The effect of climate change to palm oil price dynamics: a supply and demand model

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Abstract. The climate change may lead to anomaly in hydrological cycle. Climatic disturbance in precipitation or rainfall rate will turn to impact oil palm production. The low precipitation due to erratic rainfall will affect sex differentiation, abort female inflorescence, and subsequently decrease oil palm yield. On a larger scale, the peculiar yield trend will fluctuate oil palm supply and thus impact the crude palm oil (CPO) price. This study was aimed to assess the impact of climate change on palm oil price dynamics and to anticipate its adverse effect faced by the vulnerable smallholder in Indonesia. The system of equations was estimated by employing simultaneous equation model. The simulations were set to generate the forecasts from 2018 to 2050 using Representative Concentration Pathway (RCP) scenarios. A time series data ranging from 1980 to 2018 of CPO yield, oil palm mature areas, stock changes, export, as well as monthly rainfall rate were taken into account. The simulation revealed that the climate change in terms of fluctuating rainfall would cause unfavourable palm oil price level that eventually would exacerbate smallholder welfare.

1. Introduction
Palm oil growers tend to overlook the anomaly of agroclimatic indicator to its farm practice. In fact, it eventually affects the physiological grow of the estate crop. The disturbance in those variables would heavily affect the productivity at least in the next six months to come. The erratic rainfall would bring the outbreak of fungal disease, corrupt the sex differentiation and abort female inflorescence [1]. Thus, the effect of climate change to palm oil growers was not supposed to be neglected.

The urge of elaborating the effect of climate change to the oil palm plantation as well as to the CPO farm gate price was prominent. This was crucial particularly for the smallholder since they were price taker and among the lowest level in the value chain of oil palm industry. Hence, they were the most vulnerable group thus makes them difficult to apply Best Management Practices (BMP) in cultivating oil palm [2-4].

The good agricultural practice promoted that the palm should have adequate climatic and soil condition as well as appropriate farm cultivation technique so that it can grow optimally. Without neglecting other external factors, one of abiotic variable that act as critical input was rainfall rate. Stable rainfall rate facilitated the plant to grow healthier and less prone to disease [5]. Adequate water was needed, otherwise the attainable yield would not reach their potential [6].

Despite considerable findings on how climate change affect oil palm production, there is no recent study who discuss the effect directly to the price. The objective of this research is to evaluate the impact of climatic variables in terms of rainfall rate to the dynamics of CPO price volatility. Ultimately, the
finding is expected to be a measure to quantify how and why one should react and take measures against the adverse effects that followed.

Assessment of the effect of disturbance in hydrological cycle in terms of precipitation to palm oil price was constructed in the two stages. Initially by defining the effect to production and supply sectors, and subsequently simulating the effect to the supply and demand equilibrium in the market. The framework of simultaneous equation model was employed. The simulations were using Representative Concentration Pathways (RCP) scenarios of consecutively; RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.0 level of radiative forcing [7]. The projected data was necessary to quantify the adaptation and mitigation efforts post-the shock exposure.

2. Material and methods

2.1. Conceptual framework

In order to investigate how does climate change in regard to precipitation rate affect palm oil price, firstly one should consider to link production sector into dynamics of supply and demand model. The climatic variables are input factor of oil palm productivity or yield [8]. Under non-limiting states, oil palm transpires about 6 mm water per day and requires sufficient rainfall throughout the year. [6] suggested that moderate to severe water stress strongly restrains yield. When it comes to water stress, oil palm leaves do not wither and the opening of new leaves is delayed. Air vapour pressure deficit (VPD) and soil water availability also affected stomatal opening. When stomata is close, the plant cannot produce food for their development. Thus, it is revealed that there is a linear relationship between water availability and yield.

Furthermore [5] explained why one should care about climate change in oil palm. In terms of plant protection, fungal diseases would outbreak more often in too moist environment. It would cause diseases such as *Marasmius palmovirus*, or even *Ganoderma boninense* that generally hinder oil palm productivity [9].

