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Technical, Economical and Environmental Assessments of the Solar Photovoltaic Technology in Southeast Sulawesi, a Developing Province in Eastern Indonesia

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ABSTRACT

The aim of this study is to assess the technical, economical and environmental aspects on the application of the solar energy technology in Southeast Sulawesi, a developing province in eastern part of Indonesia. Mathematical models of the solar radiation falling on a tilted surface, the levelised cost of energy, and the solar lifecycle greenhouse gas and land use equivalent are employed to perform the assessments under a scenario of 5% solar power contribution in the electricity generation mix. The result shows that the solar technology incorporated by tracking system generates the high annual energy generated. Under some technical and economical scenarios, it is possible for the technology to obtain lower energy costs than the solar feed-in-tariff and the electricity production costs from other sources. The solar power not only generates low carbon emission, but also requires less land use, relatively to the availability land in this province.

Keywords: Solar Energy, Economy, Technical
JEL Classifications: C4, C5, O05, Q2, Q4

1. INTRODUCTION

The electricity is one of the primary drivers to the economic development of all nations (Kaundinya et al., 2009). Indonesia is one of the developing nations, which seems still to pose the problems on the electricity availability for its communities. The low electricity ratio and the low electricity consumption per capita in some regions, especially in eastern parts, and the high pace on the domestic energy demand unbalanced with its domestic energy productions are among the current power constraints. Indeed, Indonesia currently is listed as the top ten greenhouse gas emitters globally (World Resources Institute - WRI, 2014), where the electricity uses, majority from unclean fossil sources, are also responsible. Several initiations, including enacting the law umbrellas, such as the Presidential decree 5/2006 and the Law 30/2007, and involving in the international ratification of the Kyoto protocol have been conducted by the Indonesian government in order to support the sustainable development, to reduce the dependence on the fossil and to ensure the environment sustainability. One of the action plans in supporting the initiation is to expand the use of clean renewable energy technologies, by setting a target of at least 23% in the energy mix in 2025.

For Southeast Sulawesi, one of the developing provinces in the eastern part of Indonesia, the adequate power supply to support the local development seems still to be in concern. Instead of still low electricity ratio, the total electricity consumption per-capita in this province is only around 259 KWh annually, considerably lower than that of the average in Indonesia (753 KWh) (The State Electricity Company - PLN, 2013). Depending merely on the unclean limited fossil fuels in coping to this power challenges should be less appropriate, otherwise inclusion of the clean renewable locally available energy source in the power generation mix should be more acceptable. One the available clean power sources in this province is the solar energy, driven by the fact that most of its regions are geographically located around the equator line which benefits in obtaining the high solar radiation annually (Figure 1).

To encourage the solar energy development, the government of Indonesia, under the regulatory of Minister of Energy and Mineral Resources 17/2013, obligates the State Electricity Company (PLN Indonesia) to purchase the electricity generated by the solar photovoltaic (PV) power plant based on the capacity quota offered through online public auction by the Directorate General of New Renewable Energy and Energy Conservation. Instead of this power purchased law umbrella, the knowledge on the technical strategies and their economical and environmental consequences on the application of the solar technology in a region where the technology will be applied are equally essential in order to push the solar energy technology development. The aim of this study is to assess several technical strategies to optimize the solar PV technology in Southeast Sulawesi and their economic and environmental consequences (Figure 2).

2. LITERATURE STUDY

Many strategies have been proposed to gain the high energy generation for the PV technologies. Adjusting the inclination and the orientation of the solar panel is among the simply ones. Studies (Chang, 2010; Rowlands et al., 2011) have optimized the tilt angle and the orientation on the panel to maximize the solar power output in some regions worldwide. These studies indicate the optimum orientation and tilt angle are varied, depending on the geographical location. As a region lies at higher latitude, the optimum tilt angle is higher, vice versa, with the panel orienting at the equator line.

Instead of optimizing based on the fixed panel angle and direction, some studies (Kacira et al., 2004; Benghanem, 2011; Liu, 2010) have optimized the angle and direction based on a period of time (monthly). These studies indicate that the optimum tilt and direction can be varying by month. In comparison to the fixed angle and orientation strategy, the panel optimization based on the period time strategy has higher annual energy generation, around 10% difference. The optimization based on the period of time is driven by the fact that the sun is seen not only to move in east to west daily, but also, its path is seen to shift in south to north interchangeably annually (Duffie and Beckman, 1991).

