 and PS-10, respectively.

The assumptions are required for the techno-economic analysis of PTC and SPT implementation in Malaysia. The assumptions are as follows:

i) The characteristics of the CSP technologies that will be analysed are based on the two projects used as the reference. The two projects is assumed to be implemented at the selected locations in Malaysia.

ii) The direct normal irradiation (DNI) is considered as the variable climatic parameter.

iii) The annual repair and maintenance cost for this CSP technology is assumed as 5% of the operating cost.

iv) The discount rate is taken at 6%.

v) For salvage value of the CSP system that will be built, it is estimated to be small at only 3% of the capital cost.

vi) The useful lifetime for this CSP system is taken as 30 years.

3.3.5 Evaluate The Feasibility Of Location

A techno-economic analysis is to study the economic efficiency of CSP technologies in Malaysia. The analysis is a basis for investment decisions of installing and implementing the CSP technologies. CSP technology is relatively new compared to the photovoltaic system, which already developed in Malaysia.

The DNI value calculates the cost and generation, including the annual electricity generation, cost of electricity, NPV, IRR, B/C ratio, and payback period for a specific location. The sensitivity analysis is also conducted to observe the reduction and increment of the costs towards the IRR value. The calculation is done using Microsoft Excel by taking the most feasible locations as the reference for the analysis. The sensitive factors are further analyzed.

Many techno-economic studies of CSP technology are available in literature. Examples of techno-economic analysis conducted in other countries are provided by researchers [12]-[22].

3.3.6 Select The Potential Location

Finally, the research finalizes the potential locations. The financial evaluation could provide relevant information to propose installing and implementing the CSP technologies at potential locations. It is feasible for the locations that received annual solar radiation of 1850 kWh/m^2 per year and above.

4.0 RESULTS AND DISCUSSION

4.1 Annual Electricity Generation and Unit Cost of Electricity

The capital recovery factor is calculated using Equation 3 and all the assumptions to give a value of 0.0726. The unit cost of electricity uses the capital recovery factor for both ANDASOL-1 and PS-10 systems. **Table 5** presents the parameters calculated for all the locations.

Capacity factors are in the range of 42 to 49 percent, which is as high as ANDASOL-1 of 41%. The annual radiation is 1750 kWh/m^2 per year, which is less than the average annual radiation, i.e., 1800 kWh/m^2 per year. The capacity factors of PS-10 show are lower than the ANDASOL-1. Setiawan, Kuah, Kuantan, Miri, and Labuan have low capacity factors at 23 percent. The average capacity factor of PS-10 is 21 to 22 percent, which is slightly lower than ANDASOL-1.

The annual electricity generation from the ANDASOL-1 system in Spain is 179 GWh. The range of annual electricity generation for locations in Malaysia considering the use of ANDASOL-1 system is between 185 to 211 GWh. The annual electricity generation of PS-10 system in Spain is 23 GWh, which is lower than the ANDASOL-1 system. The use of PS-10 system in locations in Malaysia will generate annual electricity between 21 to 24 GWh. The annual electricity generation shows that not many locations are feasible for implementing PS-10 system. However, this parameter should be considered with others in deciding either the locations are feasible or not.

Setiawan, Kuah, Kuantan, Miri and Labuan are estimated to have higher capacity factors based on the two reference systems; ANDASOL-1 and PS-10. The locations are feasible for both CSP technologies. Having a high capacity factor means that the project can suit the location as it receives a higher amount of annual solar radiation.

The unit cost of electricity using the ANDASOL-1 system will have tariff ranges between RM 0.67 per kWh and RM 0.76 per kWh. The tariff using the PS-10 system will be in range between RM 0.64 per kWh and RM 0.74 per kWh. The tariff value is RM 0.72 per kWh to consider the tariff for the financial analysis for all locations. The analysis resulted in two locations, which are Kuah and Labuan, fall below the tariff. The result shows that two systems are feasible to be implemented in Kuah and Labuan.

Table 5. The annual electricity generation and the unit cost of electricity in Malaysia using ANDASOL-1 and PS-10 systems.

