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# Impact of Drought Phenomenon on Renewable and Non-renewable Energy Systems in the ASEAN Countries

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Over the last 30 y, there has been increasing emphasis on scientific research about climate change which has become one of the world's most challenging issues. Energy sources availability and reliability, especially renewable energy such as hydropower, solar energy and biomass-based energy, are very dependent on climate conditions. Although many studies have focused on conservation and utilization of energy, less emphasis has been given to future threats of drought on energy systems especially in ASEAN countries. The impact of drought on the region was conservative because such events were under-reported and under-monitored. The aim of this paper is to review the drought phenomenon in ASEAN region and analyse its impact as one of the climate change aspects, on the energy resources, supply, consumption and energy systems used in the ASEAN region. The review encompasses scholarly papers and news articles related to impact of drought on energy systems and analyse historical energy data for ASEAN. The study is focused on drought year in 2014 to 2016 because of extreme El Niño phenomenon. From this study, it is found that the scarcity of energy will occur if long-term drought happened. Drought will impact the biomass and hydropower as both are very vulnerable to high temperature but less impact on natural gas, coal and oil. El-Nino phenomenon in 2015 contributes about 5 % reduction of energy supply from oil, hydropower and biomass energy sources compared to previous year. In 2015, $CO_2$ emission in ASEAN recorded almost double increment (4.1 %) compared to 2016 (2.6 %) due to dependency of carbon-emitting sources like natural gas and coal to meet the energy needs during drought.

## 1. Introduction

Drought is an extreme climate event happened in an area facing minimum precipitation such as snow, rain or sleet for over a period of months to years, resulting in water scarcity. This phenomenon is not similar to the permanent aridity in arid areas like the desert. Drought usually last for a limited period of dryness and occurs worldwide, including in wet and humid regions. However, desert areas have higher chance to face drought due to very low amount of rainfall (Dai, 2011).

The main factors of drought are low precipitation and high temperature. As the ambient temperature increase, water will evaporate more and cause severe water conditions. Air circulation and weather patterns could also contribute to drought. El Niño phenomenon will cause drought in the affected area. Soil moisture deficits will lead to drought due to little water evaporation to create clouds. A region with a higher demand for water for human activities and vegetation that exceed the supply amount of water from any sources will increase the severity of drought. Drought can also lead to other natural disaster such as wildfires and heatwave phenomenon (Folger, 2017).

Renewable energy, such as solar, hydro, biofuels and wind power, play an essential role in reducing climate change by partially replacing fossil-fuel-based energy sources. However, their capacity is highly vulnerable to climate conditions, especially drought. It is challenging to keep their share in the existing energy system when it comes to reliability and stability (Perera et al., 2020). Shadman et al. (2016) have reviewed about the impact of drought on energy security in ASEAN, but only focused on the vulnerability of electricity generation options

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to drought. This paper summarises the researches regarding the impact of drought on energy systems in ASEAN region in various aspects. Drought is not only affecting the energy supply and consumption from various sources of energy, but also affect the energy systems and produce high $CO_2$ emission due to high demand of carbon-emitting sources.

## 2. Drought in ASEAN

The Association of Southeast Asian Nations (ASEAN) was founded half a century ago in 1967. Currently, ASEAN have 10 member states: Indonesia, Malaysia, Philippines, Singapore, Thailand, Brunei, Laos, Myanmar, Cambodia and Vietnam. Based on the joint research between United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) and ASEAN, drought in south-east Asia may become more intense and frequent if there are no initiatives taken to overcome the impacts (UNESCAP, 2019). It is recorded that drought phenomenon has affected 17 % population of more than 66 M people in ASEAN since 1988. Table 1 shows a summary of drought phenomenon occurred in ASEAN region.

*Table 1: Summary of drought phenomenon in ASEAN*

| Date | Location | Description | Type of drought indices | References |
|---|---|---|---|---|
| 1998 and 2014 | Sarawak, Malaysia | Severe droughts due to the strong El Niño | Standardized Precipitation Index | (Bong and Richard, 2019) |
| 1991, 2013-2014, 2014-2016 | Singapore and Johor, Malaysia | These areas have high water demand that may cause water scarcity | Palmer Drought Severity | (Chuah et al., 2018) |
| End of 2018 till August 2019 | Indonesia | About 92 % of the country experienced drought due to El Niño cycle, resulting in a drier and harsher dry season | - | (Hadi, 2019) |
| January-July 2015 | Indonesia | 16 provinces covering 102 districts / cities in Indonesia by the end of July 2015 facing water scarcity | - | (ReliefWeb, 2015) |
| February 2015-July 2016 | 16 regions in Philippines | 85 % of the country was driven by the most severe El Niño event ever recorded. | - | (UNCCD, 2019) |
| 2014-2016 | North-eastern region Thailand | Drought due to the amount of continuous rainfall is less than 1 mm over a period of 15 d | Standardized Vegetation Index and Normalized Difference Vegetation Index | (Rotjanakusol and Laosuwan, 2019) |
| 1990-2005 | Central Highland, Vietnam | Vietnam is prone to drought due to low annual precipitation amount (15-25 %) | Standardized Precipitation Index | (Vu et al., 2015) |