Instead of the optimization based on the fixed or time dependent tilt angle and orientation, the incorporation of solar tracking can be another alternative strategy to obtain the high energy generated. Several studies (Kacira et al., 2004; Caton, 2004; Wang et al., 2011; Drury et al., 2013) show considerable improvement on the energy generation by incorporating the solar tracker, relative to those of the fixed and timely adjustment strategies. Some of these studies also indicate that applying the solar tracker can reduce the solar energy cost.

3. METHODOLOGY

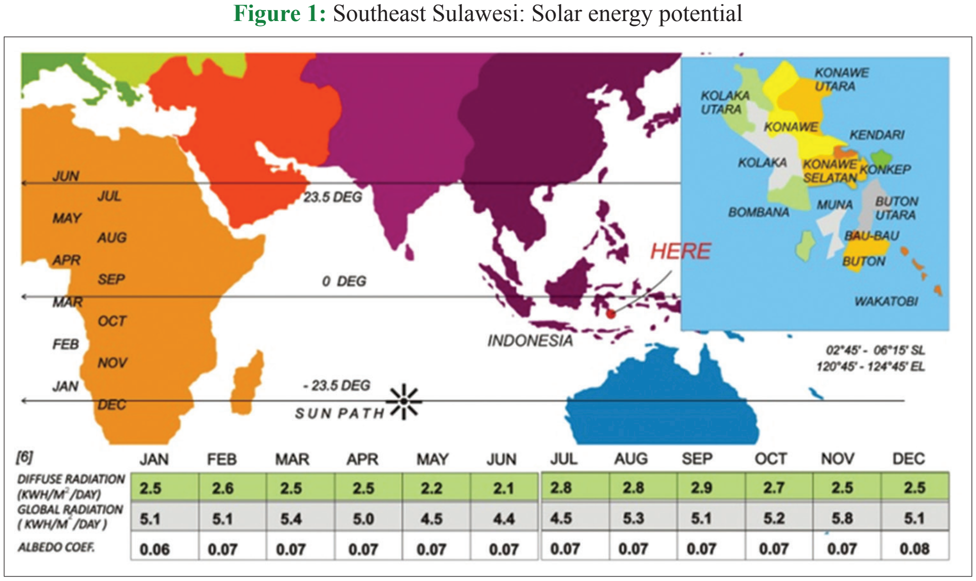
3.1. Model to Determine the Solar Energy Generation

This study proposes some technical PV strategies, including the fixed and monthly optimum angle and direction, and the application of the tracking system onto the solar panel. The assessment is conducted by a mathematical model of the solar radiation falling on a tilted surface, considering the solar panel efficiency and the percentage of sunshine days. The mathematical model is formulated byBenghanem (2011).

$$H_T = H_B(\theta,\theta_z) + H_D(\rho, \beta, H_g) + H_R(H_d, R_D) \quad (1)$$

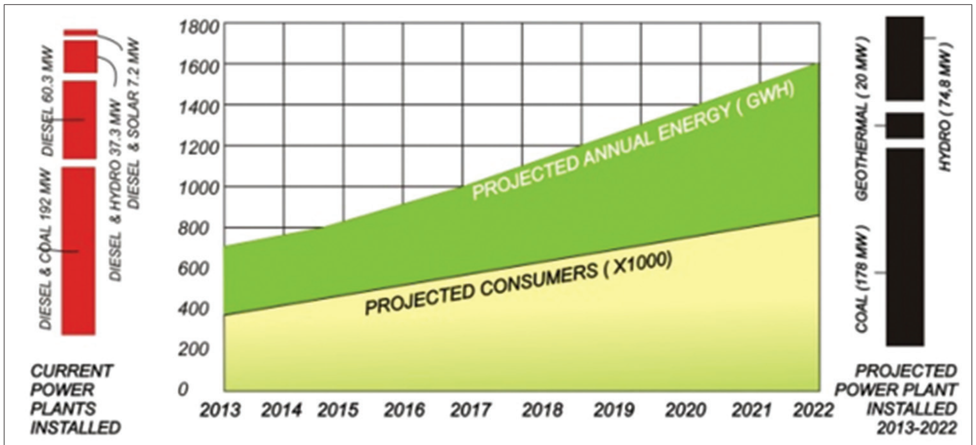
Where, H_T is the average monthly daily total solar radiation (KWH/m^2 - day), H_B is the direct beam radiation (KWH/m^2 - day), H_D is the diffuse radiation (KWH/m^2 - day), H_R is the reflected radiation on the surface (KWH/m^2 - day), ρ is the ground albedo, R_d is the ratio of the average daily diffuse radiation on a tilted surface to that on a horizontal surface, and H_g and H_d are the monthly mean daily global and diffuse radiation on a horizontal surface