![Figure 1](image-url)

**Figure 1.** Conceptual framework of the system of estimations: oval shapes remarked *endogeneous* variables, while square shapes denoted exogeneous variables.

In the helicopter view, the adverse effect caused by climate change might have an impact to the human realm. Palm oil stakeholder especially oil palm growers would be affected by declining production and price. [10] has explained how the palm oil price volatility affected by supply and demand of palm oil. The supply side of palm oil commodity heavily affected by production in mature areas, while the demand side of the palm oil market system has been impacted by the purchasing power of the nation that proxied by GDP (Gross Domestic Product), the market price of palm oil, and the price of its substitute goods, in this case is soybean oil price [11]. The more comprehensive approach of this study was well-portrayed by figure 1.
2.2. Data and materials

The secondary data that were employed through estimations were derived from Directorate General of Plantation of Indonesian Ministry of Agriculture (Ditjenbun). The data were included yield and area of oil palm mature areas. As the detail from table 1, the climatic variable for historical and projected data to be used in RCP scenarios was taken from World Bank Climate Change Knowledge Portal. The endogenous CPO price data were derived from World Bank Commodity Price (pink sheet) and so as the data of exogenous soybean prices, they were taken from the same resources. Data supports for supply side identity function such as stock change, export, import, and domestic use data was utilized from the United States Department of Agriculture (USDA). Other additional data were collected from the International Monetary Fund (IMF) and Statistics Indonesia (BPS).

| Var  | Data Description                           | Source of Data               | Year          |
|------|-------------------------------------------|-----------------------------|---------------|
| Ym   | Yield/ Productivity                       | Ditjenbun                   | 1980-2018     |
| Am   | Palm Oil Mature Areas                     | Ditjenbun                   | 1980-2018     |
| RAIN | Rainfall Rate                             | WBCC Knowledge Portal       | 1980-2018     |
| WCPO | World Price of CPO                        | World Bank Commodity Price  | 1980-2018     |
| WSOY | World Price of Soybean Oil               | World Bank Commodity Price  | 1980-2018     |
| CPI  | Consumer Price Index based year 2010=100  | IMF                         | 1980-2018     |
| Q    | Production of CPO = Y x A                 | Identity Function           | 1980-2018     |
| EXP  | Export Quantity                           | USDA                        | 1980-2018     |
| STC  | Stock Variation (opening – ending)        | USDA                        | 1980-2018     |
| QS   | Quantity supply = Q - EXP_t + STC_t + IMP | Identity Function           | 1980-2018     |
| QC   | Quantity Demand = QS/ Pop                 | Identity Function           | 1980-2018     |
| EXR  | Exchange Rate                             | World Bank/ BPS             | 1980-2018     |
| GDP  | Gross Domestic Product                    | World Bank/ BPS             | 1980-2018     |
| POP  | Total Population                          | World Bank/ BPS             | 1980-2018     |

2.3. RCP as the proxy of future climatic variables

Aside from national statistics, the simulation was operated on the projection data gathered from acknowledged international climate agency. IPCC (Intergovernmental Panel on Climate Change) is an inter-country agency under United Nations authority with an objective and scientific view of climate changes. It has formulated scenarios to forecast future climatic conditions of the earth. Among other notable scenarios, RCP (Representative Concentration Pathways) is one of a kind. The RCP scenarios has discussed about the impact of climate change on stream flow, evapotranspiration, surface runoff,
and water yield of hydrological cycles [7]. Type of RCP scenarios that was employed in these estimations was RCP 2.6, RCP 4.5, RCP 6.0, and RCP8.5.

According to [7], The RCP 2.6 scenario indicated a very low forcing level, with a peak of 3.1 Wm$^{-2}$ in the mid-21st century. Greenhouse gas emissions should be reduced significantly to match the RCP 2.6 scenario. While, forcing level of the RCP 4.5 scenario was medium level, which stabilized with radiative forcing of 4.5 Wm$^{-2}$. Furthermore, the RCP 8.5 scenario was a very high greenhouse gas emission scenario, with a rising radiative forcing pathway by 2100 up to 8.5 Wm$^{-2}$.

