

Carbon emission impact on food production and rice yield: Panel data estimation

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Abstract. Climate change is currently recognized as a global phenomenon which associates with more frequent extreme weather events that affect most agricultural communities in developing countries. The extreme climate condition can threaten the agriculture production and later cause food insecurity. Carbon emission is one of the proxies for climate change which is used in this current study to investigate its impact on food production and rice yield in nine ASEAN developing and least-developed countries using panel data. The classical panel estimations are adopted and the findings reveal significant contribution of several factors on food production such as Consumer Price Index (CPI), real gross domestic product per capita and fixed capital formation, but not carbon emission. Dynamic panel Autoregressive Distributed Lag (ARDL) technique is further adopted to rice yield and other relevant data of ASEAN countries to investigate the long-run and short-run cointegration between the variables. The findings show mixed results of impact of CO₂ emission on rice yield among ASEAN member countries in short-run. The findings postulate that although the negative impact is untraceable in long-run between carbon emission and rice yield, this impact exists in few countries in short-run. Thus, initiatives to invest on research and development efforts as well to enhance food production using climate-based technology should be put forward through collaboration between countries to address the issues of food insecurity within the region in the long-term.

1. Introduction

Climate change is currently recognized as a global phenomenon which associates with more frequent extreme weather events that affect most poor people living in agricultural communities in developing countries. Climate change is posing a threat to the production levels of the country's staple food and this is expected to have an adverse impact on the nation's food security. The effects of climate change are being felt increasingly in recent years as the higher risk of occurrence of natural disasters such as floods and prolonged dry spells, as well as the shifting rainy season and rising sea level, have influenced water availability.

Food security problem is related to the lack of staple food; hence, improving the performance of agriculture sector is one of the solutions. This sector is a basic sector in increasing the availability of food in the market and fulfilling the dietary need of all humans. Despite the benefits of agriculture sector in Southeast Asian, the sector still faces many challenges. Food insecurity related to the condition of the agricultural sector becomes a paramount concern and the issues also increase the complexity of factors

influencing food security in the region, primarily incorporating with production area. It can be from the environmental determinants, macroeconomic determinants and agricultural determinants. It is believed that food security is mostly determined by the combination of these factors which were explained at large in the literature. However, the analysis of those factors comprehensively by past studies on developing and least developed countries was relatively few. There are indeed few types of research discussing only on one or two selected countries or developing countries beyond the Southeast Asia region. In the area of food security study, most studies use survey data survey on the selected object of the study (primary data) or at micro level. The use of secondary data is rather limited to merely for one or two countries using the time-series data and method of analysis. Thus, this study attempts to fill the gap. The current study aims to widen the scope of the study by applying classical (static) panel regression on secondary panel data which is a combination of cross-sectional and time-series data, which are at macro level. Moreover, dynamic panel estimation is also applied in order to obtain robust results.

2. Literature review

The concept of food security had been introduced for almost forty-six years since the term came out in the mid-1970s. The idea was originated from the concern of food supply problems in ascertaining the stock amount and the price stability of basic foodstuffs both at national and global levels. The term was discussed in the 1974 World Food Conference [1]-[2]. According to the forum, food security is defined as: "Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices". The completed definition occurred in 2001 by including social aspect of accessibility of the food where food security is defined as: "A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" [3]. From the definition, the dimensions of the food security could be extracted; those are food availability, food access, food utilisation and food stability. The four dimensions are the core aspects of food security, as stated by Joshi and Joshi [4]. Based on the basic economic theory, where principal inputs influencing the output of production are land, labour, capital, entrepreneurship and also technology, this study derives the factors which affect 'food production' and 'rice yield' as outputs. The study categorises the factors or inputs into three: agricultural determinants such as land and labour, macroeconomics and external determinants such as capital, Gross Domestic Product (GDP), Consumer Price Index (CPI) and environmental determinant such as CO² emission.