Figure 1: Southeast Sulawesi: Solar energy potential



Sources: NASA (2014), Duffie and Beckman (1991)

Figure 2: Southeast Sulawesi: Socio-economic and electricity



	POPULATION [4]	GDP [4]	HDI [4]	ECONOMIC DEVELP. [4]	ELECTRT. RATIO [3]	ELECTRT. PER-CAP [3]	POWER PLANTS INSTALLED [3]
	M	USD		%	%	KWH-YR	GW
INDONESIA	250	3600	73,8	5,9	78	753	40
SOUTHEAST SULAWESI	2.2	1800	72	7,29	57	259	0,304

Sources: PLN (2013), BPS (2014)

(KWH/m^2-day). The parameter of θ_z is the zenith angle (°) and θ is the inclined angle of solar radiation on the surface, determined by Duffie and Beckman (1991), McQuiston et al., (2004).

$$\cos\theta = \sin\delta \cos\Phi \cos\beta - \sin\delta \cos\Phi \cos\beta \cos\gamma + \cos\delta \cos\Phi \cos\beta \cos\omega + \cos\delta \sin\Phi \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega \quad (2)$$

Where, ω is the hour angle (°), φ is the latitude angle (°), β is the tilt angle of the panel surface (°), γ is the surface azimuth angle (°) and δ is the declination of the angular position of the sun at solar noon with respect to the plane of the equator (°).

3.2. Model to Perform the Economic Assessment

To assess the economical attractiveness, this study employs the model of the levelized cost of energy (LCOE), one of the analytical tools that can be used to compare various alternative energy technologies when different scales of operation, investment or operating time period exist (Short et al., 1995). Instead of comparing the energy technologies, this model is often to be employed to consider the grid parity for emerging technologies such as solar technology (Branker et al., 2011). The calculation for the LCOE is the net present value of the total life cycle costs of the project divided by the quantity of the energy generated over the system life.

In this study to determine the some costs utilized to calculate LCOE, such as investment, operating and maintenance expenditures, it refers to IRENA (2012), EIA (2013). In determining other parameters in calculating the LCOE, such as the project life and the discount rate, it refers to EIA (2013), and in making the decision on the degradation rate, it refers to a report in Jordan and Kurtz (2012).

3.3. Method to Assess the Environment Aspects

Some potential undesirable environmental consequences on the solar power plant are the permanent use of a large land area, the zero reclamation until the plant decommissioned, the soil erosion and compaction, the wind diversion, the potential decrease in evaporation rate from soil, the modification on the landscape and the degradation of soil productivity (Abbasi and Abbasi, 2000; Tsoutsos et al., 2005). In present study, it assesses the environmental aspect from land area influenced by the existence of the solar power plant, by employing a report on land requirement for solar power plant by the National Renewable Energy Laboratories (Ong et al., 2013).

Instead of the land use; the greenhouse gas emission is another undesirable environmental impact possibly arising for the solar power. The emission can be generated in some stages in its lifecycles, such as in the manufacturing process, in the transportation, in the installation, in the operation and in the recycling (Krauter and Ruther, 2004; Fthenakis and Kim, 2007; Sovacool, 2008). In present study, it calculates the greenhouse gas emission by using the carbon dioxide emission equivalent on the solar power plant in a lifecycle assessment study on the sun energy in Moomaw et al. (2011).

3.4. Scenario

In this study, model of solar power plant is proposed. The plant has the capacity of 2 MW with the overall efficiency of 10% and the annual energy degradation of 1%. The percentage of the annual sunshine days is varied by 40% and 60%. The investment cost is assumed to be 8 million USD, for non-tracking system, and 9.34 million USD, for the tracking system. The operating and maintenance cost for the power plant with fixed angle strategy is 27.7 USD/KW annually and that with the moveable system (tracking and timed adjustment) is set to be 33.3 USD/KW annually. The discount rate is varied by 2% and 7% and the project life is assumed to be 25 years.

