An outlook on large-scale solar power production in Peninsular Malaysia for scenario year 2030

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Abstract. Traditional power generation mix lacks renewable energy (RE) sources to cover fast depletion of fossil fuel. Malaysia is picking up on solar energy with the aim of enhancing the national power generation mix by reducing the dependency on fossil fuel and thus mitigate the greenhouse gas (GHG) emissions. However, integration of large amount of solar power may pose a challenge to power system planning and operation. This paper therefore, attempts to present an outlook on large-scale solar (LSS) in Peninsular Malaysia for scenario year 2030, with objective to serve a guideline for future power planning by adopting the optimum penetration of LSS. Firstly, total optimal potential areas (OPA) for LSS power production in Peninsular Malaysia are determined based on several important geometry factors. Next, its corresponding technical potentials include energy generation potential (EGP), installation capacity (IC) and annual carbon dioxide emission reduction (CO₂ ER) are reported. Three hypothetical studies of solar penetration: 5%, 10% and 15% are demonstrated and subsequently compare with national electricity consumption forecast 2030. Peninsular Malaysia has enormous potential for LSS power production as reflected from total OPA of 10,092 km². With only 10% of solar penetration (206,691 GWh/yr), it is sufficient to cover national energy demand, forecast to be 134,642 GWh/yr. This positive finding is very encouraging to reveal the significant potential of LSS in national energy mix. It will give a much-needed boost to the country RE sector and a robust growth is envisaged.

1. Introduction
The Paris Agreement (PA) developed based on United Nations Framework Convention on Climate Change (UNFCCC) has issued a clarion call to the parties for joining hands for a climate change control on ensuring a worldwide temperature rise this century under 2°C and limiting the temperature increase to 1.5°C [1]. As of September 2017, 155 parties including Malaysia have ratified the agreement and submitted their nationally determined contributions (NDCs) [2]. Malaysia is pleased to communicate its NDC with goal of reducing GHG emissions by 45% by 2030 in relative to the emission intensity of Gross Domestic Product (GDP) in 2005, which consist of 35% on an unconditional basis and 10% is condition on receipt of climate finance, technology transfer and capacity building support from...
developed countries. Maintain at least 50% tree and forest preservation are one of the Malaysia’s commitment in supporting the climate change issue [3].

Referring to Malaysia’s Third National Communication and Second Biennial Update Report (NC3/BUR2) submitted to UNFCCC [4], for 2014, total GHG emissions were 317,627 kt-CO$_2$eq and net emissions were 50,479 kt-CO$_2$eq account for carbon removal of 267,148 kt-CO$_2$eq. This estimation was made based on five sectors: 1) energy, 2) industrial processes and product use (IPPU), 3) agriculture forestry and other land use (AFOLU)- agriculture, 4) AFOLU- land use, land-use change and forestry (LULUF) and 5) waste. Energy sector is the largest contributor to GHG emissions, nearly 80% and followed by waste 9%, IPPU 6%, AFOLU-agriculture 4% and AFOLU-LULUCF 1%. Carbon dioxide (CO$_2$) is in the large bulk of GHG emissions as compare others, consist of 248,195 kt-CO$_2$ or 78% of total, predominantly emitted by three categories under energy sector: 1) energy industries, 2) transport and 3) manufacturing industries & construction. Energy industries has the greatest CO$_2$ emission among the categories, recorded 133,097 kt-CO$_2$ (54%), contributing to the oils used by the power production sectors for natural gas transformation, electricity generation and petroleum refining [4]. Malaysia’s primary energy supply is from gas, oil and coal. Based on the statistics published by Energy Commission Malaysia (https://meih.st.gov.my/statistics), total primary energy supply for year 2016 was 93,396 ktoe, in which 94.4% of the energy production is from fossil fuels. Despite energy supplements from hydro and renewable (hydropower 4.8%, biodiesel 0.4%, biomass 0.2% and solar 0.1%), the amounts are insignificant.