Following the data collection, subsequent processes to do were data preprocessing, explorative/descriptive statistics, control and assumption checking, model selection, simulation and interpretation of the results. Estimation of foundation function in the simulations were constructed by the following model specifications:

$$Y_m = a_y + b_y \cdot \text{TREND} + b_y \cdot \text{RAIN}$$  \hspace{1cm} (1)

$$A_m = a_A + b_A \cdot \text{TREND} + b_{A2} \cdot \text{A}_{t-1} + b_{A3} \left( \frac{\text{WCPO}_{t-1}}{100} \right)^{-1}$$  \hspace{1cm} (2)

$$\text{EXP} = a_{\text{exp1}} + b_{\text{exp1}} \cdot \text{QC} + b_{\text{exp2}} \left( \text{WCPO} \cdot \text{EXR} \right) \left( \frac{\text{CPI}}{100} \right)^{-1}$$  \hspace{1cm} (3)

$$\text{STC} = a_{\text{STC1}} + b_{\text{STC1}} \left( \text{QC}_{t-1} \right) + b_{\text{STC2}} \left( \frac{\text{WCPO}}{100} \right)^{-1} \cdot \text{WCPO}_{t-1} \left( \frac{\text{CPI}_{t-1}}{100} \right)^{-1}$$  \hspace{1cm} (4)

Identity $Q_{\text{Supply}} \Rightarrow Q_t \cdot \text{EXP} + \text{STC}_t + \text{IMP} \cdot \text{DOM}_t$  \hspace{1cm} (5)

Identity $Q_{\text{Demand}} \Rightarrow Q_t / \text{POP}_t$  \hspace{1cm} (6)

$$\text{QC} = a_{\text{QC1}} \cdot \text{WCP} \left( \frac{\text{CPI}}{100} \right)^{-1} + b_{\text{QC2}} \cdot \text{WSOY} \left( \frac{\text{CPI}}{100} \right)^{-1} + b_{\text{QC3}} \cdot \text{GDP} \cdot \text{pc} \cdot \text{EXR} \left( \frac{\text{CPI}}{100} \right)^{-1}$$  \hspace{1cm} (7)

where the equation (1) to (4) referred to yield, area, export, and stock change function, while the equation (6) denoted demand function. The remaining (5) and (6) equations were identity function of supply and demand. The $t$ and $t-1$ subscripts indicated those in individual year from 1980 to 2018 and its one year of lag respectively.

Even though since 2009 Indonesia has implement biodiesel policy and committed to continue its blending realization [12], however within this study the author did not use its real number contribution. Instead, the portion of CPO product that converted to FAME (fatty acid methyl ester) as the intermediate product of biodiesel was assumed to be included already in domestic use variable (DOM_USE).

3. Results and discussion

3.1. Basic statistics

Using time series data range from 1980 to 2018, the basic statistics of the inputted variables were generated prior to running simultaneous equation modelling. The average yield or mature area’s productivity is 3.15 MT/ha. World price of CPO since the earlier 1980 to 2018 is more than 352.13 USD and no more than 810.37 USD per MT. And so, as the world price of soybean oil, it has never been peaked more than 906.64 USD per MT. Table 2 displayed basic summary of overall included variables.

3.2. Simulation result

Climatic variability was claimed to disrupt the ecosystem. As a part of the green ecosystem, oil palm worked as an ecosystem function in the landscape [13]. Environmental stress/changes allowed to salient adverse effect to the oil palm ecosystem, and so as the reverse case [14]. The climate change is not only
affecting palm oil cultivation, but there is a dual relationship that palm oil cultivation also might cure or diminish negative response of climate change. The role of palm even though benevolent in respect to climate change, its conditions might be aggravated when it comes to erratic climatic variables. In the long run, tropical countries like Indonesia and Malaysia might no longer be suitable for cultivating oil palm. The land suitability class will shift to more sub-tropical countries in the upcoming 2100’s [15]. [15] previously suggested that both countries should be aware that oil palm might no longer be their prominent commodities. However, [16] believed that the future of oil palm still bright for Malaysia by maintaining good relationship with Malaysian main trading partner, that is China. He contended that future trajectory of palm oil market as leading commodity of Malaysian people still prospective.

