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STUDY THE FEASIBILITY OF PARABOLIC DISH (PD) FROM SEVERAL PROSPECTIVE CRITERIA IN MALAYSIA ENVIRONMENT

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ABSTRACT

Promoting the use of Renewable Energy (RE) resources has become one of the top government agendas throughout the world. However, in order to develop RE such as Concentrating Solar Power (CSP) in Malaysia, several key factors that affect the performance of this system should be thoroughly investigated. Therefore, this paper aims to study the feasibility of implementing Parabolic Dish (PD) based on CSP in Malaysia environment by evaluating the CSP technologies, Meteorological data, Direct Solar Irradiance (DNI), global Parabolic Dish development, sites selection, and Levelized Cost of Energy (LCOE) of the PD system. Therefore, an innovative development and research of Parabolic Dish CSP should be carried out with an in depth consideration on both technical and economic aspects to ensure that the Parabolic Dish technology development will be as matured as the other CSP technologies.

Keywords: renewable energy, concentrating solar power, direct normal irradiance, parabolic dish, levelized cost of energy.

INTRODUCTION

It is expected that future energy will be less dependent on fossil fuel. This is due to an increasing production from Renewable Energy (RE) resources such as solar, biomass, wind and etc.

Generally, solar energy is one of the REs with a great potential, cleanliness and by far the most abundant energy resource on earth (Rafeeu and Adam, 2010), (Ahmad, Shafie, and Ab Kadir, 2012), (Arvizu *et al.*, 2011). It can be converted to electrical energy in two ways; photovoltaic (PV) system and CSP system. PV and CSP collect different fractions of solar resource and have different production capabilities as well as different region to develop their power plants. These two systems use different technologies to generate electricity.

Generally, there are four types of CSP technologies as shown in Figure-1; Parabolic Troughs system, Linear Fresnel system, Parabolic Dish System and Power Tower system (Quaschning, 2004).

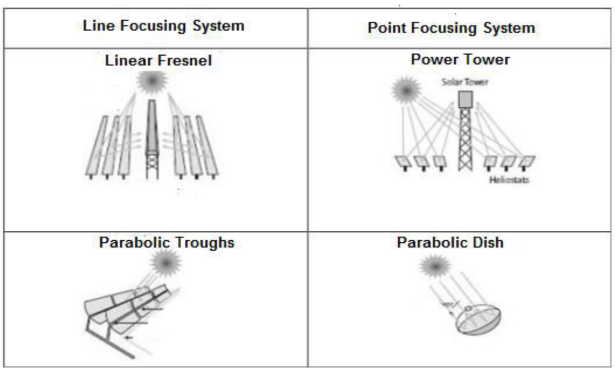

Figure-1. Four type of the CSP technologies.

CSP systems can be differentiated into line focusing and point focusing systems. Two major types of line focusing systems are Parabolic Trough and Linear Fresnel, while the Parabolic Dish and Power Tower are point focusing systems. Line focusing system is equipped with single axis tracking system. It can concentrate sun rays about 100 times and reach operating temperature up to 150°C (Quaschning, 2004), (van Voorthuysen, 2006), (Machinda *et al.,* 2011). For point focusing systems such as Parabolic Dish system and Power Tower system, they are able to concentrate sunlight as far as 1,000 times and reach operating temperature more than 1000°C (van Voorthuysen, 2006), (Machinda *et al*., 2011), (Dunn and Hearps, 2012). Point focusing systems are equipped with double axis tracking system to ensure that sunlight is always concentrated on the receiver.

In general, CSP provides economic benefits which could give a significant contribution to develop more sustainable energy, environmental friendly and fuel cost effectiveness of generating energy with no fuel cost (Quaschning, 2004), (Machinda *et al*., 2011), (Jayakumar, 2009). However, developing CSP Plant in Malaysian environment draws, public concerns on visual impacts especially the land area requirements for the centralized plant. More land is needed for the plant in order to generate high electrical energy. Nevertheless, effects of land use can be reduced by choosing areas with low population density. Furthermore, among the CSP technologies, PD is most suitable for small scale plant and they are modular. PD is suitable for small area with each unit typically generating output of 3 to 25 kW and has potential to become one of the least expensive sources of RE. In addition, the area of the CSP plant especially the

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PD is smaller than the area of the PV plant (Gerrit *et al.*, 2010).