The general conclusion that can be drawn from the summary in Table 1 is that the drought regularly happens in ASEAN. El Niño phenomenon often triggered the series of droughts, especially in the northern part of ASEAN (Thailand, Cambodia, Laos, Malaysia and Philippines). The major El Niño events on record were in 1982 -1983, 1997- 1998 and 2015- 2016. Since 1950, the El Niño event on 2015 – 2016 was observed as the strongest El Niño that affected more areas and more severe compared to 1982 and 1997 (L'Heureux et al., 2017). Apart from El Niño, droughts can result from other factors. Even in non-El Niño years, many parts of the region suffered from severe water stress. The demand for water for human activities and vegetation higher than the water supply amount from any sources also contributes to water crisis in that area. Chuah et al. (2018) studied the drought impact on water management system between Singapore and Malaysia. These areas typically have high water demand and may potentially be subjected to water scarcity.

Historically, the drought in ASEAN are prone to happen in the North and South Vietnam, southern Sulawesi and Borneo, and the central part of Java, Sulawesi and Papua. However, it is expected that the drought phenomenon will have geographical shifting and expanding to Cambodia and the southern part of Thailand, with similar conditions in the southern part of Sumatera and Borneo by 2050. In the same scenario, between the years 2071 and 2100, 96 % of the ASEAN region is likely to be affected by drought (UNESCAP, 2019). Still, the report said estimates on the impact of drought on the region were conservative because such events were under-reported and under-monitored.

Drought can be measured using continuous functions of rainfall and/or temperature, reservoir storage, river discharge or soil moisture. Rainfall data are widely used to calculate drought indices because long-term rainfall records are often available. Drought indices that are widely used to measure drought on crops are Palmer Drought Severity Index and Standardized Precipitation Index (SPI). Both indices have been used for a long time and applied in many cases including in ASEAN region (Chuah et al., 2018).

## 3. Impact of drought on energy resources and energy systems

Drought phenomenon contributes to a significant impact, especially on renewable energy resources as they can be more vulnerable to drought, due to high dependence on weather and climate. The effect of drought on the energy sector will follow the stages, from energy resources, energy conversion to final use. Energy resources which concern the amount of primary energy available during drought is discussed in this section. Based on Table 2, drought does not impact the supply of non-renewable energy sources such as oil, natural gas and coal. Oil and gas resources are not likely to be affected by climate change because of the resources involved in a process that takes millions of years and are geologically trapped. Oil and gas production may be disrupted by other extreme events such as intense hurricanes, flooding or storm surges (Ebinger and Vergara, 2011).
Renewable sources such as hydropower, solar and biofuels are highly vulnerable to the effects of weather and temperature. Hydropower generation depends directly on the availability of water resources. Rising temperature due to drought can also affect the crops productivity and quality for the production of biofuels (Ahorsu et al., 2018). The wind availability, air density and wind speed effects on wind power generation. Generally, drought would bring insignificant impact on wind energy (Urban and Mitchell, 2011). However, if drought happened in the long term with extremely high temperature, the wind speed can decrease up to 22 %, and reduce the wind power generation potential. Drought will generate high solar radiation with lower cloud cover, which is essential for solar power resources. Unfortunately, high ambient temperature during drought might cause reduction of about 0.5 % of photovoltaic efficiency for temperature increment of 1 °C due to negative impact on current thin-film and crystalline silicon modules in the photovoltaic (Patt et al., 2013). For energy infrastructure, drought will not bring a significant impact on the design as compared to other extreme weather such as hurricanes and flood. From Table 2, water availability for cooling purposes become the main concern during drought. Most of the energy system requires high amount of water in their cooling processes. Hydropower energy system is the most vulnerable to drought since low precipitation reduced the generating capacity and its efficiency.