**Table 2.** Basic summary of incorporated variables.

| Variables                        | Mean   | Standard Deviation | Unit          |
|----------------------------------|--------|--------------------|---------------|
| Yield                            | 3.154  | 0.489              | MT/ ha        |
| Mature Area                      | 3,860,769 | 3,624,148         | ha            |
| World Price of CPO               | 581.25 | 229.12             | $/ MT         |
| World Price of Soybean Oil       | 649.63 | 257.01             | $/ MT         |
| Consumer Price Index             | 55.25  | 48.04              | (index)       |
| Export Quantity                  | 8,757,077 | 9,376,030         | MT            |
| Production                       | 12,140,821 | 12,237,700        | MT            |
| Stock Change                     | -88103 | 407,049            | MT            |
| Import                           | 57,026 | 102,026            | MT            |
| Food/ Domestic Uses              | 3,352,667 | 3,339,729         | MT            |
| Demand Quantity per capita       | 0.015  | 0.012              | MT/ capita    |
| Exchange Rate                    | 6263.62 | 4593.91            | Rp/ $         |
| Gross Domestic Product per capita| 13,109,298 | 15,420,280       | Rp/ capita    |
| Population                       | 208,434,379 | 35,333,080        | lives         |
| Monthly Rainfall rate in first semester | 255.36  | 62.26              | mm/ month     |
| Monthly Rainfall rate in second semester | 275.80  | 59.77              | mm/ month     |

**Figure 2.** Historical and forecasted rainfall in the first semester (left) and second semester (right).

In the case of Indonesia’s economy, the efforts to foresee future trajectories of Indonesian palm oil in climatic scenarios initially conducted by establishing simulation of future rainfall rate in both first and second semester. The former was represented by rainfall variable in May, while the later was
exemplified by that in November. The idea of doing so was justified by performing correlation and regression analysis to the monthly precipitation rate in each month.

Basically, the sufficient rainfall is favorable to the plant development. It is one of the main input factors that ought to be satisfied; otherwise, it will exacerbate the plant to become more prone to disease [5]. The forecasted rainfall during 2018 to 2050 exhibited that there was fluctuation of rainfall of first semester in 2018 and then dropped by 2020. The unfavorable circumstances also persisted on forecasted rainfall of the second semester as shown in figure 2.

Figure 3 explained the trend of posterior yield and its trajectory up to 2050. According to yield function as specified in equation (1) of foregoing system of equations, rainfall rate contributed to affect yield or productivity of CPO. When the RCP scenarios applied to the simulation framework, it was revealed that projected productivity in 2018 to 2050 will change from 3.317 MT/ha in RCP 8.5 to 3.303 Mt/ha in RCP 2.6, much lower from that recorded in 2018 (3.67 MT/ha). The decrease in yield supported previous notions declared by [6] and [8] that rainfall is prominent input factor of plant physiology thus water-stress circumstances lead to plant hindered in development. It was happening through inflorescent delayed, abortus of female flowers, thus changed in sex differentiations [1].

Following the forecasted yield, the need to simulate the proceeding effect to the CPO trade in market was arisen. The shock in yield would relate to supply side of CPO market reasonably. It disrupted supply quantity in identity function of equation (5) and (6). Supply quantity was also proxied by stock variation (STC) dynamics as depicted in figure 4. Declining stock variation in simulated year of 2018 to 2050 explained that domestic use as well as export of CPO might link to constant decrease in these variables. By tracing back to the constructed model specification in equation (3) and (4), it was well understood that both variables (STC and EXP) were endogenous to CPO Price [10]. The higher CPO price, the more exported palm oil goods were in the market. In addition to that, increase of domestic or food use also subsequently would reduce STC.