The data of the daily global radiation, the daily diffuse solar radiation and other required data to calculate the solar radiation on the tilted surface are obtained from the NASA Langley Research Center Atmospheric Science Data Center Surface Meteorological and Solar Energy web portal supported by the NASA LaRC POWER Project using data of 22-year monthly and annual average (July 1983-June 2005) from 13 locations in Southeast Sulawesi.

4. RESULTS AND DISCUSSION

4.1. The Annual Solar Energy Generation

Figure 3 shows the comparison solar energy productions on the three proposed strategies. In general, by incorporating the tracking system, it can achieve highest energy generation among the proposed strategies, followed by those of the monthly optimization and the fixed optimum strategies respectively. At 60% - annual sunshine days, the annual energy for the solar plant with fixed optimum angle is around 3.1 GWH, slightly less than that with monthly optimum angle (around 3.5 GWH annually), and considerably less than that with tracking system (around 5.1 GWH annually). As the sunshine day percentage declines, the annual energy generated decreases as well.

Figure 4 shows the projection on the capacities of the proposed solar power plants in 2015-2025 under a scenario on a target of 5% solar energy in the electricity generation mix. The projection is based on the projected annual electricity generation mix under the business plan of the electricity provision by the Indonesian State Electricity Company (RUPTL-PLN Indonesia, 2013). It is shown that to meet the contribution of the target, for that of the fixed optimum angle strategy, it requires the build the solar power plant capacity of around 66 MW. This amount is higher than those of the solar plant based on the monthly optimum angle strategy, accounting for around 58 MW and the solar plant based on the tracking system, accounting for around 42 MW. The annual energy generations can one of the factors responsible for these results. The annual energy generation for the power plant with fixed optimum angle strategy is lower, thus to meet the contribution on the power target on the electricity generation mix (5%), it requires more plant capacity than those of the plant with monthly optimum angel and tracking system.

4.2. The Economics

In following section, it presents the projection of the investment costs from the proposed solar power plants from 2015 to 2025, under the scenario of 5% solar energy in the electricity generation mix, and their comparison to the projected investment costs for all power plants in 2025 in Southeast Sulawesi (Figure 5). In this projection, instead of based on the projected solar power plants installed in 2015-2025, it employs to the data of the installation costs for various power plants from EIA (2013). It is shown that in all years, the projected investment cost for the solar power plant with tracking system is the highest among those of the proposed strategies, followed by that of the fixed angle strategy and that of the monthly optimum angle strategy respectively (Figure 5). In 2025 the projected total investment cost for the solar plant with tracking system is around 330 million USD, while that of the fixed optimum angle is around 275 million USD and that of the monthly optimum angle is around 245 million USD.

The highest investment cost for the solar power plant with the tracking strategy is caused by its high installation cost per-plant capacity among the proposed strategies. For the fixed angle solar power plant, even the installation cost per-plant capacity is low, the plant capacity required to meet the 5% solar energy target is high. This results in the higher investment cost than that of