Crop production such as rice, maize, wheat and others as the staple food may increase or decrease depending on the availability of the land for cultivation. The land size contributes significantly to food or rice production as land is one of important resources in crop production. Positive and significant influence of land area on rice production were dictated in studies by Dewati and Waluyati [5]; Koirala et al. [6]; Shaikh et al. [7]. While similar positive relationship was traced in Azwardi et al. [8] and Bashir and Yuliana [9] but it was insignificant. The number of citizens who work in the agricultural sector is high in most developing countries. As labour is a crucial element of the production model [7], without human capital, any production activity contrived is quite impossible to be operated. Labour has a positive and significant relationship with rice production in Indonesia, where farmer is the most common type of occupation in Indonesia [9]. Since in Thailand, the workforce in the agricultural sector also plays a pivotal role in the family, Tiwasing, Dawson, and Garrod [10] argued that family worker could increase workers' capacity and reduce hired labour costs. The study concluded that, family workers have a positive and significant relationship with household food security. Capital and its performance in facilitating labours is expected to elevate agriculture productivity. Using Cobb-Douglas and neo-classical production function, the relationship between capital and agriculture output, particularly rice in Jaffarabad, Pakistan was positive and significant [7]. Nevertheless, Amegnaglo [11] obtained similar finding after examining the production model for maize production in Benin. Capital could be sourced from domestic or foreign allocation. Some studies pointed out the significant effect of Foreign Direct Investment (FDI) on food security [12]-[13] in line with the expectation of Mihalache-

O'Keef and Li [14] that foreign investment may potentially assist the rural area in modernising infrastructure and fulfil various agricultural producers' facilities.

As of macroeconomic factors such as Gross Domestic Product (GDP) and Consumer Price Index (CPI), some studies found adverse effects from GDP to food security in the short-run [15]- [12]- [16], but the relationship is not significant. Hanif et al. [12] stated that an increase in GDP does not attract investment in the agricultural sector but in industrial sector. Meanwhile, others [17]-[12] indicated a positive and significant relationship, which reflects economic development and better infrastructure, is a catalyst of more agricultural production. Nonetheless, higher food price encourages producers to produce more due to the potential of high profit. Ekpenyong and Ogbuagu [18] showed CPI, in general, has a positive and significant influence on agriculture production. They argued that the movement of price had been responded positively by farmers. However, Widada et al. [16] found that the CPI of food harms food security status in Indonesia though the impact was not significant.

The extreme climate condition can threat the agriculture production. CO² emission, as one of the proxies for climate change, contributes a negative impact to agriculture productivity [18] as well as food security [19]. In the long run, a negative and significant relationship occurred between CO² emission and food production index [12], however, Huong, Bo, and Fahad [20] insisted that the negative impact appears when CO² emission pass over the limit level, yet it will enhance productivity if only reach optimal value. Likewise, Xiong et al. [21] showed an excellent contribution of CO² fertilisation to agriculture production, in which the projected range of temperature has no adverse effect on food production.

3. Data and methodology

Two set of panel data are used in the current study. The first set of data is generally data consist of 'food production' and its determinants and the second set of data focuses narrowly on data of 'rice production' and its determinants. The panel data combines the cross-section countries data and time-series data. The countries in study are nine (out of ten ASEAN countries) namely, Indonesia, Malaysia, Thailand, the Philippines, Lao PDR, Vietnam, Cambodia, Myanmar and Brunei. Singapore is drop from the current analysis as data on rice yield and area harvested for the country are not available from FAOSTAT databank. The data span from 1961 until 2015 (55 years) resulting to 442 observations in total. The recent years data (above 2015) for all variables of each country are mostly unavailable.

The selected variables employed in the first set of data follows a standard Cobb-Douglass production function. The variables are Food Production Index (FPI), agriculture land, employment in agriculture, CO₂ emission, gross fixed capital formation (GFCF), Foreign Direct Investment (FDI), Consumer Price Index (CPI) and Real Gross Domestic Product (RGDP) per capita. For the second set of data, the variables are rice yield (RY) as a dependent variable and area harvested (AH), fertilizer consumption (FC) and CO₂ emission (CO₂). All data are transformed into natural logarithm as it can improve the fit of the linear regression as they are more normally distributed and for convenience interpretation in which the regression coefficients (βs) will be interpreted as elasticities. Following Asteriou and Hall [22], three methods are adopted: common effects, fixed effects and random effect on the following panel model:

$$\ln(FPI)_{it} = \beta_0 + \beta_1 \ln(Agriculture_land)_{it} + \beta_2 \ln(Employment)_{it} + \beta_3 \ln(RGDP)_{it} + \beta_4 \ln(FDI)_{it} + \beta_5 \ln(GFCF)_{it} + \beta_6 \ln(CPI)_{it} + \beta_7 \ln(CO_2Emission)_{it} + u_{it} \quad (1)$$

where betas (βs) are coefficients of all variables and u is the error term. At initial stage, the study employs Augmented Dickey Fuller (ADF) and Phillips Perron (PP) unit root tests for stationary of the variables or data. In order to choose the best model among the three models, Likelihood Ratio or Chow test, Hausman test and Lagrange Multiplier (LM) test are employed. In addition, two diagnostic tests, heteroscedasticity and auto-correlation tests, are employed to ensure the residuals of the model satisfy the standard.

