An Analysis of the Impacts of Solar Electricity Generation on the Electricity Industry for Thailand

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Abstract This paper provides an analysis of the impacts of solar electricity generation on the electricity industry for Thailand. In this paper, three scenarios (REF, Solar2015 and Solar2018) are developed to represent an increased level of electricity produced from solar energy. A Low Emissions Analysis Platform (LEAP) model is employed in this paper to assess the impacts for the period 2019–2037. This paper assesses the scenario impacts in terms of diversification of electricity generation, generation technology mix, primary energy requirement and CO\textsubscript{2} emissions. The analysis reveals that greater role of solar energy in the electricity generation would have positive impacts on the Thai electricity generation from several aspects including improving the diversification of primary energy supply for electricity generation, reducing fossil fuel consumptions for power production, less reliance on fossil fuel sources and environmentally friendly electricity generation. For example, 20\% share of solar in fuel mix for power generation would result in a 17\% reduction in fossil fuel consumption. Furthermore, it would contribute to a 16\% decrease in CO\textsubscript{2} emissions and 28\% reduction in SO\textsubscript{2} emissions. Despite several benefits, there are a number of emerging barriers for promoting solar based electricity generation in Thailand. These include inefficient and unreliable nature of solar energy for baseload electricity demand, high-initial cost, unsupportable grid infrastructure and unfavourable regulatory framework. This paper, therefore, recommends that development of energy storage technologies, improvement of grid flexibility and the revision of the regulations to support solar energy business could be effective strategies in order to address the barriers facing the Thai electricity industry.

1. Introduction
Electricity is one major factor in meeting the basic needs of the country. It also plays a very important role in the country's economic and social development because electricity is one of the most important factors driving the development of the industrial, commercial and residential sectors. For Thailand, a
country that has continued economic and social expansion which is widely distributed to all parts of the 
country according to government's policies. Therefore, a growth for electricity demand has consistently 
increased and tends to rise continuously. Between the years 2009 and 2019, electricity demand in 
Thailand increased annually by about 4.2%, from 135,209 GWh in 2009, to 203,714 GWh in 2019 (1-2). 
In order to meet the increasing electricity demand, Thailand has been mainly dependent on fossil fuels 
for electricity generation. However, Thailand has limited energy resources, for example, crude oil, 
natural gas and coal. As a result, a large amount of energy was imported to be used as fuel in power 
generation. With a view to reduce dependency on energy import and to diversify the energy sources used 
for generating electricity, the government promotes the use of renewable energy as a matter of priority. 
Renewable energy, specifically solar energy, appears to be an attractive option for the government due 
the fact that solar energy is clean and abundant renewable energy source available. In addition, 
Thailand has great solar potential. The average annual solar energy is relatively high compared to many 
countries, with most parts of the country exposed to the highest solar radiation between April and May 
in the range 20.23 MJ m\(^{-2}\) day\(^{-1}\) [3]. In 2018, the government has developed the Alternative Energy 
Development Plan (AEDP2018) for the period 2018-2037. Under this plan, renewable energy in Thailand 
is projected to be 30% of the total energy production by 2037 [4]. According to the AEDP, the proportion 
of electricity from solar electricity production would increase to 20% in 2037 – more than three-fold 
increase as compare to 2018. The solar generating capacity is estimated to increase substantially, from 
2,962 MW in 2018 to 15,574 MW in 2037. This paper, therefore, aims to analyze the impacts of solar 
electricity generation on the Thai electricity industry in terms of diversification of electricity generation, 
generation technology mix, primary energy requirement and CO\(_2\) emissions.

2. Methodology
To assess the impacts of solar electricity generation, the Low Emissions Analysis Platform (LEAP) is 
selected. LEAP is a widely-used software tool for energy policy, climate change mitigation and air 
pollution abatement planning developed by the Stockholm Environment Institute (SEI) [5]. LEAP has 
been adopted by thousands of organizations in more than 190 countries worldwide. Its users include 
government agencies, academics, non-governmental organizations, consulting companies, and energy 
utilities, and it has been used at scales ranging from cities and states to national, regional and global 
applications. LEAP has been employed by several studies to assess the energy and environmental 
impacts of renewable energy [6-18].