The price-induced changed in STC might explain variation in price too. Through employing RCP 2.6 scenario, the price of CPO in the market were projected to decrease year by year. During 2018 to 2050 CPO price would be at its lowest level than that in the previous year. It was argued that this happened due to either sluggish world economy or dynamics in its substitute’s goods [11]. On top of that, the climate-induced shock in supply is the primary trigger. Palm oil was becoming less attractive due to either negative sentiments or tariff and non-tariff trade barriers, thus decreasing demand in market. This circumstance might result in excessive supply of CPO, which eventually made its price down.

Depart from the interpretation of price forecast in figure 5 where the expected market price of CPO is keep decreasing, it is suggested that one should prioritize smallholder farmers since they are the most
vulnerable and most disadvantages when the adverse effects of climate change existed. It was consistent with oil palm value chain in Indonesia as depicted in figure 6. Smallholder is the latest agent who receives whatever the price is [17]. As a price taker, they were the most vulnerable actor in times of market price shock persisted.

The way to save them from this nightmare is to awaken their awareness to apply best management practice. It seems implausible when conducted individually but would bring more benefit when the smallholder gathers in a group as a cooperative. A well-mannered institutional arrangement based on collective action has proven to increase their compliance in best management practice application to their farms [18]. The government may take part to overcome this challenge by leveraging enabling condition to support weather index insurance customized for oil palm commodity. [19] has suggested that such measures are quite effective in hedging the risk of uncertain climate variability. Thus, it permits substantial production stability.

In terms of farm management practice, in order to curtail these adverse effects, adaptation and mitigation measures are needed. [20] suggested that adaptation against climate change in palm oil sector could be overcome by finding varieties that resistant to disease and tolerant to drought. Even if that exist, it is almost difficult for smallholder to obtain access to it. In the micro-level [2-4] to some extent supported this notion and seek for the same measures particularly for the smallholder. One of the actions was to implement the role of agriculture extension. The typical of mitigation and adaptation effort has been successfully adopted in Benin [21].

Another adaptation strategy that possibly be performed in the smallholder plot is climate-smart management practice. Studies had recommend to apply some practices such as soil compaction, legume cover crops planting and ablation during immature stages [9,15], make use of empty bunch mulch, pruning excessive trunk, water conservation management [22], utilization of pest and weed control bio-agents [23], fertilization with bio-fertilizers, maintenance of dishes roads, application of landscape approach (maintaining riparian ecosystems and integration of oil palm, biogas, and cattle [24,25]), diversification of land use/ intercropping, biomass utilization, bio-char soil management systems, and low tillage treatment during land preparation [14].

When all of these are successfully conducted, not only oil palm can survive from the adverse effect of climate change, but in general, it also helps to reduce the effect compare to the counterfactual. Hence, oil palm played pivotal role in the green ecosystem landscape that it enables amelioration of climate change effect [13,14].

4. Conclusions

Climate change has hit the yield performance of oil palm crop that lowering down its supply quantity. In addition to that, oil palm should survive amidst a sluggish economy as well as competition with its substitute goods. These happened to decrease the price of CPO eventually. The adverse effect of initially
caused by erratic rainfall, would consequently aggravate smallholder's welfare. The notion arises since the agents were the lowest level of palm oil value chain and among the weaker in their bargaining power. Adaptation and mitigation measures against this problem were compulsory. Enhancement in the institutional arrangement on the farmer’s collective action motives, enabling condition to apply weather index insurance on the government side, as well as climate-smart adaptation strategy in the smallholder plots will help in smoothen the effect. Additionally, in terms of constructed model specification, there remains a room for simulation improvement. Through incorporating other variables and policy scenario such as tariff and non-tariff trade barriers as well as the portion of palm oil product goes to biodiesel blending, the simulation result would be more reflecting price volatility accurately.

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