Compared to other CSP technology, PD offers the highest thermal and optical efficiency. The concentration process can achieve more than 1, 500 times (Dunn, Hearps and Wright, 2012). The current tests for PD show that solar to electric conversion efficiencies can be as high as 30%. This is significantly higher than other solar technology (Wagner, 2009). Hence, PD has the highest optical efficiencies, thermal efficiencies, concentration ratio, working temperatures and efficiencies compared to other CSP technologies. Because of these me advantages, CSP system especially the PD is viable in Malaysian environment.

CSP RESEARCH IN MALAYSIA

Preliminary research on CSP, especially for PD has been carried out by a few researchers in Malaysia. However, the researchers are mainly focusing on the sub-system levels with less detail on the feasibility of CSP implementation by referring to the Direct Normal Irradiance (DNI) in Malaysia. In 1997, a pioneer work utilizing a solar bowl as the CSP system was carried out at University Putra Malaysia (Pitz-Paal *et al.*, 2012). However the efficiencies and the annual energy collection of the solar bowl is lower when compared to other collector optics and it has no advantage in terms of compensation (Vergura and Lameira, 2011). In contrast to the solar bowl, PD technologies carries the much better prospects for off-grid operation, as well as provide the highest temperatures and efficiency (Hwang, 2010).

Rafeeua and Ab Kadir (2012) state that there is a significant variation in the efficiency of the concentrator with different reflective materials used (Li, Wang, and Yu, 2009). Concentrator in CSP is used to concentrate the solar radiation to generate high temperature. Concentrator materials with good reflectance and reflection of solar radiation are much preferred. In addition, it must have a long lifetime and low capital cost because the reflectance surface will often decline especially when being exposed to the Malaysian tropical environment with copious rainfall as well as relatively high level of humidity.

PD with aluminium reflector is more efficient than stainless steel. Reflector can be characterized by the amount of the sunlight reflected onto the receiver. The performance is influenced by the sun shape, quality of the reflector, solar tracking accuracy as well as the CSP plant location (Ng, Adam and Azmi, 2012). Materials used for the concentrator are mostly silver and aluminium and the reflecting toward the solar radiation is around 80% to 90% (Kaplani, Raiford, and Jali, 1985), (Noor and Muneer, 2009). While the previous research has revealed that under tropical environment, mirror reflector with silver back surface has a better reflectance and can reach the highest temperature (Rafeeu and Ab Kadir, 2012), (Peiyao *et al.*, 2007).

Apart from the concentrator, tracking system is important in order to maximize the output generation and efficiencies of the CSP systems. These systems can adjust the concentrator to follow the sun during the day and the absorber position to be as close to the sun beam (Peiyao *et al.*, 2007). In recent research, Aliman and Daut (2007) are able to focus images into one fixed target and maintain the images throughout the day (Stine and Diver, 1994). By a using concept of power tower system and rotation-elevation mode of sun tracking, this research has proven that the sun tracking is significant in maximizing the temperature. Hence, tracking system is important to CSP in providing a significantly greater energy yield for a given DNI compared to solar system with a fixed position.

MALAYSIA METEOLOGICAL DATA

The potential of a CSP plant is largely determined by DNI. However, the DNI will be determined by meteorological factors. Therefore, it is essential to know the meteorological data such as solar radiation, rainfall, cloud cover and the humidity before developing any CSP plant.

Solar radiation distribution in Malaysia

Malaysia is located at Southeast Asia, between 1◦ and 7◦ in North latitude and 100◦ and 120◦ in East longitude (Yousif, Al-shalabi, and Rilling, 2011), (Singh *et al.*, 2012). The total of Malaysia's landmass is about 329, 845 km2 and almost 60% of Malaysia landmass is made up of East Malaysia and the rest is Peninsular Malaysia as shown in Figure-2.

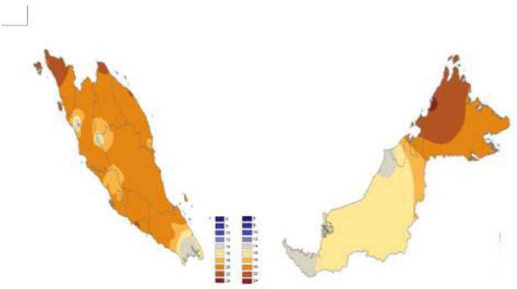

Figure-2. Annual average solar radiation (MJ/m2/day) (Yousif, Al-shalabi, and Rilling, 2011).