In this paper, the development of scenario is mainly based on the Power Development Plan (PDP) 
and the Alternative Energy Development Plan (AEDP). The scenario analysis covers for the time period 
of 2019-2037. In this study, scenario development is mainly focused on solar electricity generation. For 
this purpose, this paper develops two alternative scenarios, namely, the Solar2015 and Solar2018 
scenarios. In addition to the two alternative scenarios, this paper includes a REF scenario which represent 
a continuation of current trends in primary energy and technology mix for power generation. The two 
alternative scenarios (Solar2015 and Solar2018 scenarios) are primarily intended to increase shares of 
solar energy in electricity generation. In the Solar2015 scenario, the generating capacity of solar energy 
would increase to 6,000 MW in 2037. The solar2018 scenario is developed to represent greater role of 
solar energy in power production. The installed capacity of solar energy, under the solar2018 scenario, 
is expected to grow to 15,574 MW in 2037. Table 1 provides the details of key features of the three 
scenarios.
3. Data Consideration
The data required by this study include electricity consumption, power generation by fuel types, installed capacities by generating technologies, electricity losses, efficiencies of power plant technologies, electricity load curve and electricity demand growth. The electricity consumption data, power generation by fuel types, installed capacities and electricity losses are available from Energy Balance report and Alternative Energy Situation report, published by the Department of Alternative Energy Development and Efficiency (DEDE) [1], [19]. The information on the electricity demand growth can be achieved from the Power Development Plan (PDP2018) developed by the Energy Policy and Planning Office (EPPO), Ministry of Energy [20]. The shares of installed capacity by each plant type (e.g., steam turbine, combined-cycle, co-generation, gas turbine, hydro, solar, wind, biomass, biogas, municipal solid waste and geothermal) can be taken from the PDP2018 [20]. The information on the efficiencies of power plant technologies can be taken from external sources including International Energy Agency (IEA) and Energy Information Administration (EIA) [21-22]. The data on electricity load curve can be obtained from the Electricity Generating Authority of Thailand (EGAT) and the relevant literature [23-24].

| Scenario               | Scenario features                                      |
|------------------------|--------------------------------------------------------|
| REF scenario           | • Continue with current primary energy and technology mix for electricity generation.  
                         | • The share of solar energy in electricity production would be 5% until the year 2037.  
                         | • The generating capacity of solar energy is expected to grow to 4,517 MW in 2037 |
| Solar2015 scenario     | • Slight increase of solar electricity installed capacity to 6,000 MW in 2037. |
| Solar2018 scenario     | • Greater role of solar in electricity production, thus resulting in a considerable increase of solar electricity installed capacity to 15,574 MW in 2037. |

4. Empirical Results and Discussion
This paper assesses the impacts of solar electricity generation on the Thai electricity industry in terms of diversification of electricity generation, fossil fuel consumption, CO₂ emissions and SO₂ emissions for the period 2019-2037.

4.1. Diversification of electricity generation
Figure 1 shows that electricity production under the REF, Solar2015 and Solar2018 scenarios would increase from 207 TWh in 2019, to 340 TWh in 2037. Over the entire studied period, the electricity produced from natural gas under the REF, Solar2015 and Solar2018 scenarios would increase, from 127 TWh, to 209 TWh, 203 TWh and 184 TWh respectively. Over the period 2019-2037, the generation of electricity from coal and lignite under the REF, Solar2015 and Solar2018 scenarios would increase, from 37 TWh, to 60 TWh, 56 TWh and 49 TWh respectively. It is noticed from Figure 1 that the electricity generation from solar energy would increase considerably. Electricity generated from solar energy in 2037 is expected to rise by 1.6 times in the REF scenario, 2.2 times in the Solar2015 scenario, and 5.8 times in the Solar2018 scenario as compared to 2019. Electricity produced from Solar in 2037 is expected to grow to 10 TWh in the Solar2015 and 26 TWh in the Solar2018 – more than double increase as compared to 2019.
In view of electricity generation share by fuel type, the percentage share of natural gas in total electricity generation in the case of Solar2015 and Solar2018 scenarios in 2037 would decrease to 59% and 54% respectively (as shown in Figure 2). Moreover, the share of coal and lignite would also decrease to 17% in the Solar2015 scenario and 15% in the Solar2018 scenario. These decreases would be contributed by the government's policy to diversify primary energy supply for electricity generation. The decreases would be substituted by an increased share of solar energy in power production. The share of solar energy in power production under the Solar2018 scenario is expected to grow considerably from 2% in 2019, to 8% in 2037.