For the second set of data, since T (number of years) > N (number of countries), this study also adopt a more appropriate estimation technique, panel ARDL. The panel ARDL technique is attempted to investigate the long-term and short-term cointegration correlations between the variables and extract the ECM (error correction model) of the panel characteristics to develop the short-term dynamic. Panel ARDL that ought to be analysed for the bounds test method is presented as the following:

$$\Delta \ln RY_{it} = \beta_1 + \sum_{i=1}^k \alpha_{ij} \Delta \ln RY_{j,t-i} + \sum_{i=1}^k \partial_{ij} \Delta \ln AH_{j,t-i} + \sum_{i=1}^k \phi_{ij} \Delta \ln FC_{j,t-i} + \sum_{i=1}^k \gamma_{ij} \Delta \ln CO2_{j,t-i} + \theta_1 \ln RY_{j,t-1} + \theta_2 \ln AH_{j,t-1} + \theta_3 \ln FC_{j,t-1} + \theta_4 \ln CO2_{j,t-1} + \varepsilon_{jt} \quad (2)$$

where t is time, i refers to the studied country, Δ is the first difference, k is the ideal lag length and ε_{jt} is a random disturbance term. The long-term cointegration correlation between the determinants is investigated with the null hypothesis that $\theta_1 = \theta_2 = \theta_3 = \theta_4 = 0$ (There is no cointegration) against the alternative hypothesis of otherwise. This cointegration test is conducted by applying the F test. The test uses panel autoregressive distributed lag bounds, which relies on whether the variables are purely I(0), purely I(1), or a combination of I(0) and I(1). Two critical values are computed; I(0) identified with lower restriction (lower bound), and I(1) identified with higher restriction (upper bound). If the F statistics surpass the upper bound, it can be concluded that there is a cointegration among variables. If the F statistics below the lower bound, the null hypothesis cannot be rejected, and if the F statistics is between the I(0) and I(1), a derivation cannot be made. A proof of cointegration among variables will lead to below long-run and short-run equations, respectively:

$$\ln RY_{it} = \beta_2 + \sum_{i=0}^k \alpha_{i2} \ln RY_{j,t-i} + \sum_{i=0}^k \partial_{i2} \ln AH_{j,t-i} + \sum_{i=0}^k \phi_{i2} \ln FC_{j,t-i} + \sum_{i=0}^k \gamma_{i2} \ln CO2_{j,t-i} + \varepsilon_{it2} \quad (3)$$

$$\Delta \ln RY_{it} = \beta_3 + \sum_{i=1}^k \alpha_{i3} \Delta \ln RY_{j,t-i} + \sum_{i=0}^k \partial_{i3} \Delta \ln AH_{j,t-i} + \sum_{i=0}^k \phi_{i3} \Delta \ln FC_{j,t-i} + \sum_{i=0}^k \gamma_{i3} \Delta \ln CO2_{j,t-i} + \mu ECT_{j,t-1} + \varepsilon_{jt3} \quad (4)$$

The error correction term (ECT) is formed as in Equation (4) where the coefficient of the lag ECT, μ , can validate the quickness of the dependent variable's movement towards the equilibrium. Moreover, the coefficient gives input regarding the long-term correlation between variables in Equation (3). In Equation (4), $\ln RY_{it-1}$ implies the lagged dependent variable included to capture the dynamic nature in the equation. The residual diagnostic tests are also conducted on the model.

4. Findings and discussion

Results of panel regression for common effects (Pooled OLS), fixed effects and random effects, using first set of data, are displayed on Table 1. Based on the pooled OLS and random effects methods, the R² of 0.70 in both models implies that 70 % of the variation of FPI is explained by the explanatory variables. The estimated coefficients of Agriculture land, FDI, CPI are positive and significant at the 0.05 level as expected. Consistent to the study by Ekpenyong and Ogbuagu [18], high price, reflected by higher CPI, leads to high production of agriculture and food. We also found that FDI is important for local food production which supports the findings of Mihalache-O'Keef and Li [14], Hanif, Nisa, & Yaseen [12], and Slimane, Huchet-Bourdon, & Zitouna [13]. Foreign investment in the region is perceived to assist the agricultural area in modernising infrastructure and fulfil various agricultural producers' facilities that support the food production. The positive contribution of land area on food production is supported by findings of Dewati and Waluyati [5]; Koirala, Mishra, and Mohanty [6]; Shaikh, Hongbing, Khan, and Ahmed [7]. The employment (labour) and fixed capital formation (capital), however, significant but with negative sign of coefficients. Intuitively, labour force and capital appear to be the factors that reduce the food production in the case of ASEAN countries. The other control variables seem to be insignificant in the model. The results from the random effects model are