Figure 3: The annual solar 2 MW energy production

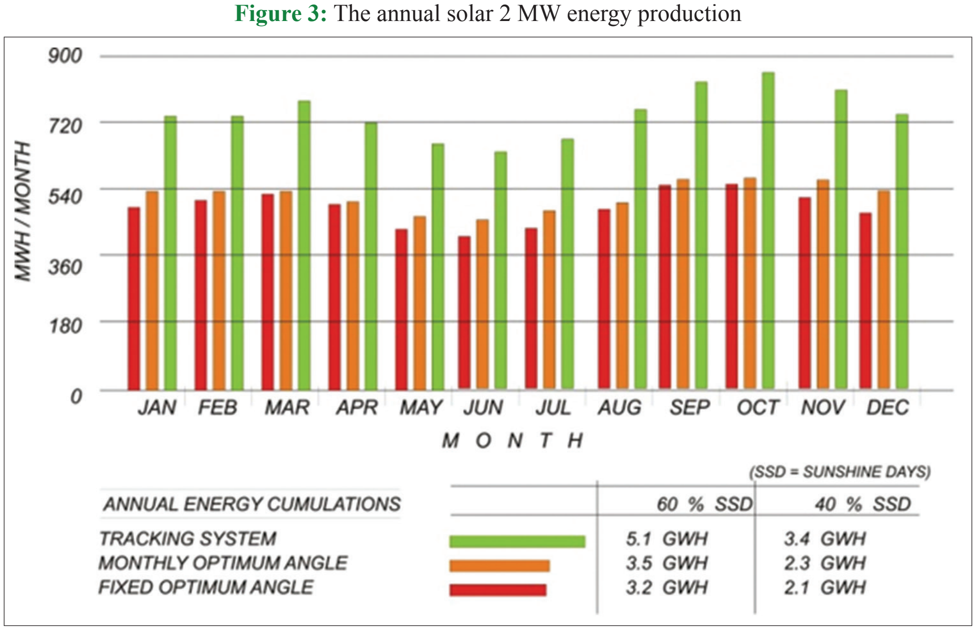


Figure 4: The projected solar power plant installed to meet 5% target

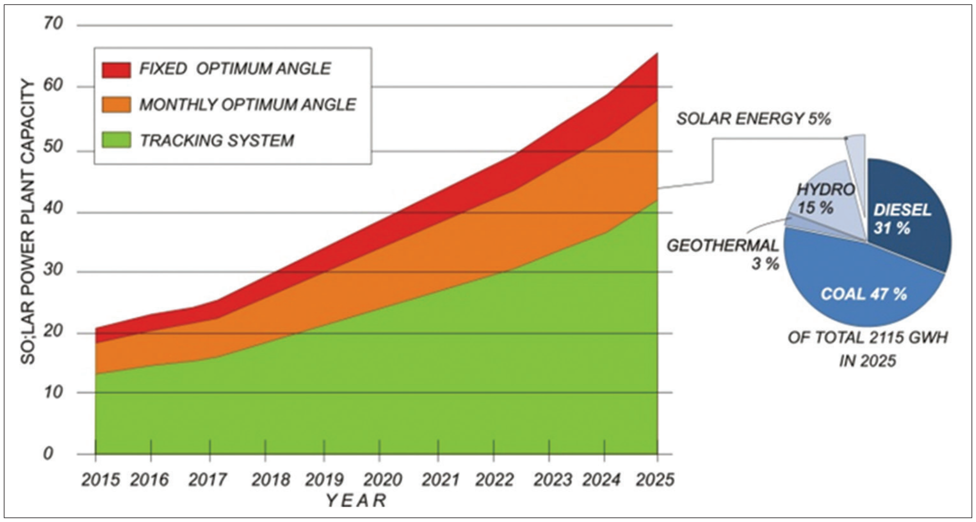
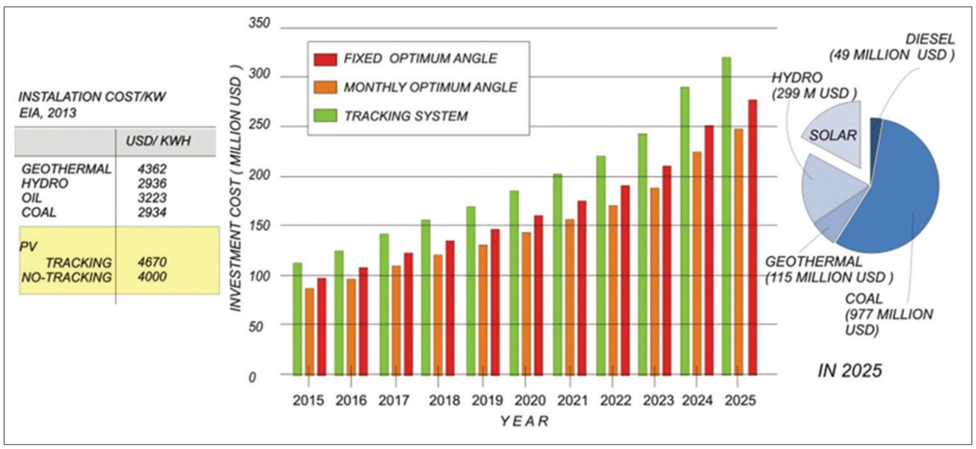


Figure 5: The investments



the monthly strategy, even, still relatively lower than that with tracking system.

Figure 6 shows the LCOEs on the proposed solar strategies and their comparisons to the solar-electricity purchased price of the Indonesian government (feed-in-tariff [FIT]) under the regulatory of Minister of Energy and Mineral Resources 17/2013, and the electricity costs by other energy sources (in the assumption of 1 dollars equal to 10,000 rupiahs).