![Figure 1. Electricity generation by fuel type for the period 2019-2037](image1)

![Figure 2. Electricity generation by fuel type](image2)
4.2. Fossil fuel consumption

This paper employs fossil fuels consumption as an indicator to assess a decline in fossil fuel consumption attributed to an increased electricity generation from solar. Table 2 shows the fossil fuels consumption for power generation in the case of the REF, Solar2015, and Solar2018 scenarios. And, Figure 3 provides changes in fossil fuel consumption by fuel type in 2037 for the Solar2015 and Solar2018 scenarios in comparison with the REF scenario.

It can be seen from Table 2 that over the period 2019-2037, fossil fuel consumption in the case of REF scenario increased considerably, from 33,143 KTOE in 2019, to 55,996 KTOE in 2037. In 2037, fossil fuel consumption in the Solar2015 and Solar2018 scenarios would be 9.9% and 17.5%, respectively, lower than in the case of the REF scenario. The fossil fuel inputs for electricity generation under the Solar2015 scenario is expected to grow to 50,408 KTOE in 2037 – a decrease of 5,588 KTOE in comparison with the REF scenario. In the Solar2018 scenario, fossil fuel consumption in 2037 is expected to be 46,204 KTOE – a reduction of 9,792 KTOE in fossil consumption for power production as compared with the REF scenario.

Table 2. Fossil fuels consumption for electricity generation

| Year | REF scenario | Solar2015 scenario | Solar2018 scenario |
|------|--------------|---------------------|---------------------|
|      | kKTOE        | Changes from REF scenario | Changes from REF scenario |
|      |              | (KTOE)              | (%)                 | (KTOE)              | (%)                 |
| 2019 | 33,143       | -                   | -                   | -                   | -                   |
| 2027 | 43,166       | -2,208              | -5.1                | -3,965              | -9.2                |
| 2037 | 55,996       | -5,588              | 9.9                 | -9,792              | -17.5               |

Notes: Number in brackets show percentage change from the REF scenario.

Figure 3. Changes in fossil fuel consumption by fuel types in 2037
From Figure 3, it appears that major contribution to a decline in fossil fuels consumption for electricity generation in the case of Solar2015 and Solar2018 scenarios would be from natural gas and coal and lignite. The decline in the demand for both natural gas and coal and lignite would help reduce fossil fuels imports for electricity generation. This is because natural gas and coal imports have been consistently increasing since 2000s [1-2]. In addition, natural gas imports accounted for 30% of total natural gas supply in 2019 and more than 75% of total natural gas consumption has been employed as fuel inputs for power production [1]. For coal and lignite, coal consumption for power generation accounted for more than 30% of coal imports in 2019 [1]. An increased electricity generation from solar energy would, therefore, help reduce fossil fuel imports and hence help enhance security of energy supply.

4.3. \( \text{CO}_2 \) emissions

In view of \( \text{CO}_2 \) emissions, Table 3 shows that \( \text{CO}_2 \) emissions under the REF scenario is estimated to increase from 92 million tonnes in 2019, to 150 million tonnes in 2037, an increase of 58 million tonnes over the 2019 emission level. In the case of Solar2015 and Solar2018 scenarios, \( \text{CO}_2 \) emissions in 2037 would be, respectively, 9.4 million tonnes (6.3%) and 24.8 million tonnes (16.6%) lower than the emissions in the REF scenario. A reduction in \( \text{CO}_2 \) emissions is a result of a decrease in fossil fuels consumption for power generation.

| Year | REF scenario (Million tonnes) | Solar2015 scenario Changes from REF scenario (Million tonnes) | (%) | Solar2018 scenario Changes from REF scenario (Million tonnes) | (%) |
|------|-------------------------------|-------------------------------------------------------------|-----|-------------------------------------------------------------|-----|
| 2019 | 92                            | -                                                           | -   | -                                                           | -   |
| 2027 | 118                           | -3.81                                                       | -3.2| -10.10                                                      | -8.6|
| 2037 | 150                           | -9.40                                                       | -6.3| -24.82                                                      | -16.6|

4.4. \( \text{SO}_2 \) emissions

Table 4 reveals that \( \text{SO}_2 \) emissions, under the REF scenario, would increase from 351 thousand tonnes in 2019, to 573 thousand tonnes in 2037, an increase of 222 thousand tonnes over the 2019 emission level. The \( \text{SO}_2 \) emissions in the case of Solar2015 and Solar2018 scenarios in 2037 would be, respectively, 23.2% and 27.5% lower than the emissions in the REF scenario. A decline in \( \text{SO}_2 \) emissions would be mainly from a decrease in coal and lignite consumption for power generation (as previously discussed in Section 4.2).