almost similar to the results of Pooled OLS effects model. Having said this, the results of fixed effects model is found to be outperformed than the other two models based on goodness-of-fit statistics (R square) and the selection tests (Chow test and Hausman test). The R^2 of fixed effects model is far higher than the other models with the value of 0.85 which implies variation of dependent variable could be 85 percent explained by the model. Meanwhile, the results of Chow and Hausman tests show that fixed effects model is preferable than Pooled OLS and random effects models. Moreover, Glesjer test result has shown that the model does not have heteroscedasticity problem.

Table 1. Results of common effects (Pooled OLS), fixed effects and random effects.

Variables	Dependent Variable: Food Production Index		
	Coefficient		
	Pooled OLS	Fixed effects	Random effects
Agriculture land	0.177632***	-0.075683	0.177632***
Employment in Agriculture	-0.062288***	0.062625	-0.062288***
CO ² Emission	-0.022809	0.039178	-0.022809
Gross Fixed Capital Formation	-0.087745***	0.075477*	-0.087745***
Foreign Direct Investment Inflows	0.045518***	0.004820	0.045518***
Consumer Price Index	0.466177***	0.173336**	0.466177***
Real Gross Domestic Product per Capita	-0.025254	0.328314***	-0.025254
Constant	2.728231***	-0.590120	2.728231***
R-Squared	0.70	0.85	0.70
F-Statistic	23.34***	29.49***	5.944***
Chow test(chi-square)		56.61***	
Hausman test (chi-square)		67.18***	

Notes: ***, **, * denote rejection of null hypothesis at 1%, 5%, and 10% level of significance

From all variables in the fixed effects model, only three variables significantly affect the dependent variable of Food Production Index. Those are real gross domestic product per capita, Consumer Price Index and fixed capital formation. The positive sign of real gross domestic product per capita supports previous finding on the importance of economic development to boost food production in the countries of study [17]-[12]. Besides, RGDP or income per capita may also enhance food production due to the additional demand from the consumers as income has been considered as a factor enables consumers to access food. As for CPI, the result is consistent to the study by Applanaidu et al. [15] and Ekpenyong and Ogbuagu [18]. Rationally, higher price, particularly for food, tends to encourage producers to produce more food. The studies found a positive relationship between price and agriculture or food production in Malaysia and Nigeria, respectively. The significant and positive contribution of capital to the food production found in the model also supported by findings of studies by Shaikh et al. [7] and Amegnaglo [11]. However, the study finds that there is no significant correlation between agriculture land and food production index in the fixed effects model. The finding is similar to findings of studies by Azwardi et al. [8]; Bashir and Yuliana [9]; Iqbal, Khan, Suhail, and Zaman [23] where land size does not significantly affect food production. Azwardi et al. [8] argued that no significant effect of land size over food production, especially rice, due to the traditional management or small area of land owned by farmers in Indonesia. Since most countries in the region are also developing and least-developed countries, the management of the land is not far different to Indonesia. The land size for agriculture in ASEAN, particularly for food production is found to be small in size. FDI does not contribute significantly to food production in this model. This result is in contrast to findings of some previous studies discovering significant effect from FDI to agriculture production such as Hanif et al. [12]; Slimane et al. [13]. The finding could be because FDI inflows for agricultural sector is hardly occur in Southeast Asian countries for the last few years as compared to other sectors. For instance, in 2017, the

share of FDI for agricultural sector in Southeast Asia region remained at 3 per cent only, which was at low level [24].