The daily solar irradiation in Malaysia is around 4.7 to 5.8 kWh/m2 (is said to be achieved 6.8kWh/m2 in August and November), monthly is 133.0 kWh/m2 and yearly value around 1596.5 to 1643 kWh/m2/year (Sembiring *et al.*, 2007), (Nair and Ford, 2012). The sunshine duration is more than 2, 200 hours per year and annual temperature varies from 26 to 28◦C.

The northern states and several places in the East Malaysia receive high solar radiation throughout the year (Nair and Ford, 2012). Solar radiation is decreased from the northern states to the southern states. Northern states such as Perlis, a part of Kedah, Penang, Kelantan, a part of Melaka and a few places in East Malaysia (especially Sabah) receive the most amount of solar radiation, while

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Johor at the southern Peninsular Malaysia and most parts in Sarawak receive the lowest solar radiation. Nevertheless, by evaluating the solar radiation data in Malaysia, northern states and several places in east Malaysia are viable place for CSP compared to other places in Malaysia.

Rainfall

Malaysia is located in the tropical wet climate zone where annual rainfall is about 2250 mm/year. Generally, Sabah and Sarawak receive a larger amount of rainfall compared to other states in Peninsula Malaysia (Mekhilef *et al.*, 2012). Kuching and Bintulu in Sarawak, experience heavy rainfall with the measurement of 11.68 mm and 11.02 mm, whereas areas with lower rainfall are Sitiawan, Tawau and Melaka with the measurement of 4.86 mm, 5.33 mm and 5.42 mm (Hussin *et al.*, 2010). Areas that experience heavier rainfall such as Kuching and Bintulu have low potential for CSP development compared with Sitiawan, Tawau and Melaka the large amount of rainfall will affect the efficiency of the concentrator as well as the overall of the CSP system.

Cloud cover

Cloud cover is relatively high throughout the year and it is very rare to have clear skies for a full day even in the dry period. Many areas in Malaysia have the highest values of cloud cover in October until February and lowest value of the cloud cover from Mac to September. According to Engel-Cox *et al* (2012), Tawau has a significantly lower cloud cover compared to other locations in Malaysia; whereas Kota Bharu, Kota Kinabalu, Kuantan and Labuan are the ones with the highest cloud cover (Hussin *et al.*, 2010). Meanwhile, Melaka and Bayan Lepas have been identified as locations with low cloud cover in Peninsular Malaysia. Cloud with specific weather patterns is among the most important factor that limit, restrict and eliminate a large amount of sunlight from reaching the atmosphere and subsequently affecting the amount of radiation received at the earth's surface.

Humidity

Humidity in Malaysia varies from 80% to 90%. The low relative humidity area was Subang and Bayan Lepas; 78.6% and 79.4%. The higher relative humidity areas are a few cities in Sarawak such as Kuching, Bintulu, Miri and Sibu. Others are Kuantan, Sitiawan and Tawau, while areas with a slightly lower humidity are Kota Bharu, Kota Kinabalu, Melaka, and Labuan.

Overall, heavy rainfall, constant high temperature, high levels of cloud cover and relative humidity are the characteristics of Malaysian tropical climate. However, northern states and several places in Sabah receive high solar radiation, lower rainfall, lower cloud cover and lower humidity. These places can be considered as viable for CSP development compared to other places in Malaysia.

DIRECT NORMAL IRRADIANCE

Knowledge on the quality and future reliability of the sunlight is essential to get an accurate analysis of CSP system performance (Solangi *et al.*, 2011). CSP technologies uses direct sunlight and it is depending on the intensity of the sun's radiation referred as DNI.

DNI is the amount of radiation that comes in a direct line from the sun. Under clear sky conditions, DNI represents more than 80% of the solar energy that reach the Earth's whereas in a cloudy day the DNI is nearly zero. Some of the solar radiation which reaches the earth's surface is absorbed and scattered. The solar radiation is absorbed by ozone, oxygen and water vapor.

