Environmental Science and Pollution Research (2022) 29:41557–41566
https://doi.org/10.1007/s11356-021-18210-x

RESEARCH ARTICLE

Dynamic linkages between climatic variables and agriculture production in Malaysia: a generalized method of moments approach

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Received: 29 July 2021 / Accepted: 14 December 2021 / Published online: 30 January 2022

Abstract
Climate change continues to pose a threat to the agricultural sectors worldwide, jeopardizing food and nutritional security, which is a critical component of the sustainable development agenda. Consequently, this study attempts to examine the impact of climatic variables (CO_2 emissions, energy resources, rainfall, temperature, fossil fuel consumption, and humidity) on agricultural production of rice, cereals, vegetables, coffee, and agriculture value added (as a percentage of GDP) in the Malaysian context. To this end, this study applied a generalized method of moments (GMM) estimator on the data obtained from the metrological station Malaysia, Department of Statistics Malaysia and World Development Indicators (WDI) spanning the period 1985–2016. The results revealed that temperature and energy consumption negatively and significantly affect rice and vegetable production, while the negative effect of rainfall, temperature, fossil fuel consumption, and humidity on cereal production is insignificant. The results also confirmed that CO_2 emissions have a negative and significant impact on coffee production. Likewise, temperature, energy consumption, and fossil fuel consumption exhibit a negative and significant influence on agriculture value added. These observations evidenced the adverse effect of climate change on various agricultural products in Malaysia. Therefore, in order to ensure robust and sustainable agricultural output in Malaysia, policymakers as well as environmentalists should work together to formulate appropriate adaptation strategies.

Keywords Agriculture production · Climate change · Environmental factors · And Malaysia

Introduction

Agriculture is the mainstay of most developing countries' economy, providing nourishment and a source of livelihood for many people. However, this sector is very vulnerable to climate change, and developing countries are at increased risk (Twumasi and Jiang 2021). Due to climate change, the occurrence of floods, droughts, and heat stress has increased significantly, which severely affects agricultural sectors (Rasul 2021). A recent investigation by Wang et al. (2018) on crop-specific production analysis revealed the influence of climate change on the global production of four major crops, namely wheat, rice, corn, and soybeans. Analogously, IPCC (2007) and Hossain et al. (2019) confirmed that climate change affects the yields of various agricultural products.

Dell et al. (2009) and Mendelsohn et al. (2006) reported that climate change has a significant negative impact on economic growth in developing countries. Since numerous developing countries are agriculture-based economies, their farmers are said to be more affected by to climate unpredictability (IPCC 2007; Mokhtar et al. 2010). Malaysia, as a developing country, is confronted with significant issues in its agricultural industry. Between 1960 and 2017, the agricultural sector's contribution to the country's GDP decreased from 43.7 to 8.02%. This is counterintuitive, considering the country's agricultural land expansion from 9.4% in 1961 to 26.3% of total land area in 2015 (World Bank 2021). On the

Communicated by Eyup Dogan.

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other hand, this may allude to significant hidden problems and demonstrate unequivocally that Malaysia's agricultural sector has been unproductive. Consequently, the country experiences food shortages or starvation (Lee and Baharuddin 2018) and must rely on importation to meet its food consumption demand. In 2018, Malaysia imported around one million tons of rice, four billion tons of maize, 6.5 billions of tons cereal, 914, 228 tons of oil seeds, and 249,528 tons of coffee (DOSM 2020). This reliance on imported food may be quite dangerous for the country, especially if international food supplies are suddenly depleted as a result of catastrophic weather events or crop disease.