Malaysia first identified RE as fifth energy source in the 8th Malaysia Plan (2001-2005) [5] and in 2010, the Renewable Energy Policy and Action Plan (NREPAP) has been formulated [6]. Today, Malaysia has recognized RE as one of mitigation actions to address the emission challenge with emphasis on biomass, biogas, small hydropower, solar photovoltaic (PV) and LSS. The government has set an ambitious goal for increasing the share of RE in overall fuel mix from current 2% to 20% by 2030 [6]. RE was first promoted to nation through the 2012 Feed-in Tariff (FiT) mechanism implementation upon establishments. This mechanism was complemented by Net Energy Metering (NEM) and LSS program in 2016, aimed to enhance RE usage for achieving policy goal of 2.1 GW and 3.5 GW of grid-connected RE capacity by the year 2020 and 2030 respectively [4].

LSS is a competitive bidding program opens for qualified private companies to construct, own and run the LSS power plants to sell and supply electricity energy to utility companies under long term power purchase contract. The selection would base on the most competitive offer prices up to the total capacity. Two phases of LSS projects were implemented to date, namely LSS 1 and LSS 2 for commercial operation date 2017-2018 and 2019-2020 respectively with accumulative installed capacity of 958 MW [7]. Perak and Kedah are states granted the most installed capacity accumulated about 200 MW each from both LSS 1 and LSS 2. While the bid of third round LSS (LSS 3) for another 500 MW worth RM2 billion was closed in August 2019 and the outcome is expected to be announced by year end.

This paper therefore, attempts to present an energy outlook study on LSS power production in Peninsular Malaysia for scenario year 2030. It reports available land areas in Peninsular, that is optimal for LSS power plants development alongside its potential installation capacity, energy generation, and emission reduction. Also, an optimum level of solar penetration for year 2030 is proposed in this paper to ensure it caters for energy demand.

2. Methodology
This research was initiated by determining the OPA in Peninsular, Malaysia for LSS power plant purpose. There were four essential criteria for OPA shortlisting [8]: 1) land areas that was under 60m in elevation with a slope less than 5°; 2) land availability by excluding forest and reserves, forest and wetlands, paddy, other agriculture areas, water bodies and build-up areas; 3) identified local grid and road networks system, as defined OPA was neither too close nor too far from the grid and road networks. Areas of distance in between 500m and 10,000m from the grid and road networks were most suitable and selected; 4) solar radiation data of areas across eleven states in Peninsular were collected from
NASA, where sunny locations with long-term and average annual solar radiation supply were targeted primarily. This study embraced locations with solar radiation of approximately 5 kWh/(m²/day). The evaluated output, OPA was further used to determine the technical potentials: EGP, IC and CO₂ ER.

EGP referred to the estimated annual electricity potentially produced (GWh/yr), computed by using Eq. (1). Packing factor (PF) of 0.8 and panel efficiency (PE) of 15% were adopted in this study. Annual solar radiation (ASR) of states in Peninsular were retrieved from [9].

\[ EGP = OPA \times PF \times PE \times ASR \]  
\[ (1) \]

IC was defined as maximum output of electricity that a generator can produce under ideal conditions (GW), computed by using Eq. (2). Capacity factor (CF) of 13% was used in the study.

\[ IC = \frac{EGP}{8760 \times CF} \]  
\[ (2) \]

CO₂ ER is the measurement of reduction in emissions of carbon dioxide (or other greenhouse gases) due to energy generation technology (kt-CO₂), computed by using Eq. (3). Carbon emission factor (CO₂ RF) of 0.63 kg/kWh was adopted in this study for Peninsular Malaysia.

\[ CO₂ER = CO₂RF \times EGP \]  
\[ (3) \]

Next, a study of 5%,10% and 15% solar penetrations were conducted and further compared with national electricity consumption forecast in 2030. These preliminary findings are critically essential to demonstrate the appropriate share and proportion of large-scale solar power generation that is in need against national energy demand in Peninsular Malaysia for scenario year 2030.