Weather conditions such as storms and clouds become the main elements that change solar radiation to the surface. Meanwhile, a good solar resource is a top priority for CSP technology. Therefore in order to be economically feasible, CSP technology requires DNI of at least 1900-2000kWh/m2/year or daily solar radiation value of at least 5kWh/m2/day (Wagner, 2009). Malaysian DNI is around 1,401-1,600 kWh/m2/year (Aliman and Daut, 2007).

The CSP plant is established mostly in a country with DNI higher than 1800kWh/m2/year. Nevertheless, there is no technical reason why CSP plants cannot run at DNI levels lower than 1800kWh/m2/year (Azhari, Sopian, and Zaharim, 2008). Previous studies have revealed that most world regions except Canada, Japan, Russia and South Korea have significant potential areas for CSP (Quaschning, 2004), (Stoffelet *et al.*, 2010), (Janjai, Laksanaboonsong and Seesaard, 2011). Therefore, the most promising areas for developing CSP plants are areas with high sun exposure, low cloud cover and in dry arid mid-latitude zone.

GLOBAL PARABOLIC DISH DEVELOPMENT

The development of CSP Technologies especially the parabolic dish technology is still at the early stage (Buck, Heller and Koch, 1996). At the end of 2010, about 1,300 megawatt (MW) of CSP was in operation worldwide (SunShot Vision, 2012). In 2012 the global installed capacity of CSP plants increased to 2 gigawatts (GW). However, by 2015 there is an additional of 12 GW being planned for the installation? However, most of the CSP projects that are undergoing or currently under construction are based on the parabolic trough technology (IRENA, 2012) in which, more than 90% are using parabolic trough technology (Table-1).

Parabolic trough is the dominant and most mature technology in CSP, followed by Power Tower. Two other technologies which are Linear Fresnel and Parabolic dish are still in the early growth of phases. Globally, the installed capacity for solar power tower is 70MW whereas linear Fresnel has a capacity of 31MW in Spain and 4MW in Australia (IRENA, 2012). The electricity generation cost for parabolic dish is quite higher compared to the other CSP technologies such as parabolic trough or tower power plants despite its high efficiencies.

In 2010, the global installed capacity for parabolic dish was 1.5MW and located in Arizona. In 2013, the installed capacity of the Parabolic Dish increased to 3MW with additional plant located in Utah and a few number of prototype dish engine systems are currently operating in Nevada, Arizona, Colorado and Spain.

SITE SELECTION FOR THE PARABOLIC DISH TECHNOLOGY

Parabolic dish has a few advantages such as it is modular, suitable for small scale plant and most sophisticated for small CSP plant. However, selecting a suitable site is one of the most crucial parts for developing a viable solar CSP plant such as the parabolic dish technology. The aims in selecting a site or the location are to maximize production and minimize cost. Fundamental to the siting of CSP technologies, the parabolic dish facilities require direct abundant solar radiation in order to generate electricity as only strong direct solar irradiation can be focused to generate the highest temperatures required for electricity generation. On the other hand, indirect sunlight cannot be concentrated and locations with considerable cloud cover are unsuitable for parabolic dish plant (Affandi, Gan, and Ab. Ghani, 2015). Hence, the electricity generation of any of the plant is mostly influenced by the solar irradiance. Moreover, more than 5 kWh/m2/day of Direct Normal Irradiance (DNI) is required in order to function and be economic.

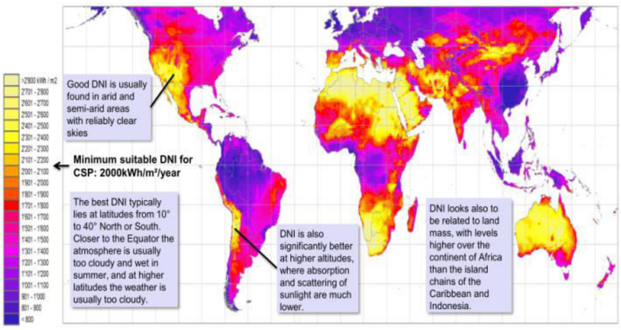

Figure-3. World direct normal irradiance source: Meteonorm 7.0 (www.meteonorm.com).

Globally, a few sites or locations with excellent solar resources and most desirable for developing the parabolic dish based CSP plants exist; North Africa, Middle East, Southern Africa, Australia, Western of the United States America and parts of South America as shown in Figure-3. Even so, this apparently depends on average meteorological conditions over a year as the direct solar irradiance will be influenced by the cloud cover, humidity and local environmental factors such as debris and air contamination.