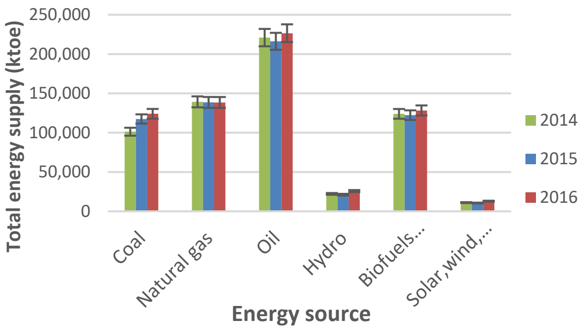
*Table 2: Summary of impact of drought on energy resources and energy systems.*

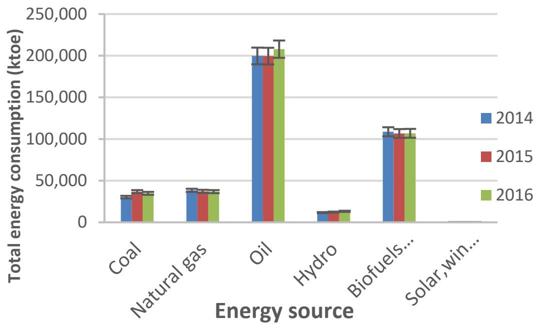
| Power options | Impact on energy resources | Impact on energy systems | References |
|---|---|---|---|
| Coal | None | Potential impact on water availability for cooling purposes | (Schaeffer et al., 2012; Urban and Mitchell, 2011) |
| Natural gas | None | Potential impact on water availability for cooling purposes | (Schaeffer et al., 2012) |
| Oil | None | Decreased availability of water for cooling purposes. | (Urban and Mitchell, 2011) |
| Hydro power | Increased evaporation, lower water levels. | Low of effective generating capacity due to reduced runoff and increased surface water evaporation | (Shu et al., 2018) |
| Wind | Reduce wind speed | Indirect impact on air density and wind patterns. | (Urban and Mitchell, 2011) |
| Solar | Increase solar radiation and lower cloud cover | Better conditions if accompanied by increased solar radiation, lower cloud cover. High PV panel temperature contributed to the negative impact on output performance. | (Amelia et al., 2016; Ismail et al., 2020; Urban and Mitchell, 2011) |
| Biomass | Lower biomass availability. Losses in suitable areas for growing crops | Potential impact on water availability for cooling purposes. | (Schaeffer et al., 2012) |

### 3.1 Impact on energy supply, consumption and $CO_2$ emission

Energy supply is the transformation of energy and delivery to the consumers, including energy exploitation, pre-treatment, conversion process and transmission, generation, distribution and fuel storage. Energy consumption can be defined as energy use by any human activities such as from residential area, industrial processes, electricity, transport fuels and fuels for heating. Drought cause higher ambient temperature which may imply in lower demand for heating and higher demand for cooling (Schaeffer et al., 2012). Van Vliet et al. summarise that the energy consumption during drought will increase, but the supply will reduce due to drought-related power curtailments (Van Vliet et al., 2016). Water scarcity due to drought has caused a shortage of electricity supplies. Hydropower makes up 86 % of the renewable electrical generation in the world. International Energy Agency reported that 18 % of ASEAN energy comes from hydropower and will be projected for next decade (IEA, 2019). However, it is extremely vulnerable to drought and relies on freshwater from rivers and streams (Hamududu and Killingtveit, 2012).

In this section, the data on total energy supply and demand for different energy sources in ASEAN region are analysed. The data in Figure 1a and 1b are taken from International Energy Agency (IEA, 2017) and focused on the countries in ASEAN that are affected by drought in 2015. The figures are reviewed and analysed in detail to determine the trend of energy supply and consumption during the drought in ASEAN. The time duration was chosen between years 2014 to 2016 due to 2015 was recorded as the warmest year since 1880. The year 2015 was characterised by one of the strongest El Niño in history and with record-high ocean temperatures globally (0.74 °C higher than the average over the 20th century). The global land temperature for 2015 was 1.33 °C above the 20th-century average (Olivier et al., 2016). Based on the summary of drought event in ASEAN in Table 1 also recorded that most of the drought phenomenon happened from 2014 to 2016.




* The data for electricity and heat trade are excluded.

*Figure 1a: Total energy supply in ASEAN from different energy source and 1b: Total energy consumption in ASEAN from different energy source*

From Figure 1a and 1b, oil becomes the most significant element in the regional mix. Biofuels and biomass source recorded as the highest renewable total primary energy supply in ASEAN. Some countries such as Vietnam, Cambodia, Thailand and Indonesia encompass a large share of biomass and waste as renewable energy use. Biomass energy consists of traditional biomass and modern bio-energy. Modern bio-energy uses liquid biofuels such as ethanol and biodiesel, to generate electricity and transportation. Traditional biomass is primarily used for cooking and heating and become the main energy source in developing countries. This method has a negative health impact because of open burning and uncontrolled. In these uses, solid biomass is not considered “modern” renewable energy, but still included in this data depiction (Gumartini, 2009).