| Year | REF scenario (Thousand tonnes) | Solar2015 scenario Changes from REF scenario (Thousand tonnes) | (%) | Solar2018 scenario Changes from REF scenario (Thousand tonnes) | (%) |
|------|-------------------------------|-------------------------------------------------------------|-----|-------------------------------------------------------------|-----|
| 2019 | 351                           | -                                                           | -   | -                                                           | -   |
| 2027 | 450                           | -53.2                                                       | -11.8| -63.0                                                      | -14.0|
| 2037 | 573                           | -133.3                                                      | -23.2| -157.8                                                     | -27.5|
The foregoing results suggests that greater role of solar energy in the electricity generation would help diversifying primary energy mix for power generation. Moreover, it would contribute to a reduction in fossil fuels consumption for electricity generation and hence result in a decrease in fossil fuel imports. An improvement in the diversification of primary energy supply supplemented by a decline in fossil fuels imports would, therefore, help enhance the energy security of the country. Furthermore, increased electricity generation from solar energy would have a positive impact on the environment. As previously discussed, increased contribution of solar energy to electricity generation would considerably reduce the use of fossil fuels for electricity generation and, therefore, help mitigating CO$_2$ and SO$_2$ emissions. The attractiveness of solar energy would considerably enhance when considering in the context of Thailand – country that has great solar potential.

Despite the fact that solar energy would provide several benefits to the Thai society, the promotion of solar energy could face numerous barriers. For example, the intermittency of solar energy would make it inefficient and unreliable for supplying electricity to the system. Another barrier would be the capital-intensive investment for solar energy. Due to its high initial capital cost but inefficient and unreliable nature would make solar energy get a low rate of return on investment. Unsupportable grid infrastructure would emerge as one major barrier. This is because the current structure of the Thai electricity sector is in the form of centralized electricity system which is not designed to support distributed generation characterizing by small-scale and intermittent generators like solar energy. The issue of regulatory framework would be also important. The regulatory arrangements for the Thai electricity industry for the last sixty years have been primarily designed to support centralized electricity system. The traditional regulatory framework would, therefore, hinder the penetrations of solar energy. To address the barriers facing the Thai electricity industry, this paper, therefore, recommends that development of energy storage technologies, improvement of grid flexibility and the revision of the regulations to support solar energy business could be effective strategies.

5. Conclusion
This paper analyses the impacts of solar electricity generation on the Thai electricity industry in terms of diversification of electricity generation, fossil fuel consumption, CO$_2$ emissions and SO$_2$ emissions for the period 2019-2037. The analyses reveal that greater role of solar energy in the electricity generation would have positive impacts on the Thai electricity generation from several aspects including improving the diversification of primary energy supply for electricity generation, reducing fossil fuel consumptions for power production, less reliance on fossil fuel sources and environmentally friendly electricity generation. For example, 20% share of solar in fuel mix for power generation would result in a 17% reduction in fossil fuel consumption. Furthermore, it would contribute to a 16% decrease in CO$_2$ emissions and 28% reduction in SO$_2$ emissions. Despite several benefits, the promotion of solar energy could face numerous barriers including inefficient and unreliable nature of solar energy for baseload electricity demand, high-initial cost, unsupportable grid infrastructure and unfavorable regulatory framework. This paper, therefore, recommends that development of energy storage technologies, improvement of grid flexibility and the revision of the regulations to support solar energy business could be effective strategies in order to address the barriers facing the Thai electricity industry.

References
[1] Department of Alternative Energy Development and Efficiency 2019a Energy Balances Report 2012-2019, annual reports, Bangkok, Thailand.
[2] Department of Alternative Energy Development and Efficiency 2011 Thailand Energy Situation Report 2000-2011, annual reports, Bangkok, Thailand.
[3] Department of Alternative Energy Development and Efficiency 2014 *Handbook for the Development and Investment in Renewable Energy Series 2 Solar Energy*, Bangkok, Thailand.

[4] Department of Alternative Energy Development and Efficiency 2019 *Summary of the public hearing on the draft of the Alternative Energy Development Plan 2018 (AEDP2018)*, Bangkok, Thailand.