In general, the lower LCOEs can be obtained at the lower discount rate and the higher sunshine days, *viz*. (Figure 6). Indeed, the application of tracking system enables the solar technology to obtain the lower LCOEs than those of the fixed angle and monthly optimum angle strategies. In the comparison to the government purchased prices (FIT), all LCOEs in the proposed PV strategies at the discount rate of 2% can compete well, while at the discount rate of 7%, only those operating at 60% - sunshine days are able to compete well. In comparison to the electricity production cost based on the diesel power plant, almost LCOEs in all proposed strategies can compete well; except those with fixed angle and monthly angle strategies at 40% - sunshine days. In comparison to the electricity generation cost based on the gas power plant, only those with the scenario of 40% - sunshine days at 7% - discount rate are difficult to compete. In comparison to the electricity production costs based on hydro, steam, and geothermal, it seems that the LCOEs of all proposed strategies are difficult to compete well.

4.3. The Environment

Figure 7 shows the projection of the land area and the carbon emission from the proposed solar power plants to meet the 5% solar energy contribution in the electricity generation mix from 2015 to 2025. In 2015, it requires the area around 0.48 km^2 to build the power plant based on the tracking system, while for the solar plant with monthly optimum angle, it is around 0.8 km^2, and for the solar plant with fixed optimum angle, it is around 0.75 km^2. The low area for the solar plant with tracking system can be related to its high annual energy generated per plant capacity installed. The solar plant under the tracking strategy has the highest electricity generated among those of the proposed strategies under the same capacity installed (Figure 3). As the annual energy needed to be

Figure 6: The levelised cost of energy

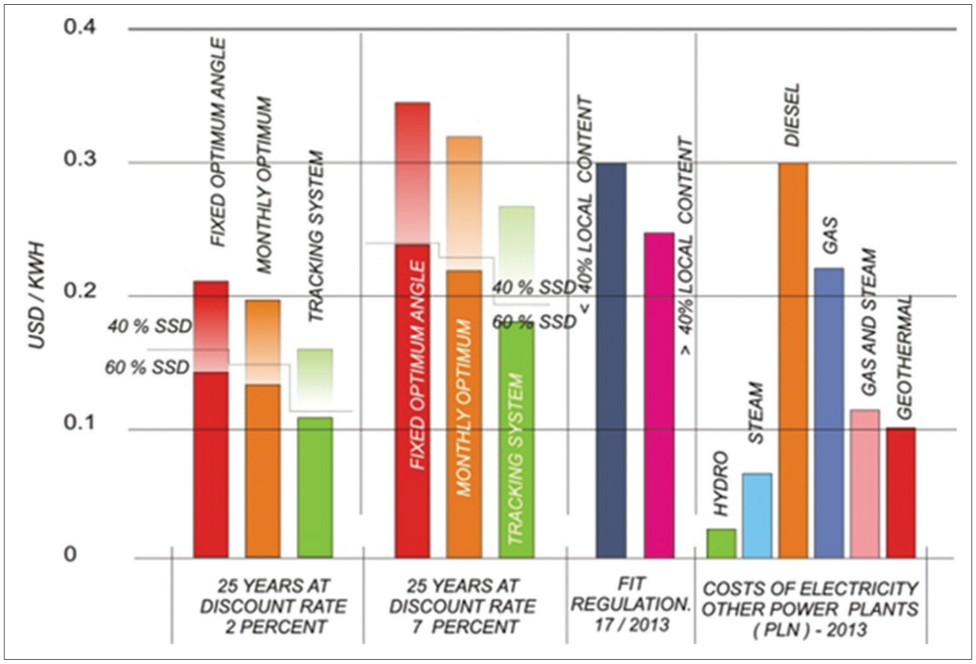
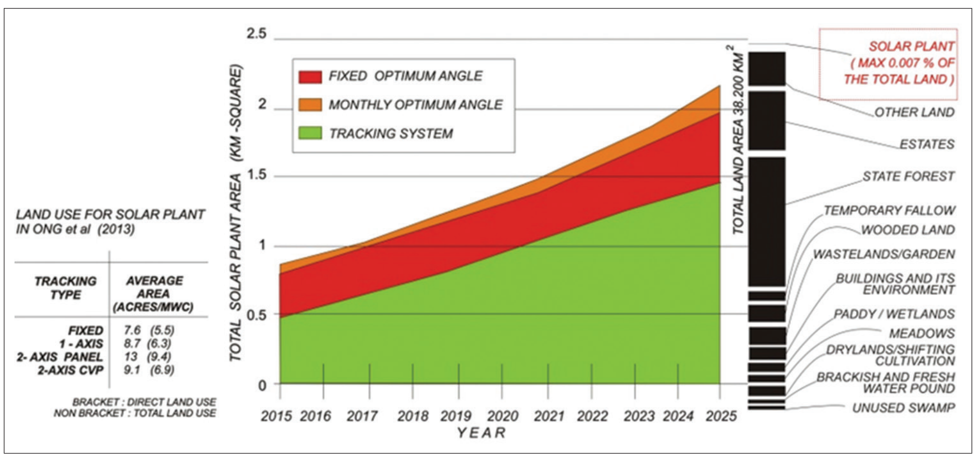