In recognition of the importance of rice production to food security, the Malaysian government has prioritized self-sufficiency in rice production as its national policy goal (Omar et al. 2019). This is a welcoming development, considering that Malaysia lies in the tropical latitudes and is thus susceptible to climate change. Tangang et al. (2012) projected a temperature rise of 3–5 °C in Malaysia by 2100, while IPCC (2007) also envisaged that the temperature would increase by 0.6–4.5 °C by 2060. Firdaus et al. (2020) have demonstrated that the minimum and maximum temperatures in granary areas increase by 0.3–0.5 °C and 0.2–0.3 °C, respectively, each decade. This will reduce paddy yields and ultimately jeopardize the achievement of food security in Malaysia. Studies by Ibrahim et al. (2014), Firdaus (2015), Tang (2019), and Vaghefi et al. (2016) revealed that climate change lowers the yields of paddy and other agricultural crops. However, there is a paucity of research on the dynamic relationships between environmental conditions and agricultural production in Malaysia. Hence, this study attempts to bridge this gap by investigating the effect of environmental factors such as CO_2 emissions, precipitation, temperature, humidity, and energy consumption on the productivity of rice, cereals, coffee, vegetable cultivation, and agriculture value added in Malaysia.

Literature review

As a result of climate change, the agricultural sector has become increasingly vulnerable (Poonia et al. 2021). This is further worsened by the large size of the sector and its dependence on weather parameters, thus threatening the global economic stability and food security (Ortiz-Bobea et al. 2021; Zhou and Feng 2011). Climate change poses many challenges to agriculture, including increased susceptibility to pests (Pathak et al. 2021). Furthermore, the average global temperature is expected to rise by 2 °C by 2100, which may induce significant global economic downturn (Malhi et al. 2021), as Liu et al. (2020) in China indicated that temperature rise due to climate change results in an average crop yield loss of 2.58% per °C at the national level. Chen and Gong (2021) also discovered that excess heat negatively affects the agricultural output (yield) of China in the short run.

It has been reported that the impact of rising temperatures, precipitation variation, and CO_2 fertilization depends on the crop type, location, and level of fluctuation in the parameters (Malhi et al. 2021). According to Aragón et al. (2021), high temperatures reduce agricultural productivity, increase the amount of crop area, and alter crop mix. Given that staple food crops strongly rely on sunlight, temperature, and water for their growth (Chen et al. 2013), they will be highly vulnerable to climate change effects (Bassu et al. 2014; Ruane et al. 2013; Tao et al. 2016). Adams et al. (1998) discovered a decrease in crop yield due to temperature rise and suggested that it could be offset by an increase in precipitation (Adams et al. 1998).

To better grasp the long-term impact of global warming, it is essential to investigate the effect of temperature increase (Marklein et al. 2020). Parker et al. (2020) noted that climate change and extreme heat could impede food production. Karimi et al. (2018) discovered that adaptation abilities and crop type, climate scenario, and CO_2 fertilization determine crop productivity in Iran. Besides, the net income of farmers was reported to have dropped significantly owing to a reduction in precipitation or rise in temperature in Cameroon (Costa et al. 2020). Similarly, statistical evidence revealed that temperature influenced the productivity of coffee cultivation in Veracruz, Mexico; it was further forecasted that coffee production may become difficult to sustain in the long run, given the 34% reduction in the current production (Gay et al. 2006).

Depending on the area and irrigation application, a varying impact of the climate on the crop yields can be observed. Expansion of irrigated areas promotes crop yields, although it can be harmful to the environment (Kang et al. 2009). In addition, some agricultural areas such as arid, semi-arid, and coastal are very sensitive to changes in their soil salinity due to climate change. Similarly, the negative impact of climate change on agriculture has been reported, particularly in arid regions (Corwin 2021). According to Mahato (2014), rise in temperature reduces crop yield by shortening crop duration (Mahato 2014). As a result, if temperate and tropical regions warm by 2 °C, aggregate production of wheat, rice, and maize is expected to fall (Challinor et al. 2014).

Apart from temperature and rainfall, other factors such as humidity and wind speed have shown significant influence on crop yields, and the absence of these factors has led to the over-estimation of the climate change consequences. The rising temperatures and recurring extreme weather such as droughts and snowstorms as a consequence of climate change over the past 20 years have degraded the ecological environment and continuously diminished grassland productivity (Bai et al. 2019). Furthermore, the Intergovernmental Panel on Climate Change projected that some areas will experience an increase in the occurrence of droughts owing to climate change (Dall'Erba et al. 2021). Farmers in highland areas typically experience a greater decline in yields, whereas those in flood-prone areas are forced to increase farm labour supply in agricultural activities to compensate for weather uncertainties (Daga 2020). The reduction in crop yields causes food price inflation, which may result in the annual loss of global agriculture revenue amounting to 0.3% of global GDP by 2100 (Stevanović et al. 2016). Moreover, heat stress as a result of global warming could reduce agriculture's labour capacity by up to half, thereby raising food prices and the level of unemployment in the agricultural sector (de Lima et al. 2021).