[5] Stockholm Environment Institute 2020 *Low Emissions Analysis Platform (LEAP): training materials*, Stockholm, Sweden.

[6] Kusumadewi TV, Winyuchakrit P, Misila P and Limmeechokchai B 2017 GHG Mitigation in Power Sector: Analyzes of Renewable Energy Potential for Thailand's NDC Roadmap in 2030 *Energy Procedia* 138 pp 69-74.

[7] Hu G, Ma X and Ji J 2019 Scenarios and policies for sustainable urban energy development based on LEAP model – A case study of a postindustrial city: Shenzhen China *Applied Energy* 238 pp 876-886.

[8] Emodi N, Emodi C, Girish G P and Emodi A 2017 Energy Policy for Low Carbon development in Nigeria: A LEAP Model Application *Renewable and Sustainable Energy Reviews* 68 pp 247-261.

[9] Rivera-González L, Bolonio D, Mazadiego L F and Valencia-Chapi R 2019 Long-Term Electricity Supply and Demand Forecast (2018-2040): A LEAP Model Application towards a Sustainable Power Generation System in Ecuador *Sustainability* 11 pp 5316.

[10] Mirjat N H, Harijan K and Valasai G 2018 Long-Term Electricity Demand Forecast and Supply Side Scenarios for Pakistan (2015-2050): A LEAP Model Application for Policy Analysis *Energy* 163 pp 512-526.

[11] Wang J, Hua C and Li L 2018 Long-term Energy Sustainability Development Analysis to Reducing Carbon Emissions and Air Pollutions of China Based on LEAP Simulation Model *Ekoloji* 27(106) pp 173-179.

[12] Kresnawan M R, Safitri I A and Darmawan I 2018 Long Term Projection of Electricity Generation Sector in East Kalimantan Province: LEAP Model Application. 12th South East Asian Technical University Consortium (SEATUC) Yogyakarta, Indonesia, doi: 10.1109/SEATUC.2018.8788875, pp 1-5.

[13] Bhuvanesh A, Christa S T J and Kannan S 2017 Least Cost Electricity Generation Planning for China with Low GHG Emission Using LEAP and EnergyPLAN, 2017 IEEE International Conference on Computational Intelligence and Computing Research, ICCIC 2017, 8524458.

[14] Shahinzadeh H, Fathi S H and Hasanalizadeh-Khosroshahi A 2016 Long-term energy planning in IRAN using LEAP scenario: Using combined heat and power (CHP) 2016 Iranian Conference on Renewable Energy & Distributed Generation (ICREDG), Mashhad, doi: 10.1109/ICREDG.2016.7875915, pp 32-37.

[15] McPherson M and Karney B 2014 Long-term scenario alternatives and their implications: LEAP model application of Panama's electricity sector *Energy Policy* 68 pp 146-157.

[16] Park N, Yun S and Jeon E 2013 An analysis of long-term scenarios for the transition to renewable energy in the Korean electricity sector *Energy Policy* 52 pp 288-296.

[17] Afreen S and James L Wescoat Jr 2013 Energy use in large-scale irrigated agriculture in the Punjab province of Pakistan *Water International* 38.5 pp 571-586, DOI: 10.1080/02508060.2013.828671.

[18] Lin J, Cao B, Cui S, Wang W and Bai X 2010 Evaluating the effectiveness of urban energy conservation and GHG mitigation measures: The case of Xiamen city, China *Energy Policy* 38
pp 5123-5132.

[19] Department of Alternative Energy Development and Efficiency 2019b *Thailand alternative energy situation2019*, Bangkok, Thailand.

[20] Energy Policy and Planning Office 2018 *Power Development Plan (PDP2018)*, Bangkok, Thailand.

[21] International Energy Agency 2013 *Southeast Asia energy outlook: World energy outlook special report*, Paris, France.

[22] Sorapipatana C2013 *An Assessment of Energy Security in Thailand’s Power Generation*, Final Report submitted to the National Science and Technology Development Agency (NSTDA). (In Thai)

[23] Siritiprussamee P, Suwannarat W and Dulyarittirong R 2014 Analysis of Thailand Electricity Demand Pattern *Journal of Environmental Management* 10(1) pp 1–18. (In Thai)

[24] Electricity Generating Authority of Thailand 2018 *Electricity Peak Demand of National Grid*, Nonthaburi, Thailand.

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