EXECUTIVE SUMMARY

REPORT

Impacts of Climate Change in Indonesian Agriculture

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Introduction

Climate change has caused an increase in air temperature - which causes changes in rain patterns, sea-level rise, and extreme climate events that impact the agricultural sector. Changes in rainfall patterns and extreme climatic events affect planting time, planting methods, loss of yield due to crop damage by floods, droughts, explosions of plant pest organisms (OPT), and decreased overall production. Sea level rise causes seawater intrusion and tidal waves that impact flooding and increases the salinity of agricultural lands located on coastal areas. Overall, the existence of climate change decreases agricultural productivity.

This study focuses on rice commodities in paddy fields and swamps as well as coffee in dry lands. Rice is the main food commodity that is very important for the people of Indonesia, while coffee (arabica and robusta) is the primary plantation commodity in Indonesia. Indonesia is the fourth largest coffee producer and exporter globally, with an average role of 4.76% of total world exports. This study aims to 1) provide scientific findings on the impact of paddy and coffee production over the past few years, 2) to assess historical and projected the productivity and economic value changing under different climate scenarios, and 3) to present the economic performances (benefit and loss from productivity, price change, export, and import) of rice and coffee commodities under mitigation action or without mitigation measures against climate change in the future. This study analyzes the historical climate and projection data by using the outputs from the Coordinated Regional Climate Downscaling Experiment – Southeast Asia (CORDEX-SEA) models consisting of two climate change projection schemes based on RCP4.5 and RCP8.5.

Results

A. Impact of climate change on the historical paddy and coffee production

<u>Rice in Coastal Areas</u>

Sea level rise and salinity have affected paddy and coffee production. Under the scenario of 1 meter of sea-level rise (SLR-1), which is set based on RCP 8.5 predictions for 2100 (Kopp et al. 2017; Strauss et al. 2021), around 134,509 ha of coastal rice fields (51% are located on the island of Java) is submerged. This SLR-1 scenario will eliminate almost 1 million tons of rice production - which would otherwise meet the rice needs of 5 million people. Meanwhile, 2 meters of sea-level rise (SLR-2) will have a more massive impact where 430,775 ha of Indonesian coastal rice fields will be submerged. More than 70% of the rice fields affected by SLR-2 are located on Java Island. This event will eliminate 3.5 million tons of rice production, equivalent to the rice needed to feed 17.7 million people.

The salinity threshold for rice plants is 3 dS m-1 where any excess will cause a decrease in rice productivity (Radanielson et al. 2018; Zeng and Shannon 2000). By calculating the reduction of rice production, which corresponds to each level of increasing electrical conductivity (Electrical Conductivity / EC), the modelling shows that an increase in EC of up to 4 dS m-1 will cause a loss of 1.8 million tons of rice production. In addition, an increased EC of up to 9 dS m-1 will cause a loss of rice production by 50% of its potential yield or equal to 8 million tons - which is equivalent to fulfilling the rice consumption of 42 million people.

Therefore, the agricultural sector needs to immediately formulate necessary measures to adapt to the above conditions. To adapt to rising sea levels, it is essential to increase the productivity of non-coastal rice fields by applying land intensification technology and creating high-yielding high yielding varieties. The opening of new rice fields in non-coastal areas, especially outside Java Island, is vital to replace lost rice fields that are submerged in seawater. Meanwhile, to overcome the increase in salinity, it is necessary to create saline-resistant and high-yielding varieties. Improvements to irrigation infrastructure, including rubber dams, soil amendment materials such as organic matter and gypsum, conservation farming practices, phytoremediation and bioremediation, utilization of planting calendars, as well as the granting of credit and insurance for farming are important parts of adaptation efforts.