Figure 7: The projected land use



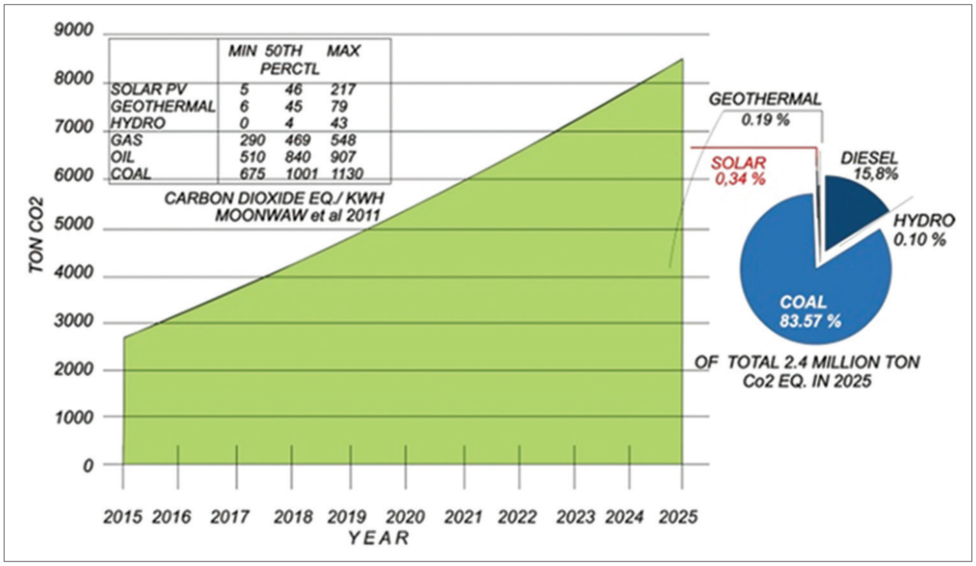
achieved by all proposed power plants is same (5% to the annual electricity generation mix), the power plant with the higher energy generated per-plant capacity can require less plant areas than those of the lower energy ones. Another figure from the result on the calculation is the requirement of considerably low land area of the proposed solar plants, relative to the total land area in Southeast Sulawesi. In 2025, the maximum land area utilized for the proposed solar plants, obtained by the strategy of the monthly optimum angle, is only around 2 km^2, <0.006% of the total land area in this province (38.200 km^2).

In 2015, the greenhouse gas emission from the proposed solar power plants is projected to be around 2.7 thousand metric ton carbon dioxide equivalent annually (Figure 8). This amount increases to around 8.5 thousand metric ton annually in 2025, contributing around 0.34% on the total greenhouse gas emission from all projected electricity generated from the power plants installed (2.4 million metric ton carbon dioxide equivalent) in this province. This also can say that, to meet the 5% electricity contribution target in 2025, the electricity generation from the proposed solar power plants only contributes <0.4% total greenhouse gas emitted from all electricity productions in this province.

5. CONCLUSION

The application of the tracking system enables the solar technology to obtain the highest annual energy generation among the proposed strategies, followed by those of the monthly optimization and the fixed optimum angle strategies, respectively. Even the solar technology with the tracking system has the highest investment cost; its energy cost (LCOE) is the lowest among the strategies. In some conditions, it is possible for the proposed solar technology to obtain the lower energy costs than the government purchased prices (FIT) and the electricity costs based on the diesel and gas power plants, but not with those of hydro, steam and geothermal.

Figure 8: The projected greenhouse gas emission (50th percentile)



The maximum land use for the proposed solar plants is <0.006% of the total land area with the emission generated <0.4% total lifecycle carbon dioxide gas emitted from all projected electricity production in this province under the scenario of 5% target of the sun energy in the electricity generation mix in 2025.

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