Figure 1a also shows that the El-Nino phenomenon in 2015 contributes to the reduction of energy supply from oil, hydropower and biofuels or biomass energy sources. The amount of energy supply from coal, natural gas and solar are not affected by drought. Generally, non-renewable energy such as coal, natural gas and oil have less impact by drought in terms of the resources. In contrast, renewable energy is more vulnerable to any climate change or extreme weather (Urban and Mitchell, 2011). Oil refining requires substantial water consumption activity for processing crude oil and cooling purposes. Sun et al. reported that about 19,078 $m^3$/ day of water needed in an oil refinery for each barrel (Sun et al., 2018). Drought will impact the biomass and hydropower as both are very vulnerable to the high temperature. Van Vliet et al. (2016) found that hydropower supply rates were significantly reduced by 5.2 % during the majority of investigated drought years and in almost all sub-regions. Biomass was also affected by drought since this process is dependent on agricultural profile and crop yield (Schaeffer et al., 2012).

The impact of drought in the energy system is not limited to the supply side as this phenomenon can also influence the energy consumption. Drought will imply in lower demand for heating and higher demand for cooling (Schaeffer et al., 2012). However, Figure 1b shows that the drought from El-Nino phenomenon did not show a significant impact on energy consumption in ASEAN. The World Energy Balance Report states that the industrial sector is the primary sector that consumed the most energy usage in ASEAN (IEA, 2019). Climate change, such as drought has less impact on industrial energy consumption due to the temperature difference between the industrial processes is higher than the ambient temperature fluctuations. Industries have stable demand because most of the continuous processes are usually functioning at a fixed surrounding temperature, although some of them may face water scarcity impact (Grecksch and Stefán, 2018). Based on Figure 1a and 1b, the amount of energy supply are more than energy consumption in ASEAN especially for coal and natural gas although in drought condition. This is because Indonesia and Malaysia are among the world's major producers and exporters for coal and natural gas. Production of these energy sources are substantially outweigh the region's consumption.

$CO_2$ emissions in ASEAN has shown a trend of rising from 2014 to 2016 as illustrated in Figure 2. The raw data is obtained from Our World In Data website reported by Ritchie and Roser (2020). Although $CO_2$ emission will be projected each year due to industrialization and population growth, the higher reading of $CO_2$ in 2015 shows that drought may affect the annual $CO_2$ emission since utilities are dependent on carbon-emitting sources like fossil fuels combustion and coal to fill the energy need, especially when renewable energy supply is less reliable. In 2015, $CO_2$ emission in ASEAN recorded almost double increment (4.1 %) compared to 2016 (2.6 %) due to dependency of carbon-emitting sources like natural gas and coal to meet the energy needs during drought. A group of researchers has found out that drought phenomenon causes an extra 100 Mt of $CO_2$ saturated in the atmosphere due to high usage of carbon-emitting power sources instead of hydroelectric power during drought (Herrera-Estrada et al., 2018). In addition, Humphrey et al. (2018) figured out that the concentration of $CO_2$ increases faster during the driest years such as 2015 compared to normal years. This is because the photosynthesis activity has reduced during drought and the struggling ecosystem absorb less $CO_2$ from the surrounding air. The concentration of $CO_2$ in the atmosphere increased faster in 2015 than in normal years.

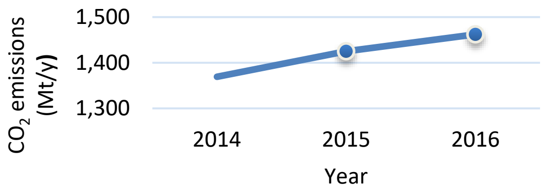



*Figure 2: Annual $CO_2$ emissions in ASEAN for 2014 – 2016.*

## 4. Conclusions

Drought phenomenon have affected 17 % population or more than 66 million people in ASEAN since 1988. From the review, it is recorded that most of the drought phenomenon in ASEAN happened from 2014 to 2016 due to El Niño. Drought phenomenon contributes to a significant impact, especially on renewable energy resources as they can be more vulnerable to drought, due to high dependence on weather and climate. Oil become the most significant element in the regional mix. El-Nino phenomenon in 2015 contributes to the reduction of energy supply from oil (3.3 %), hydropower (5.7 %) and biomass energy sources (2.5 %) compared to previous year. Industrial sector has the highest consumption of energy usage in ASEAN. Drought shows an insignificant impact on energy consumption in ASEAN. The higher reading of $CO_2$ in 2015 and double increment compared to 2016 also shows that drought may affect the annual $CO_2$ emission since utilities are dependent on carbon-emitting sources like fossil fuels combustion and coal to fill the energy need.

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