Rice in Swamps

Another climate indices that affect agricultural production is The El Niño Southern Oscillation (ENSO). The ENSO event is closely related to the pattern and intensity of rain and extreme climate events in Indonesia. Changes in rainfall patterns and extreme climatic events are the dominant factors affecting rice and coffee production. ENSO criteria use Ocean Nino Index (ONI) $+0.5^0$C, while La Nia with ONI -0.5^0C lasts for five consecutive months. This criterion is used to quantify planted area, harvested area, and lowland rice production at the district level in Indonesia.

Swamp lands are usually naturally occurring landscapes inundated with water from overflowing rivers or rain either partially or throughout the year. Swamp lands are very vulnerable to extreme climatic events. Heavy rainfall due to La Nina will increase the water level to reduce available land. On the other hand, during El Niño, there is an increase in planted area due to lower water levels - especially in lowland swamps. The highest growth in planting area during El Niño reached 82% in Pulang Pisau Regency (Central Kalimantan), which was dominated by swamp land, and Banyuasin Regency (South Sumatra Province), which reached 57% and was dominated by tides.

The increase in harvested area under El Niño conditions ranged from 6-20%, the highest being in Tapin Regency (Central Kalimantan), Mempawah Regency (West Kalimantan), Muaro Jambi Regency (Jambi Province), Musi Banyuasin Regency (South Sumatra Province), and Seruyan Regency (South Kalimantan). However, El Niño conditions in acid sulphate swamps can cause an increase in pyrite oxidation such that, when inundated, it can cause sulfate and iron poisoning. In contrast, Al poisoning, increased salinity, as well as pests and disease outbreaks occurred during dry conditions. Nevertheless, environmental impacts due to climate change on swamp lands may be minimized by implementing environmentally friendly swampland management technology for rice.

Rice in the paddies

Indonesia's rice production continues to increase due to technological developments, but rice production is highly correlated with the incidence of ENSO. El Nino correlates with a decrease in rice production due to drought, whereas La Nina in some areas increases production due to an increase in planted area. The highest production decline during El Nino occurred in Papua and Maluku, and parts of Sumatra, Kalimantan and Sulawesi. Meanwhile, the increase in production during La Nina occurred in some districts in Indonesia. On the other hand, several districts on the coast of West Java and Central Java experienced a decline in production due to flooding.

The results of this study indicate that during El Nino, both in the rainy season and dry season, there is an increase in the area of rice plants affected by drought. In contrast, during La Nina there is an increase in rice plants affected by flooding in most parts of Indonesia. Areas of rice fields affected by drought during El Nino average around 450,000 hectares, with the highest area reaching more than 80,000 hectares. Damage to rice crops in paddy fields due to flooding in La Nina averaged around 145,000 hectares, with the highest area reaching more than 250,000 hectares. Subsequently, during La Nina, the area of damage to rice plants due to the attack of the Brown Planthopper on the Constitutional Court reached 100 thousand hectares.

To reduce the negative impacts of climate change on lowland rice, it is necessary to implement climate change adaptation and mitigation efforts. Suitable adaptation steps include adjusting planting time and planting pattern, using high yielding varieties tolerant of drought and submergence, optimizing the use of alternative water sources, as well as developing flood, drought, and pest early detection systems by utilizing the use of climate stations and the use of 4.0-based telecommunications facilities. Meanwhile, mitigation measures are carried out through intermittent irrigation, utilization of low-emission varieties, and balanced fertilization.

Lowland and Highland Coffee

The two dominant types of coffee cultivated in Indonesia are Robusta coffee in the lowlands and Arabica coffee in the highlands. Robusta coffee production centers are in the provinces of South Sumatra, Lampung, Bengkulu, Central Java, and East Java. Meanwhile, Arabica coffee production centers are in the provinces of Aceh, North Sumatra, East Java, East Nusa Tenggara, and South Sulawesi.