COST AND LEVELIZED COST OF ELECTRICITY (LCOE)

Generally, good resources for developing CSP plant are widely distributed in several locations. However, the abundance of resources is not an attractive factor to develop CSP, unless the cost start to decline (Hinkley *et al*., 2013). Nevertheless, since 2006 as a result of declining investment costs and LCOE, as well as new support policies from several countries such as Australia, United States and Spain, a new number of CSP plants have been brought on line (IRENA, 2012), (Natalia and Kulichenko, 2012).

Parabolic dish and linear Fresnel are assumed to have higher risks technologically and financially. Nevertheless, parabolic trough is the most mature technology; has the lowest development risk and lower technological risk. This is followed by power tower, in which the technology is closest to the commercial maturity stage. Therefore, the investment, operation and management costs (O&M) for parabolic through and for power tower technologies involves a reduction in financial risks (Benz, 2010). Furthermore, previous assessments indicate that the LCOE is dominated by the parabolic trough and power tower capital cost (Clifton and Boruff, 2010).

Currently, the levelized cost of electricity (LCOE) for the CSP plants is high. However, LCOE for the CSP technologies often varies by its technology, country, renewable energy resource, operating costs and the efficiency or performance of the CSP technology (Simbolotti, 2013). Nowadays, by assuming that the capital cost is 10%, LCOE for parabolic trough plants is in the range of USD 0.20 - USD 0.36/kWh and LCOE for solar towers is between USD 0.17-USD 0.29/kWh. Nevertheless, LCOE in areas with excellent solar resources could be as low as USD 0.14 to USD 0.18/kWh. The cost ranges given are inclusive for all of the CSP technologies such as parabolic trough, power tower, linear Fresnel and parabolic dish. Different CSP technologies will show different performance under different DNI level.

Primarily, LCOE depends on capital costs and solar resource in which, there is a strong relationship among DNI, power output and LCOE (IRENA, 2012). Plants located in high DNI areas will yield more energy, allow greater electricity generation and have lower LCOE compared to the CSP plants that are located in lower DNI areas (IRENA, 2012), (Affandi, Gan, and Ab. Ghani, 2015), (Trainer, 2013), (Hinkley *et al*., 2011).

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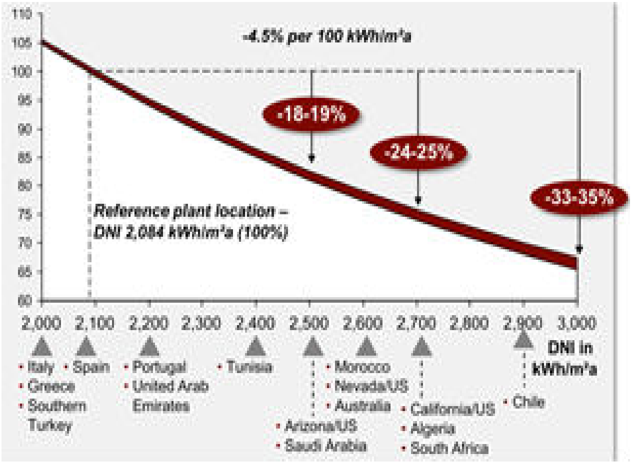

Figure-4. Tariff/LCOE development over DNI level (Trainer, 2013).

The LCOE of identical CSP plants will be around one-quarter lower for locations with higher DNI such as United States, Algeria or South Africa with the DNI level of 2700 kWh/m2/year or 8 kWh/m2/day compared to the locations such as Spain with DNI level of 2100 kWh/m2 /year or 5.8 kWh/m2/day as shown in Figure-4 (Irena, 2012). Nevertheless, the practical impact on the LCOE of a given CSP plant, with individuality design and capital costs, of higher DNI can be substantial (IRENA, 2012).

Costs of electricity from CSP plant such as the parabolic dish system are relatively high and currently it is still higher than the conventional fossil fuel technologies. However, cost reduction opportunities will be better if the plant designs are perfect and the CSP plants operate in a larger size of CSP plant (IRENA, 2012). Cost reduction opportunities due to advances in R and D, competitive in supply chain, improvements in the solar field performance, solar-to-electric efficiency as well as the thermal energy storage systems are significant, and the LCOE is expected to reduce (Sun Shot Vision, 2012).