Prior to panel ARDL estimation, the panel unit root tests are conducted and all variables are found to be stationary at first difference or I(1). The selected model suggested is ARDL (2,1,1,1) based on Akaike info criterion (AIC) statistics. The long-run estimation is displayed in Table 2. The results show that two independent variables, namely fertilizer consumption and area harvested, are highly significant with positive sign. Observing the magnitude of the coefficients, it seems that the impact of area harvested on rice yield is bigger than the fertilizer consumption in the long-run. However, CO² emission not significantly contribute to rice yield in long-run for ASEAN region. The importance of harvested area to rice yield is also supported by prior studies such as Dawe [25] who found that the main determinant of (per capita) rice production in Southeast Asia is not rice yield per hectare, but rather the amount of per capita rice area harvested. In almost similar study, Affoh et al. [26] found that the impact of total arable land was positive in Togo with a one percent increase in arable land led to an increase in rice supply in Togo by 0.05 percent. The empirical findings of Autoregressive Distributed Lag (ARDL) model by Chandio et al. [27] further supported that area and fertilizer consumption for rice has a significant effect on the rice production in both short-run and long-run in Pakistan. Fertilizer is such a kind of production input whose demand cannot be avoided to obtain maximum yield or sustainable crop production from a piece of land even when other management technologies are evolved by researchers [28]. In fact, according to Vlek and Byrnes [29], Nitrogen fertilization is a key input in increasing rice production in East, South, and Southeast Asia.

Table 2. Results of Panel ARDL: Long run estimation (Selected model: ARDL (2,1,1,1)).

Dependent Variable: lnRY	
Variable	Coefficient
lnAH	0.577*** (4.197)
lnFC	0.239*** (10.80)
lnCO2	-0.043 (-0.969)

Notes: 1. ***, **, * denote rejection of null hypothesis at 1%, 5%, and 10% level of significance
2. t-statistics in parentheses
3. Model selection method: AIC

Table 3 provides short-run equation for each country. Looking at individual country, the impact of area harvested, fertilizer consumption and CO² emission on rice yield are significant in several ASEAN countries. Those are Malaysia, Brunei, Cambodia, Laos, Myanmar, Philippines and Vietnam. The area harvested positively affect rice yield in Malaysia, Cambodia, Myanmar, Philippines and Thailand but negatively affect rice yield in the case of Brunei, Laos, and Vietnam in short-run. In Laos, rice production is the main farming accounting for over 80% of the total cultivated area [30]. The negative impact of area harvested on rice yield in Laos could be contributed by the fact that almost all rice was produced under rainfed conditions and subject to periodic droughts and (in the lowlands) floods and most of the lowland wet-season crop was still based on traditional low-yielding varieties [31]. As in Vietnam, since 2016/17, rice area in Vietnam has declined on an annual basis. This is because the rice area is being converted to uses such as urban and commercial development or transitioning to more profitable crops. Meanwhile, in Brunei Darussalam paddy rice area harvested tend to decrease through 1971 - 2020 period. There is also limited or no availability of proper water in the area and the major issue of water supply in Brunei is due to the lack of proper irrigation available for rice farmers [32].

The positive relationship between fertilizer consumption and rice yield is found for Indonesia, Laos, Myanmar and Philippines in short-run. The negative relationship however apparent for Malaysia,

Brunei, Cambodia, Thailand and Vietnam. A steady growth in the Lao rice sector in terms of area, production, and yield from the mid-1990s has made the country notionally self-sufficient in rice in 1999. This was attributable to the widespread use of improved rice varieties and management practices, especially the use of fertilisers [33]. On the other hand, Cambodian rice farmers face serious constraints in productivity and output quality, including high costs of energy, fertilizers, and pesticides. Chemical fertilizer use is extremely low and native soils are often very infertile. The average amount of fertilizer use in Cambodia is below the nationally recommended rate [34].

CO₂ emission negatively affects rice yield in the short-run in the case of Myanmar and Philippines but the positive impact is traced in majority of countries: Malaysia, Brunei, Cambodia, Indonesia, Laos and Vietnam. Some studies [35]-[36]-[37]-[38] projected that increased atmospheric CO₂ concentration would have positive and negative effects on rice production, consumption, distribution as well as national development depending on the specific climate scenario, geographical location, and nature of study. In Japan, for instance, the positive effects of CO₂ on rice yields would generally more than offset any negative climatic effects [39] while, in China, major climate changes were predicted and to a certain extent warming would be beneficial for yield increasing in the country due to diversification of cropping systems. Increased atmospheric carbon dioxide concentration along with temperature, precipitation, soil conditions, and solar radiation would also have mixed impacts on rice yields. Under a high CO₂ emission scenario, Petersen [35] projected that rice and soybeans in the U.S. will have an increase in yield due to the CO₂ fertilization effect. Tan et al. [40] assessed the impact of climate variables (i.e., minimum and maximum temperature and precipitation) on rice yield in Malaysia and the variance of the impact during the main season and off-season indicated that while the maximum temperature was found to be negatively associated with yield during the off-season, the minimum temperature showed a positive effect in both main and off-season.