During El Niño and La Nina events, most production centers experienced a decline in both Robusta and Arabica coffee production. The highest drop in Robusta coffee production (>3,000 tons) occurred in Bengkulu and Lampung Provinces, while during La Nina the highest declines occurred in Central Java and East Java. The impact of El Nino on the decrease in Arabica coffee production is not as high as that of Robusta coffee. The centers of Arabica coffee production with the highest decline in production are the Provinces of Aceh and East Nusa Tenggara. The impact of La Niña is more significant on Arabica coffee production, where almost all Arabica coffee-producing districts experience a decline in production.

Today's adaptation and mitigation technology is based on Climate Smart Agriculture (CSA). Climate change adaptation technologies in coffee cultivation include: 1) Use of shade, organic mulch, and cover crop, 2) Technology of land management with Rorak, 3) Technology of rain harvesting and surface runoff through the construction of dams, dams and ditches used to meet crop water needs, especially during the dry season, 4) Water-saving technologies such as sprinkler irrigation, drip irrigation, water, irrigation and drainage, and 5) Development of drought-tolerant varieties. Mitigation technologies recommended in coffee cultivation include 1) Land management through alley cropping and intercropping, 2) Use of organic fertilizers, and 3) Plantation of mixed coffee with fruit, vegetable and plantation crops.

B. Climate Assessment

Results from climate modeling practice within the CORDEX-SEA framework were used as the primary data source for further analyses of possible changes in the future climate

Climate models (global and regional) have been employed as tools for projecting the state of the climate based on the assumption of long-term changes - which in this case is the future pathways of the atmospheric radiative forcing heavily linked with the concentration of greenhouse gases. Regional model results from the CORDEX-SEA project provide options in such scenarios - with RCP4.5 considered the closest scenario to the current emissions pathway and RCP8.5 as the worst-case scenario.

<u>Advancement in the multi-model ensemble method (weighted) provides significant improvement of models in representing actual conditions - as shown by the comparison with gridded observation data</u>

Utilizing multi-model simulation results as a basis for analysis is a way to reduce the uncertainties commonly produced within different model runs. Numerical models are subject to biases, and it is necessary to treat these biases from multi-model simulations in a way that they should be minimized. This study employs a skill scoring of models, resulting in a better representation of multi-model averaging algorithms which has proven to be more skillful in reducing biases than the simple ensemble mean method.

<u>Models are quite skillful in representing several aspects of past climate with regard to rainfall and temperature data</u>

Rainfall simulation results within models show a good performance in representing the annual cycle (monthly total) compared to the rainfall observations, even over several regions with double rainy seasons (bimodal rainfall pattern). In terms of simulating the timing of monsoon season, model results are relatively skillful, as shown by the compatibility ratio between grid points of model and observation, with the agreement of around 57% for simulating the driest three months and around 37% for simulating the wettest three-months period. Similarly, the temperature within models also provides a good comparison to the observation, in terms of both spatial pattern as well as the annual cycle, with an agreement of around 52% (coldest month) and 36% (warmest month) over the entire grid in Indonesia.

<u>Projected change in precipitation shows a decreasing tendency of total rainfall, an increasing length of dry spell, and an increase in frequency and intensity of extremes, relative to the baseline period (1986-2005)</u>

Under both emission scenarios, the total rainfall is projected to decrease over most regions for all projection periods with a larger magnitude at the end of century - i.e. -4.1% under RCP4.5 and -7.2% under RCP8.5. Similarly, the tendency of a drier world is also consistently shown by the increase of dry spell occurrences of 14% under RCP4.5 and 37% under RCP8.5. Although total rainfall is expected to decrease, the incidence of extremes are generally projected to increase for all projection periods - as represented by the frequency of heavy rainfall (R50mm) and intensity of annual maximum of daily rainfall (RX1day). Under the worst-case emissions scenario, the R50mm may increase up to 4%, while the RX1day may increase up to 10% at the end of the century.