Location	Annual Radiation (kWh/m^2 per year)	Capacity factor (%)		Annual Electricity Generation (GWh)		Unit Cost of Electricity (RM/kWh)	
		ANDASOL-1	PS-10	ANDASOL-1	PS-10	ANDASOL-1	PS-10
Bayan Lepas	1810.40	42.42	22.39	185.41	21.61	0.76	0.73
Setiawan	1861.50	43.61	23.02	190.64	22.22	0.74	0.71
Kuah	1938.15	45.41	23.97	198.49	23.14	0.71	0.68
Kota Bharu	1803.10	42.24	22.30	184.66	21.52	0.76	0.74
Kuala Terengganu	1850.55	43.36	22.88	189.52	22.09	0.74	0.72
Kuantan	1894.35	44.38	23.42	194.00	22.61	0.73	0.70
Seremban	1835.95	43.01	22.70	188.02	21.92	0.75	0.72
Miri	1887.05	44.21	23.33	193.26	22.53	0.73	0.70
Bintulu	1843.25	43.18	22.79	188.77	22.00	0.75	0.72
Labuan	2062.25	48.32	25.50	211.20	24.62	0.67	0.64
Kota Kinabalu	1832.30	42.93	22.66	187.65	21.87	0.75	0.72
Sandakan	1828.65	42.84	22.61	187.28	21.83	0.75	0.73

4.2 NPV, IRR, B/C Ratio and Payback Period

The calculation for net present value (NPV), internal rate of return (IRR), benefit-to-cost (B/C) ratio and payback period for both systems use Equations 4 to 7. The electricity tariff is RM 0.72 per kWh. **Table 6** shows the value of NPV, IRR, B/C ratio, and payback period according to locations in Malaysia.

All locations in Malaysia, as listed in **Table 6**, have a positive value of NPV. The IRR value of the PS-10 system for all locations is higher than the discount rates, which are assumed as 6%. The payback period for the PS-10 system is in the range of 11 to 14 years. The B/C ratio is between 4.8 to 6.1. Four locations, Kuah, Kuantan, Miri, and Labuan, have high values of B/C ratio with 5.74, 5.61, 5.58, and 6.11, respectively. The payback period is the range between 11.9 to 14.0 years. The payback periods for Kuah, Kuantan, Miri, and Labuan are 12.93, 13.31, 13.38, and 11.97 years.

Four locations, which are Kuah, Kuantan, Miri, and Labuan, have higher IRR value using the ANDASOL-1 system than the discount rate. The payback period for installing and implementing the ANDASOL-1 system is expected between 13 to 15 years. The B/C ratio of the ANDASOL-1 system is between 3.9 and 4.0, lower than the PS-10 system. The payback period of the ANDASOL-1 is in the range of 14.3 to 15.7 years, which is longer than the PS-10 system. Kuah, Kuantan, Miri, and Labuan have better benefit-to-cost ratios and shorter payback periods than other locations.

The comparison between the ANDASOL-1 and PS-10 systems indicates that Kuah, Kuantan, Miri, and Labuan could become potential locations for installing and implementing either the ANDASOL-1 or PS-10 system. The financial evaluation could provide information related to potential locations to propose building the CSP technologies in Malaysia. It is feasible for the locations that received annual solar radiation of 1850 kWh/m^2 per year and above.

Table 6. The NPV, IRR, B/C ratio, and payback periods according to locations in Malaysia.

Location	NPV		IRR		B/C Ratio		Payback Period (years)	
	ANDASOL-1	PS-10	ANDASOL-1	PS-10	ANDASOL-1	PS-10	ANDASOL-1	PS-10
Bayan Lepas	1.929	1.019	5.22	7.23	3.86	4.85	15.66	14.09
Setiawan	1.984	1.047	5.63	7.54	3.97	5.51	15.09	13.61
Kuah	2.065	1.090	6.56	8.07	4.13	5.74	14.33	12.93
Kota Bharu	1.921	1.014	5.09	7.19	3.84	5.34	15.74	14.18
Kuala Terengganu	1.972	1.041	5.48	7.52	3.94	5.48	15.21	13.71
Kuantan	2.019	1.065	6.03	7.98	4.04	5.61	14.75	13.32
Seremban	1.956	1.033	5.37	7.41	3.91	5.44	15.37	13.84
Miri	2.011	1.061	6.01	7.87	4.02	5.58	14.83	13.38
Bintulu	1.964	1.037	5.46	7.49	3.93	5.46	15.29	13.78
Labuan	2.198	1.160	6.93	8.32	4.40	6.11	13.23	11.97
Kota Kinabalu	1.953	1.031	5.32	7.36	3.91	5.43	15.41	13.88
Sandakan	1.949	1.029	5.26	7.28	3.90	5.42	15.45	13.91