Table 3. Short-run equations.

Variable	Coefficient (t-statistic)				
	Malaysia	Brunei	Cambodia	Indonesia	Laos
ECT _{t-1}	-0.169*** (-28.88)	-0.109*** (-5.88)	-0.124*** (- 105.00)	-0.409*** (- 47.57)	-0.102*** (-61.67)
D(lnRY) _{t-1}	-0.403*** (-21.38)	-0.322*** (-7.132)	-0.249*** (- 33.33)	0.241*** (21.76)	-0.235*** (-8.736)
D(lnAH)	0.356*** (18.92)	-0.380*** (-7.968)	0.159*** (45.08)	0.016 (1.153)	-0.133*** (-8.736)
D(lnFC)	-0.151*** (-49.79)	-0.031*** (-11.70)	-0.018*** (- 79.70)	0.0051*** (9.311)	0.004*** (17.17)
D(lnCO ₂)	0.111*** (18.09)	0.074** (3.476)	0.0058*** (6.766)	0.091*** (70.17)	0.011* (2.874)
Constant	0.188 (2.117)	0.501 (1.507)	0.171* (2.526)	0.072 (0.089)	0.222** (4.694)
	Myanmar	Philippines	Thailand	Vietnam	
ECT _{t-1}	-0.123*** (-74.87)	-0.091*** (-55.92)	-0.037*** (-24.45)	-0.119*** (-31.76)	
D(lnRY) _{t-1}	0.119*** (8.378)	-0.0087 (-0.518)	0.289*** (-17.09)	0.033 (1.899)	
D(lnAH)	0.289*** (19.89)	0.081** (4.315)	0.211*** (12.17)	-0.362** (-5.005)	
D(lnFC)	0.0008** (3.402)	0.074*** (30.960)	-0.045*** (-23.57)	-0.002* (-2.486)	

D(lnCO ₂)	-0.014*** (-6.868)	-0.239*** (-18.77)	0.0009 (0.107)	0.034*** (22.082)
Constant	0.093 (1.345)	0.052 (1.464)	0.012 (1.758)	0.041 (0.617)

5. Conclusion and policy recommendation

The objective of study is twofold. First, it attempts to examine the relationship between food production and several key variables in the ASEAN region from 1961 until 2016. In analysing the impact of agricultural, environment and macroeconomic determinants on food production in ASEAN countries, the classical panel estimation is adopted. The fixed effect model has been selected as an appropriate model and it reveals significant contribution of several factors on food production such as CPI, real gross domestic product per capita and fixed capital formation, while FDI, agricultural land, employment and CO₂ are insignificant. The second objective is to investigate the longterm and short-term cointegration correlations between rice yield, as a dependent variable, and independent variables such as area, fertilizer consumption and CO₂ emission. The results from panel ARDL show that fertilizer consumption and area harvested, are highly significant with positive sign in the long-run but CO₂ emission not significantly contribute to rice yield in longrun for ASEAN region. In short-run, however, it is found that CO₂ emission negatively affects rice yield in the case of Myanmar and Philippines while the positive impact is marked for Malaysia, Brunei, Cambodia, Indonesia, Laos and Vietnam. The mixed results of impact of CO₂ on rice yield among majority of ASEAN member countries in short-run signify the positive CO₂ fertilization effect in the region on rice yield.