3. Result and Discussion

### Table 1. Distribution of OPA and ASR by state.

| State        | Label | OPA (km²) | ASR (MWh/m²/yr) |
|--------------|-------|-----------|-----------------|
| Perlis       | PLS   | 39        | 1.81            |
| Pulau Pinang | PNG   | 136       | 1.88            |
| Perak        | PRK   | 2239      | 1.70            |
| Kedah        | KDH   | 570       | 1.81            |
| Selangor     | SGR   | 1342      | 1.76            |
| Kuala Lumpur*| KUL   | 0         | 1.76            |
| Putrajaya    | PJY   | 0         | 1.76            |
| Negeri Sembilan | NSN | 319       | 1.70            |
| Melaka       | MLK   | 297       | 1.70            |
| Kelantan     | KTN   | 512       | 1.71            |
| Terengganu   | TRG   | 725       | 1.73            |
| Pahang       | PHG   | 1482      | 1.68            |
| Johor        | JHR   | 2433      | 1.66            |

*Federal territories of Malaysia

Table 1 shows the distribution of OPA and ASR in Peninsular Malaysia. The total OPA available is 10,092 km². Higher ASR is observed in northern states, where Pulau Pinang (PEN) receives the highest solar radiation among the 11 states, followed by Perlis (PLS) and Kedah (KDH), and gradually
weakening in the south-east direction. Johor (JHR) has the weakest solar radiation level, followed by Pahang (PHG).

Figure 1. Distribution of estimated EGP at different level of solar penetration.

Figure 1 shows the distribution of EGP at 5%, 10% and 15% of solar power penetration levels. In general, the total EGPs in Peninsular Malaysia at 5%, 10% and 15% penetration levels are 103,345 GWh/yr, 206,691 GWh/yr, and 310,036 GWh/yr, respectively. Due to the calculation of IC and CO$_2$ ER are governed by EGP, they share the same trend as depicted in Figures 2 and 3, respectively. In general, a total of 182 GW installation capacity is needed to realize the 10% penetration assumption with a total CO$_2$ reduction of 130,215 kt-CO$_2$/yr. Compared with the German’s national energy initiative on annual PV expansion of at least 5 GW to reach 200 GW by 2050 from 45.9 GW in 2018 [10], the 10% solar penetration assumption by 2030 in Peninsular is seemingly too optimistic, not to mention the projected installed capacity of only 3.3 GW (about 0.18% of solar penetration) by 2030 envisioned by the Malaysian government [4].

Figure 2. Distribution of estimated IC at different level of solar penetration.
Figure 3. Distribution of estimated CO₂ ER at different level of solar penetration.

Figure 4 shows the percentage break-down of historical electricity consumption of each state from 2010 to 2017 estimated based on the energy intensity per capita statistics published by Energy Commissions Malaysia and population statistics published by the Department of Statistics Malaysia (www.dosm.gov.my). Note that the percentage share of each state is relatively steady across the seven years. Therefore, the authors assumed that this trend remain unchanged throughout the forecast horizon. Following the electricity consumption growth rates published by the Energy Commissions Malaysia [11], the total electricity consumption in Peninsular Malaysia in 2030 is estimated to be 134,642 GWh. This indicates that a solar penetration level of 10% is more than enough to cover the forecast demand, discounting the existing power generation plants. In terms of land area, about 0.8% of Peninsular land area is needed to produce such amount of solar power.

Figure 4. Percentage break-down of electricity consumption by state from year 2010 to 2017.

4. Conclusions
LSS is technically feasible in Peninsular Malaysia for power production attributed to the large OPA and high ASR. Noted that 10% of solar penetration is more than enough to cover energy demand of Peninsular in year 2030, with involved land area of 0.8%. Yet, it has been a considerable gap between
estimated and existing IC, 182 GW and 1.5 GW respectively, showing that LSS deployment in the nation is relatively low and expansion is certainly needed.

Although solar power can provide direct and indirect benefits to economy and environment, transformation of traditional power grids to smart grids with greater flexibility is deemed necessary for penetration of solar power in large scale to ensure grid stability and energy security.

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