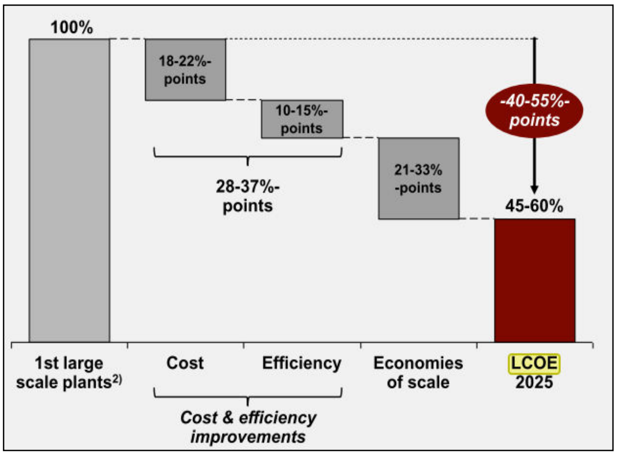

Figure-5. Projected tariff development for CSP plant by measure or over time (Trainer, 2011).

CSP plants which has thermal energy storage such as parabolic trough, power tower and linear fresnel have similar or lower LCOE than CSP plants without storage such as parabolic dish (IRENA, 2012), (Natalia and Kulichenko, 2012). The thermal energy storage system in CSP plant help to increase the reliability, capacity factors and the dispatch ability requirements demand (Hinkley *et al.*, 2013). Furthermore, the total installation cost for CSP plants without storage is higher than for PV and it is expected that the cost will fall around 15% by 2015 owing to technology learning, economies of scale, and improvements in manufacturing and performance reducing the levelized costs of electricity from CSP plants to around USD 0.15-0.24/kWh. By 2020, expectations of the capital cost reductions of 35% - 50% could be achieved and even the higher reductions of 40-55% by 2025 will be possible as shown in Figure-5 (IRENA, 2012), (Hinkley *et al.*, 2013), (Hearps, Mcconnell and Sandiford, 2011), (Energy, 2012).

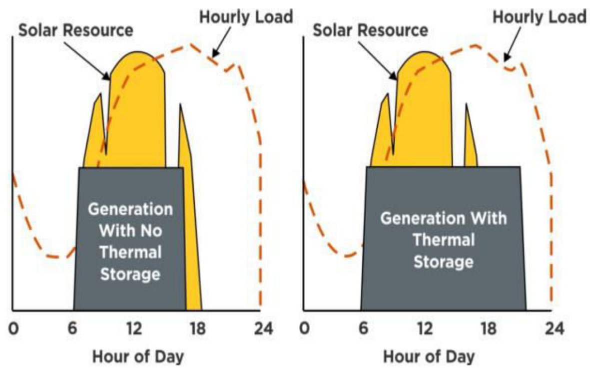

Figure-6. Thermal storage and utility demand (Hinkley *et al.*, 2013).

Moreover, the growths of the CSP sector falter as a result of prices decline for the PV module. Hence, several high profiles CSP projects are converted to PV. Nevertheless, in the long term, the ability of CSPs to combine the energy storage and supplement conventional power generation offers benefits beyond the kilowatt-hour generated (Lau, Gan, and Tan, 2014).

As the energy storage can become a key for bridging the gap between energy supply and demand across the globe main obstacle in reaching the "grid parity" exist. Grid parity or the point at which electricity generated from Renewable Energy (RE) sources costs the same as electricity produced by fossil-fuelled power plants. Grid parity occurs when the cost of generating RE is equivalent or lowers than the cost of generating electricity from the conventional fossil fuels.

A global objective is to have a rapid cost reduction for the solar electricity to achieve grid parity. However, compared to the CSP systems, the grid parity has been achieved in many places with PV panels. In Malaysia, it is expected that the solar grid parity for the residential consumers will be in year 2026, which is one

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year earlier than the projected solar grid parity determined by Sustainable Energy Development Authority (SEDA) by using FiT rate (Lau, Gan, and Tan, 2014). Obviously, the feed-in tariff system in Malaysia is designed mainly for achieving the grid parity.