It is recommended that each country's authority to focus on allocating investment efficiently on agricultural and food sector in their plan action of economic development that aim for food security. Land management policy, primarily incorporated with the expansion strategy is required. One suggestion is to put a restriction of shifting cultivation land to industrial area in the policy. In addition, creating special Act to encourage urban farming implementation is also necessary. Government can give incentive to farmers who attempt to apply urban farming in the city. High risk from climate change especially in the short-run in some countries of the region should be taken seriously. Bearing in mind that climate change is not only sourced from CO₂ emission alone, some efforts to minimise the bad impact can certainly be sought through the adaptation and mitigation strategies. Accordingly, government can transfer some incentives through crop insurance program for farmers as a climate change adaptation strategy in order to secure their work from extreme climate change. Since ASEAN countries have similar geographical topology, agricultural technology can be shared to achieve effective and efficient adaptation to climate change as well as to increase food security condition collectively. In addition, as the Philippines and Thailand's government support an organic farming by mandating in the Act, the government in other Southeast Asia countries is recommended to replicate that action. By setting the strategy in the Act, local government as well as farmers can work without restraint. Furthermore, FAO, recently, proposes the concept of Climate-Smart Agriculture (CSA). This approach guides and supports agriculture within changing of climate to maintain development and ensure food security. If each country attempts to adopt this approach by fitting with the local condition of the country, climate change problem may gradually be mitigated as well. Besides, each country is recommended to participate in international negotiations addressing climate change and food security issue, such as Kyoto Protocol that has been extended to Doha Amendment. Since some countries are developing ones, different treatment related to adaptation and mitigation of climate change will be received. Developing countries will obtain more benefits such as receive technology and funds through this agreement. Nevertheless, greater collaboration between ASEAN countries to address the issues in agriculture, food and rice production is indeed a necessary. Not only it will overcome the problems in the country individually, it will also enhance cooperation in solving regional issues for food security.

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References

- [1] Clay E 2003 Food security: concepts and measurement. *Trade reforms and food security: conceptualizing the linkages* (Rome: Food and Agriculture Organization of the United Nations) pp 25–32
- [2] FAO 2006 *Food Security - Policy Brief* (FAO's Agriculture and Development Economics Division)
- [3] FAO 2001 *The state of food security in the world 2001* (Rome: Food and Agriculture Organization of the United Nations)
- [4] Joshi G R and Joshi B 2017 Household food security: Trends and determinants in mountainous districts of Nepal *Future of Food: Journal on Food, Agriculture and Society* **5** 42-55
- [5] Dewati R and Waluyati L R 2018 Production Risk of Rice in Kebonsari, Madiun Regency *Agro Ekonomi* **29** 161-72
- [6] Koirala K H, Mishra A K and Mohanty S 2014 Determinants of Rice Productivity and Technical Efficiency in the Philippines *Selected Paper for Presentation at Southern Agricultural Economics Association (SAEA) Annual Meeting* (Dallas)
- [7] Shaikh S A, Hongbing O, Khan K and Ahmed M 2016 Determinants of Rice Productivity: An Analysis of Jaffarabad District – Balochistan (Pakistan) *European Scientific Journal* **12** 41–50
- [8] Azwardi A, Bashir A, Adam M and Marwa T 2016 The Effect of Subsidy Policy on Food Security of Rice in Indonesia *International Journal of Applied Business and Economic Research* **14** 9009–22
- [9] Bashir A and Yuliana S 2018 Identifying Factors Influencing Rice Production and Consumption in Indonesia *Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi Dan Pembangunan* **19** 172-85
- [10] Tiwasing P, Dawson P and Garrod G 2018 Food Security of Rice-Farming Households in Thailand: A Logit Analysis *The Journal of Developing Areas* **52** 85–98
- [11] Amegnaglo C J 2018 Determinants of maize farmers' performance in Benin, West Africa *Kasetsart Journal of Social Sciences* 1–7
- [12] Hanif N, Nisa M and Yaseen M R 2019 Relationship between Food Security, Macroeconomic Variables and Environment: Evidences from Developing Countries *Journal of Applied Economics and Business Research* **9** 27–37
- [13] Slimane M B, Huchet-Bourdon M and Zitouna H 2016 The role of sectoral FDI in promoting agricultural production and improving food security *International Economics* **145** 50-65
- [14] Mihalache-O'Keef A and Li Q 2011 Modernization vs. Dependency Revisited: Effects of Foreign Direct Investment on Food Security in Less Developed Countries *International Studies Quarterly* **55** 71–93
- [15] Applanaidu S D , Bakar N A A and Baharudin A H 2014 An Econometric Analysis Of Food Security And Related Macroeconomic Variables In Malaysia: A Vector Autoregressive Approach (VAR) *UMK Procedia* **1** 93–102
- [16] Widada A W, Masyhuri and Mulyo J H 2017 Determinant Factors of Food Security in Indonesia *Agro Ekonomi* **28** 205-19
- [17] Aker J and Lemtouni A 1999 A Framework for Assessing Food Security in Face of Globalization: The case of Morocco *Agroalimentaria* **8** 13–26
- [18] Ekpenyong I and Ogbuagu M 2015 Climate Change and Agricultural Productivity in Nigeria: An Econometric Analysis 1–11
- [19] Edoja P E, Aye G C and Abu O 2016 Dynamic relationship among CO2 emission, agricultural productivity and food security in Nigeria *Cogent Economics & Finance* **4** 1–13