4.3 Sensitivity Analysis

Sensitivity analysis is a method to measure the impact of uncertainties of one or more input variables, leading to uncertainties on the output variables. The analysis could improve the model's prediction or reduce the uncertainties to any changes in input variables based on a qualitative or quantitative model response. The expected values of various parameters are used to evaluate the robustness resulted from any changes. The sensitivity analysis could also reduce the uncertainties of the parameters or input variables and locations for the CSP technologies. Labuan is used as a reference location for the sensitivity analysis because it shows better values of all parameters than other locations.

4.3.1 Annual Electricity Generation

Figure 6 shows the relationships between the annual electricity generation and IRR concerning the parabolic trough collector (PTC) and solar power tower (SPT). IRR value of SPT technology will increase and reach up to 12.46 percent when the annual electricity generation increases to 20 percent. The IRR of PTC technology will increase 11.05 percent, slightly lower than SPT, when the annual electricity generation increases to 20 percent.

Based on the sensitivity analysis, it is observed that the annual electricity generation does have a significant effect on the IRR value. It is because the annual electricity generation could determine the income produced by a specific technology. Therefore, it is essential to optimize and increase the electricity generation to improve the cost-benefit of the CSP technologies. The direct normal irradiation (DNI) value plays a vital role in generating electricity. The decision-maker should choose a location with a higher DNI value to build the CSP technology.

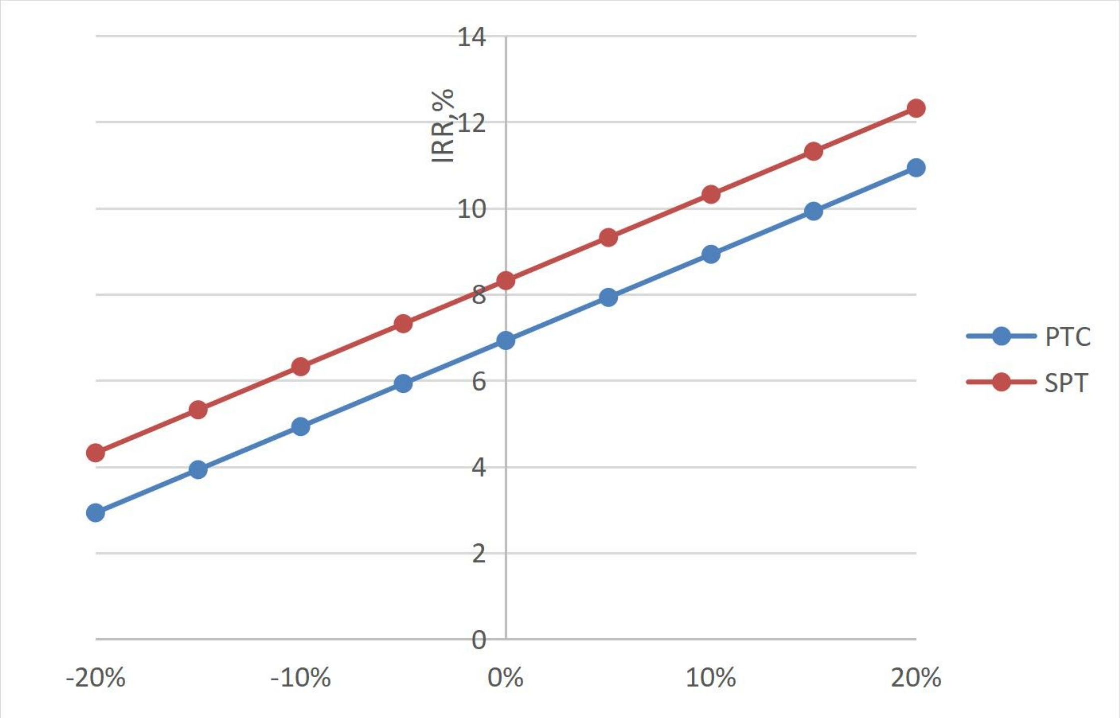


Figure 6. Sensitivity analysis of IRR with regard to the annual electricity generation.