Projected change in monsoon attributes shows a tendency of a delayed monsoon onset in both future scenarios, but a different trend in monsoon duration

The RCP4.5 scenario results show an increase in monsoon duration, while RCP8.5 displays an opposing tendency. Projected change under RCP4.5 shows a delayed onset of around 32 days in the near-term period, with a decreasing number of days in the mid- (30 days) and long-term period (24 days). On the other hand, projected change under RCP8.5 shows a delayed onset of around 37 days in the near-term period, with an increasing number of days in the mid-term (47 days) and long-term period (58 days). As for the duration, both scenarios provide an opposing trend, in which RCP4.5 displays an increase in monsoon duration, while RCP8.5 shows a shortening trend. Based on those findings, RCP4.5 poses a relatively lower risk considering the impact caused by drier conditions.

Analyses of temperature suitability on various crops (rice and coffee beans) illustrate a consistent decrease in the number of days within the range of optimum temperature and an increase in the number of days over the threshold of critical temperature

A decreasing trend is expected in the number of days within the range of optimum temperature for rice crop, Arabica coffee, and Robusta coffee over all the different ranges in the future period. For instance, the national average decrease in the number of days within the range of optimum temperature for Arabica coffee under RCP4.5 are 18, 53, and 94 days, for near-term, mid-term, and long-term periods respectively, and 34, 85, and 191 days under RCP8.5 for the same order of periods. Such findings emphasize that there will be a potentially higher impact imposed by higher GHGs concentration. On the other hand, the increase in the number of days over the critical temperature threshold is only prevalent, particularly within the long-term (end-of-century) projection, under the RCP8.5 scenario in which the temperature increase is expected to be very intense.

In general, changes under RCP8.5 condition provide a more significant change compared to the lesser scenario of RCP4.5

Some examples include: temperature increases under RCP8.5 is 1.7 warmer than those of under RCP4.5, increase in dry spells under RCP8.5 is 23% longer than those of under RCP4.5, decrease in monsoon duration under RCP8.5 is more prominent than those of under RCP4.5, and decrease in the number of days within the range of optimum temperature for rice crop under RCP8.5 is 88 days larger than those of under RCP4.5. These findings confirm that improved mitigation efforts are essential in reducing the severity of climate impacts.

C. Productivity estimation and economic value changes

The third section of the report presents productivity estimation and economic value changes for rice and coffee in the future using climate projection assessments based on the RCP4.5 and RCP8.5 scenarios. Productivity estimation models development for rice and coffee use the productivity data from Indonesian Central Bureau of Statistics (BPS) at the district level from 2015 to 2020. The productivity estimation model used is Fixed Effect Model to include region and time factors with temperature and rainfall as inputs that affect productivity. The model calibration for rice and robusta use productivity data from BPS during odd years (2015, 2017, 2019) and the validation uses even years (2016, 2018, 2020). Meanwhile, for arabica the model uses three years (2016, 2017, 2018) for calibration and the two latest available years (2019 and 2020) for validation. The R-Square values from the model calibration are 86% (rice), 85% (arabica), and 88% (robusta); while the model validation results are 79% (rice), 72% (arabica), and 72% (robusta).

Future scenarios of changing rainfall and air temperature were driven based on RCP4.5 and 8.5. The future scenarios were divided into three periods, i.e., 2021-2050, 2051-2080, and 2081-2100. Historical data for the baseline simulation of crop yields were calculated for the historical periods of 1991-2020. Historical productivity data for rice, arabica, and robusta were supplied by BPS 2015 - 2020 at district level in ton/ha yearly. The productivity change is calculated using future scenarios and historical periods which is then determined using the median value from each district for every period. Overall, in the future, rice productivity in Indonesia is projected to decrease around 0.5% to 7%. However, there is a bit of variance between locations - the impact of climate change for each major island in Indonesia is projected to decrease productivity around 1% to 4% in Sumatera, 0.5% to 3% in Java, 1% to 3% in Kalimantan, 1% to 6% in Sulawesi, 1% - 3% in Bali and Nusa Tenggara, 4% - 5% in Maluku, as well as 6% - 7% in Papua.