- [20] Huong N T L, Bo Y S and Fahad S 2019 Economic impact of climate change on Agriculture using Ricardian approach: A case of northwest Vietnam *Journal of the Saudi Society of Agricultural Sciences* **18** 449-57
- [21] Xiong W, Lin E, Ju H and Xu Y 2007 Climate change and critical thresholds in China's food security *Climatic Change* **81** 205–21
- [22] Asteriou D and Hall S G 2011 *Applied Econometrics* (United Kingdom: Palgrave Macmillan)
- [23] Iqbal M, Khan M F, Suhail M and Zaman Q 2017 Determinants of Various Factors for Wheat Production *Journal of Agricultural Research* **55** 379-85
- [24] ASEAN 2018 *ASEAN Key Figures 2018* (Jakarta: The ASEAN Secretariat)
- [25] Dawe D 2013 Geographic determinants of rice self-sufficiency in Southeast Asia *ESA Working paper No. 13-03*
- [26] Affoh R, Guiyu Z, Quoi A J, Dangui K and Swallah M S 2019 Factors Influencing Rice Availability in Togo *Journal of Food Security* **7** 109-14
- [27] Chandio A A, Jiang Y, Rehman A and Dunya R 2018 The linkage between fertilizer consumption and rice production: Empirical evidence from Pakistan *AIMS Agriculture and Food* **3** 295–305
- [28] Mustafi B A A and Islam M R 2008 Development of Agricultural Policies in Bangladesh *Bangladesh Journal of Agriculture and Environment* **4** 1–8
- [29] Vlek P L and Byrnes B H 1986 The efficacy and loss of fertilizer N in lowland rice *Fertilizer Research* **9** 131-47
- [30] Bestari N G, Shrestha S and Mongcopa C J 2006 *Lao PDR: An evaluation synthesis on rice. A case study from the 2005 sector assistance program evaluation for the agriculture and natural resources sector in the Lao People's Democratic Republic* (Asian Development Bank)
- [31] Inthapanya P, Boualaphanh C, Hatsadong and Schiller J M 2006 The history of lowland rice variety improvement in Laos *Rice in Laos* (Los Banos: International Rice Research Institute)
- [32] Galawat F and Yabe M 2012 Profit efficiency in rice production in brunei darussalam: A stochastic frontier approach *Journal of the International Society for Southeast Asian Agricultural Sciences* **18** 100–12
- [33] Schiller J M 2008 *Rice production: Status and needs relating to future food security of Lao PDR and potential development options for Southern Lao PDR* (Vientiane: Asian Development Bank)
- [34] Blair G and Blair N 2010 Soil fertility constraints and limitations to fertilizer recommendations in Cambodia *19th World Congress of Soil Science, Soil Solutions for a Changing World* (Brisbane)
- [35] Petersen L K 2019 Impact of Climate Change on Twenty-First Century Crop Yields in the U.S. *Climate* **7**
- [36] Wang W, Yuan S, Wu C, Yang S, Zhang W, Xu Y, Gu J, Zhang H, Wang Z, Yang J and Zhu J 2021 Field experiments and model simulation based evaluation of rice yield response to projected climate change in Southeastern China *Science of The Total Environment* **761**
- [37] Ujiie K, Ishimaru K, Hirotsu N, Nagasaka S, Miyakoshi Y, Ota M, Tokida T, Sakai H, Usui Y, Ono K, Kobayashi K, Nakano H, Yoshinaga S, Kashiwagi T and Magoshi J 2019 How elevated CO₂ affects our nutrition in rice, and how we can deal with it *PLoS ONE* **14**
- [38] Muehe E M, Wang T, Kerl C F, Planer-Friedrich B and Fendorf S 2019 Rice production threatened by coupled stresses of climate and soil arsenic *Nature Communications* **10**
- [39] MOSTE 2001 *National response strategies to climate change* (Putrajaya: Ministry of Science, Technology and the Environment)
- [40] Tan B T, Fam P S, Firdaus R B R, Tan M L and Gunaratne M S 2021 Impact of Climate Change on Rice Yield in Malaysia: A Panel Data Analysis *Agriculture* **11**