4.3.2 Initial Cost

Figure 7 shows the impact of the initial cost on the IRR for both PTC and SPT technologies. When the initial cost is increased to 20 percent for the SPT technology, the IRR value decreases to 10.12 percent. The IRR value can increase to 23.01 percent when the initial cost is decreased, becoming -20 percent. Similarly, the IRR of the PTC technology will increase from 13.83 to 21.87 percent when the initial cost is reduced to -20 percent. The IRR value of PTC technology will decrease to 9.00 percent when the initial costs increase to 20 percent.

The initial cost of technology should be reduced in order to increase the IRR value. Reducing the initial cost can impact other costs such as operating and maintaining the PTC or SPT technology. It will also increase the NPV and the benefit-cost ratio, and consequently, it increases the feasibility of the projects.

The initial investment of PTC or SPT technology requires a high initial investment to start up the technology. The projection could also happen for both ANDASOL-1 and PS-10 systems, which requires a high initial investment. Both technologies are new, and not many countries could install and implement the technology as it requires a high direct normal irradiation (DNI). The initial investment in new technology usually is high because there are not many experts. The investment cost could be reduced if there are many research and development of PTC and SPT technologies.

The expansion of the project's scale and the market could result in large concentrating solar power (CSP) plants. The mass production of the equipment and materials and the optimization of PTC and SPT technologies could reduce the initial cost for the construction of CSP technology. However, there is a concern regarding expertise in the CSP technology, particularly the PTC and SPT. The management of CSP projects, engineers, contractors, and professional technical personnel should improve the design and construction of the CSP plants to reduce the initial costs [23],[24].

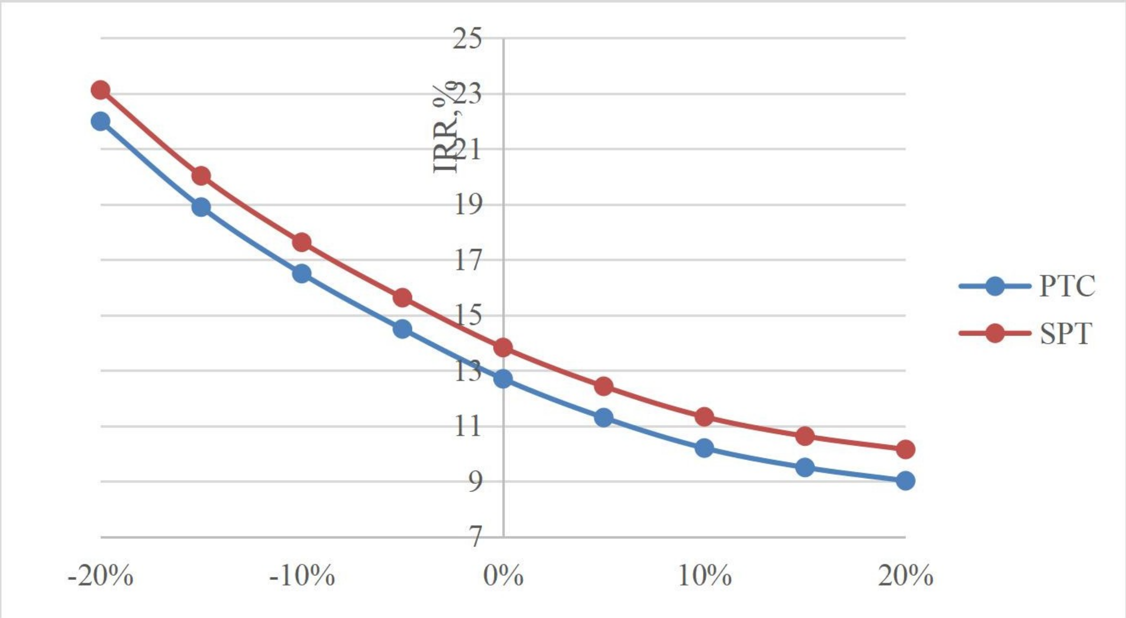


Figure 7. Sensitivity analysis of IRR with regard to the initial cost.