To get a clearer view of where the CSP stands in the race to grid parity, it is necessary to evaluate and compare the cost of both CSP and PV power generation. Several factors should be considered when assessing the cost competitiveness of PV and CSP such as LCOE. After grid parity is reached, the feed-in approval holders will be paid based on the prevailing displaced cost for the remaining effective period of their RE power purchase agreements (Energy, 2012).

Table-1. List of Countries with CSP Plant (IRENA, 2012), (Ahmed *et al.,* 2012), (Affandi, Gan, and Ab. Ghani, 2015).

*Under Development

Country	**Installed Capacity** (MW)	**Start Year**	**Technology**	**DNI value** (kWh/m²/year)
Algeria	25	2011	Parabolic Trough	2,700
Australia	3	2011	Power Tower	2,600
	9	2012	Linear Fresnel	
	44	2013*	Linear Fresnel	
Chile	360	2015*	Parabolic Trough	2,900
China	1.5	2012	Power Tower	2,000 - 2,100
	50	*	Power Tower	
Egypt	20	2011	Parabolic Trough	2,431
France	12	2014*	Linear Fresnel	1,800 - 1,930
	250	2012	Linear Fresnel	
	9	2015*	Linear Fresnel	
Germany	1.5	2008	Power Tower	902
India	50	2013*	Parabolic Trough	2,200
	2.5	2011	Power Tower	
	100	2013*	Linear Fresnel	
	100	2013*	Parabolic Trough	
	50	2013*	Parabolic Trough	
	25	2013*	Parabolic Trough	
	100	2013*	Parabolic Trough	
	50	2013*	Parabolic Trough	
Italy	5	2010	Parabolic Trough	1,936
Mexico	14	2013*	Parabolic Trough	2,050 - 2,30
Morocco	3	2013*	Parabolic Trough	2,400 - 2,600
	1	2014*	Linear Fresnel	
	20	2010	Parabolic Trough	
	160	2015*	Parabolic Trough	
South Africa	50	2015*	Parabolic Trough	2,700
	100	2014*	Parabolic Trough	
	50	2014*	Power Tower	
	50	2008	Parabolic Trough	
	50	2009	Parabolic Trough	
Spain	50	2011	Parabolic Trough	1,950 - 2,291
	49.9	2011	Parabolic Trough	
	50	2013*	Parabolic Trough	
	5	2012	Parabolic Trough	
	100	2013	Parabolic Trough	
Thailand	1	2010	Parabolic Dish	1,400
United Arab Emirates	1.16	2006	Parabolic Trough	1,934

United States	280	2013*	Parabolic Trough	2,636 - 2,725
	600	2016-2017*	Power Tower	
	250	2014*	Parabolic Trough	
	392	2013*	Power Tower	
	5	2008	Linear Fresnel	
	280	2014*	Parabolic Trough	
	250	2014*	Parabolic Trough	
	500	2016*	Power Tower	
	50	2013*	Parabolic Trough	
	150	2016*	Power Tower	
	5	2009	Power Tower	
	13.8	1984	Parabolic Trough	
	30	1985	Parabolic Trough	
	30	1985	Parabolic Trough	
	120	1989	Parabolic Trough	
	89	1989	Parabolic Trough	
	89	1990	Parabolic Trough	
	50	2013*	Parabolic Trough	
	2	2010	Parabolic Trough	
	75	2010	Parabolic Trough	
	2.0	2009	Parabolic Trough	
	200	2014*	Power Tower	
	200	2015*	Power Tower	
	110	2013*	Power Tower	
	75	2007	Parabolic Trough	
	1.5	2013	Parabolic Dish	

CONCLUSIONS

In conclusion, many limitations and barriers should be overcome in order to develop CSP in Malaysian environment. Apart from the tropical settings that will affect the CSP performances; things that should be given serious attention are the lack of technical expertise locally in CSP technology, and Malaysia has a very limited experience in CSP market. Anyhow, changes in global RE markets, investments, industries and policies have been so rapid in recent years. Other RE technologies (wind and PV), featured a high initial cost but decreased Cumulative Capacity (MW) when installed capacity increases. The same trend will apply to CSP, whereby it will be cost competitive when the technology evolves toward maturity and the technologies attain the commercial viability. Therefore, an innovative development and research of Parabolic Dish CSP should be carried out with an in depth consideration on both technical and economic aspects to ensure that the Parabolic Dish technology development will be as matured as the other CSP technologies.

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