The economic assessment of the continued impact of changes in productivity due to climate change produces two main micro-economic indicators namely a change in prices as well as its impacts on imports and exports. The assessment is divided using a statistical approach of the distribution of potential impacts across districts in Indonesia. For price changes, the RCP8.5 scenario has a greater impact than the RCP 4.5 scenario. For rice, the range of price changes can increase to a maximum of 33% in the RCP 4.5 scenario while price changes under RCP 8.5 can reach 55% in 2100. For the projected years up to 2050, the optimum price change rate is in the range of 32%. Meanwhile, for both Arabica and Robusta coffee, a price change of

56% - 109% is expected to occur between 2050 and 2100. Another consequence of the decline in productivity of rice plants is that nationally there is a potential for a decrease in export yields ranging from 2% - 35% and an increase in import needs reaching a maximum range of 117% which will occur under scenario 8.5. Estimation of the macro-economic impacts was developed using a recursive dynamic model approach (CGE model). The model construction refers to INDOF (Oktaviani, 2001) and ORANI GRD (Horridge, et. 2002). Several datasets used in the operationalization of this model include factors regarding production, regions, institutions, household groups, and industries.

Conclusion

This study assesses the historical impact of climate change and the future projection of two important agricultural commodities in Indonesia, rice and coffee. The production estimation and economic value (i.e., price, export, and import) are then assessed based on the climate historical and future projection assessment using CORDEX-SEA models under two climate change projection schemes of RCP4.5 and RCP8.5.

The study concludes that:

1. Sea level rise has proven to affect rice and coffee production with the reduction of 3.5 million tons of rice production, equivalent to fulfilling the rice consumption of 26.6 million people.
2. The increase in salinity of up to 9 dS m-1 caused a rice production loss of 50% of its potential yield or equal to 8 million tons, which is equivalent to fulfilling the rice consumption of 42 million people.
3. ENSO appears to have a different influence on rice production in swamp areas. La Nina will increase the water level to reduce available land. On the other hand, planted area may increase during El Niño due to lower water levels, especially in lowland swamps.
4. Number of rice planting areas affected by droughts will increase during El Nino, both in the rainy season and dry season. Rice planting areas affected by flooding will also rise due to La Nina.
5. The decline in Robusta and Arabica coffee production occurred during El Niño and La Nina in most of the production centers.
6. Projected change in precipitation shows a decreasing tendency of total rainfall, an increasing length of dry spell, and an increase in frequency and intensity of extremes, relative to the baseline period (1986-2005)

7. Projected change in monsoon attributes shows a tendency of a delayed monsoon onset in both future scenarios, but a different trend in monsoon duration
8. Analyses of temperature suitability on various crops (rice and coffee beans) illustrate a consistent decrease in the number of days within the range of optimum temperature and an increase in the number of days over the threshold of critical temperature
9. In general, changes under RCP8.5 condition provide a more significant change compared to the lesser scenario of RCP4.5
10. The productivity is projected to be decreased due to climate change in each major islands in Indonesia such as 1% to 4% (Sumatera), 0.5% to 3% (Java), 1% to 3% (Kalimantan), 1% to 6% (Sulawesi), 1% - 3% (Bali and Nusa Tenggara), 4% - 5% (Maluku), and 6% - 7% (Papua).
11. The change of productivity of the two commodities influences their economic aspects such as prices as well as imports and exports. The range of rice price changes increased to a maximum of 33% and 55% in 2100 under scenarios RCP 4.5 and RCP 8.5 respectively. For the projected years up to 2050, the optimum price change rate is in the range of 32%. Meanwhile, both Arabica and Robusta coffee prices will change around 56% - 109% between 2050 and 2100.
12. Rice export yields will also decrease around 2% - 35% - which consequently increases the demand for imports, reaching a maximum of 117% under RCP 8.5 scenario.