4.3.3 Operation and Maintenance Cost

Figure 8 presents the effect of operation and maintenance cost on the IRR of PTC and SPT technologies. The IRR of the SPT technology could reduce to 8.12 percent if the operation and maintenance cost is 20 percent. The IRR can be increased to 12.16 percent when the operation and maintenance costs are reduced to -20 percent. A similar trend can be observed for the PTC technology. If the operation and maintenance cost had been decreased, then the IRR of the PTC technology would increase to 11.50 percent. The IRR will decrease when the operation and maintenance costs increase to 20 percent. Both observations indicate that the value of IRR is inversely proportional to the operation and maintenance cost.

The increment of IRR is smaller because the operation and maintenance costs do not cover the whole process. The operation and maintenance costs mainly consist of the equipment and machine used for building the technology. Such factors should also be considered to improve the cost-benefit analysis, increase the IRR value, and subsequently become profitable to investors.

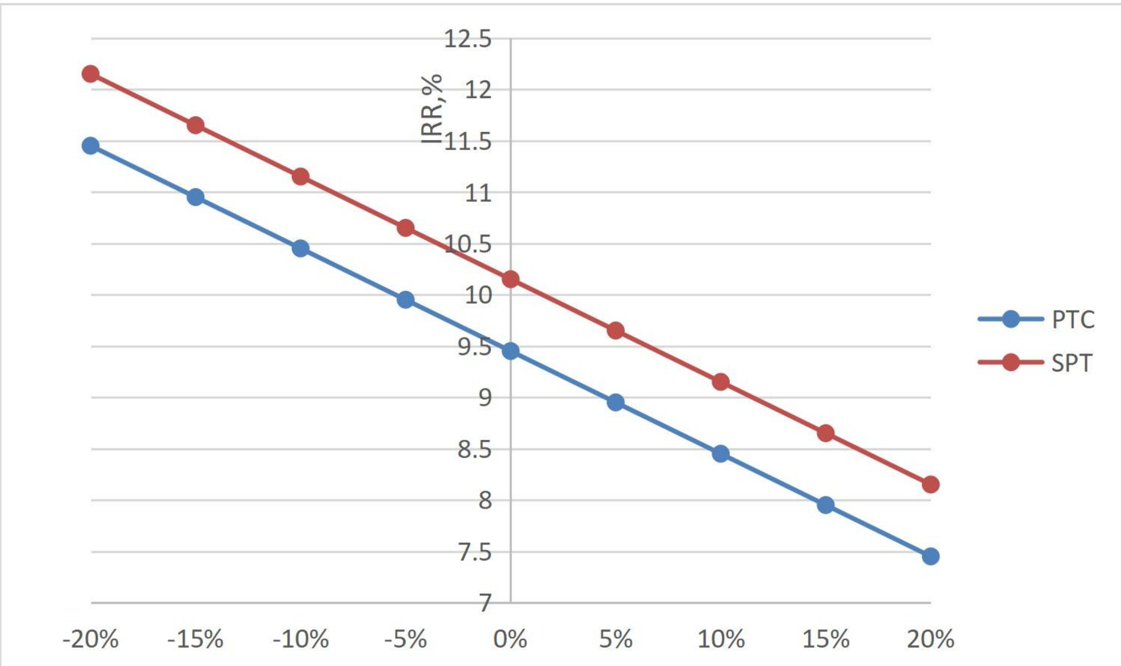


Figure 8. Sensitivity analysis of IRR with regard to the operation and maintenance costs.

4.3.4 Interest Rate

Figure 9 shows the effects of the interest rate on the IRR for PTC and SPT technologies. If the interest rate of PTC technology decreased to 20 percent, the IRR would increase to 11.21 percent. Increasing the interest rate to 20 percent will decrease the IRR value to 7.13 percent. The sensitivity analysis of the IRR of SPT technology shows a similar trend with the PTC technology. Based on the sensitivity analysis, it is expected that the project or investors will get a high IRR value if the interest rate of technology is low.

Prior to constructing the CSP technology, an investment for the initial start-up of the technology is the first thing that should be included in the planning and feasibility study. The loan interest is crucial in determining other parameters, such as the higher the rate, the lower the annual net cash flows. Low-interest rate of the technology could reduce the loan interest and, at the same time, increase the IRR value.

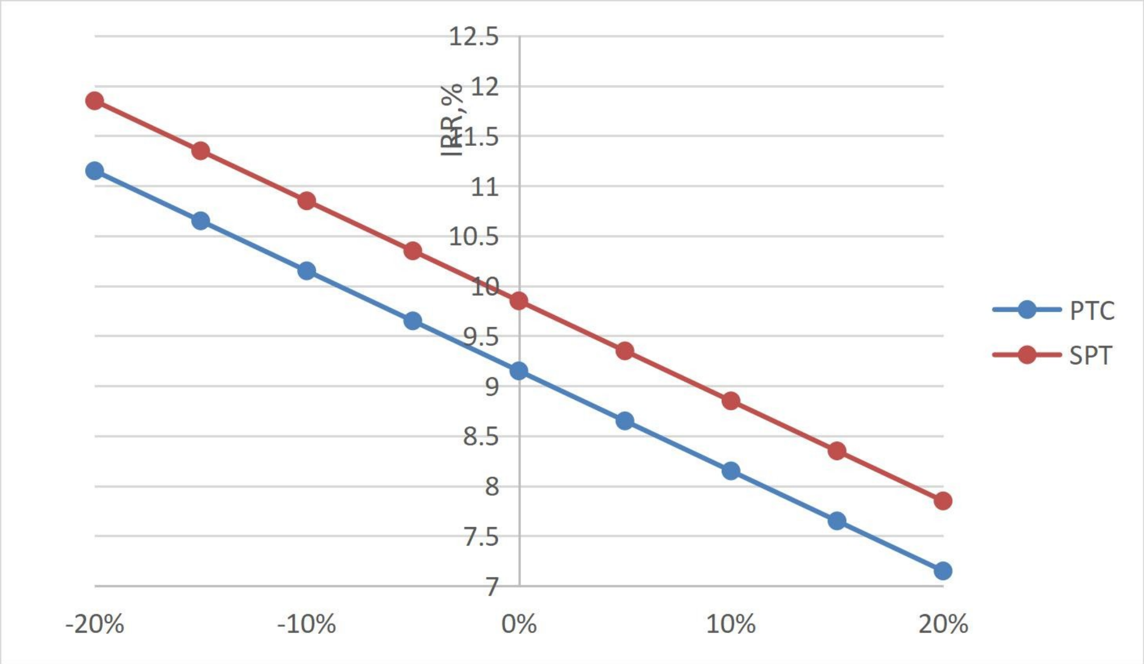


Figure 9. Sensitivity analysis of IRR with regard to the interest rate.

5.0 CONCLUSIONS

5.1 Conclusions

The techno-economic analysis for both parabolic trough collector (PTC) and solar power tower (SPT) technologies shows that both parabolic trough collector (PTC) and solar power tower (SPT) technologies are possible to be installed and implemented in Malaysia. However, the potential locations must be analyzed and studied correctly. Kuah, Kuantan, Miri and Labuan are the potential locations. Labuan could be the most promising PTC and SPT technology project because it has the highest direct normal irradiation (DNI) received annually. Two reference projects, ANDASOL-1 and PS-10 systems in Spain, are used as references for the techno-economic analysis.

The sensitivity analysis is conducted after the techno-economic analysis considering Labuan as the reference location, among others. Annual electricity generation and the initial cost of investment are two sensitive factors affecting the IRR value of the PTC and SPT technologies. The implementation of PTC and SPT technologies in Malaysia can generate electricity to give a long-term supplement to the energy and substitute the non-renewable energy.

The availability of resources throughout the year and the cost of constructing the technology are two main aspects of installing and implementing the PTC and SPT technologies. Currently, there is no such technology that has been built in Malaysia. The investment cost plays an important role in initiating the installation and implementation of the technology.

5.2 Future Work

The study should include an analysis of SPD and LFR to overview all of the systems and compare the system's feasibility. More detailed research is required to consider all the factors regarding the land suitability and site selection for implementing the technology for selecting potential locations. The CSP technology requires extensive research in determining the best configuration to optimize the output from projects.

Any CSP technology will consume huge spaces, making both the land suitability and site selection essential factors in the study. Therefore, a potential location with large spaces and equipped with facilities is the best option to improve the production of renewable energy in Malaysia.

Acknowledgements

This paper is a project of Final Year Project (*Projek Sarjana Muda*) of the School of Chemical and Energy Engineering.

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