Although Bosello and Zhang (2005) noted that the world food supply is largely unaffected by climate change, this is not the case for developing countries. India is expected to witness a temperature rise of 2.33–4.78 °C coupled with a two-fold increase in CO_2 concentration and a prolonged period of heat waves, all of which could harm its agricultural sector (Kumar and Gautam 2014). The arid region of Rawalpindi, Pakistan, is to anticipate a 1 °C increase in temperature by 2100 with an expected annual loss of INR 4180/acre by farmers. On the contrary, an increase in precipitation rate of 8% and 14% is expected to increase the region's net revenue by INR 377.4 and INR 649.21, respectively (Shakoor et al. 2011). With a 1 °C increase in the global mean surface temperature, it is forecasted that the yield of cereal grains such as rice, maize, and wheat will contract by 10–25% (Deutsch et al. 2018). Likewise, the average crop productivity in sub-Saharan Africa is expected to shrink by 6–24% owing to climate change (Waha et al. 2013).

By conducting a meta-analysis on the productivity of wheat, rice, maize, and soybean cultivation, it was observed that various weather events due to climate change would significantly lower crop yields (FAO 2017). In Malaysia, Solaymani (2018) discovered that extreme heat and rainfall affect many agricultural products, thus reducing their availability and accessibility in the market. These hostile conditions truncate the socioeconomic progress attained over the years. Although Sundaram and Gen (2019) stated that Malaysia has overcome the issue of food accessibility, the country is yet to manage the problem of food affordability resulting from raised food costs, price variations, income imbalance, consumption patterns, and food choices. Moreover, Malaysia's food supply chains and stability system are troubled by policy incoherence, complex administrative systems and institutions, and high reliance on foreign food products and raw materials (Yap 2019).

Data and methodology

This paper investigates the dynamic relationship between environmental factors and various agricultural production in Malaysia. To achieve the research objective, the time-series annual data from 1985 to 2016 was obtained from the metrological station Malaysia, Department of Statistics Malaysia and World Development Indicators (WDI). This paper considers the following studied variables: agricultural production, which includes variables such as rice production (kilogrammes per hectare), cereal production (tonnes), vegetable production (tonnes), coffee production (tonnes), and agriculture value added (as a percentage of GDP), and environmental factors, which include CO_2 emissions (kilotons), total energy consumption (kilotons of oil equivalent), rainfall (mm), temperature (Celsius), fossil fuel energy consumption, and humidity. Figure 1 reveals the trend of the study variables for quick reference.

We employed the GMM technique in this study to examine the association between the environmental factors and agricultural production, to correct the country's fixed effects and endogeneity issues in the given models. This method is utilized in the evaluation of simultaneous equations to lessen the issue of simultaneity in the model. The GMM technique is best favoured for its identification of endogeneity of the explanatory variables in the lagged-dependent variable models. Besides, it gives room for flexible assumption of strong exogeneity of the dependent variables by supporting their correlation with current and previous outcomes of the error terms. For the GMM estimator to be stable, the instruments employed in the model and the assumption of no serial correlation in the error term should be strong. The OLS estimator could be utilized instead of the GMM estimator. However, it is affected by the serial correlation issue and thus gives unbiased parameter estimates (Baum et al. 2003). While the GMM estimator is widely favoured in panel data settings, its usage in time-series modelling for a single country is also sought after for the estimation of simultaneous equation modelling (Costantini and Martini 2010; Alam et al. 2015; Qureshi et al. 2016). Consequently, we formulated and examined five different models relating to agriculture production and environmental factors to limit the problem of simultaneity in the models.

Model 1: The influence of environmental factors on rice production

$$\begin{aligned} Ln(Rice)_t = \beta_0 + \beta_1\ Ln(Rice)_{t-1} + \beta_2 Ln(Rnf)_t + \beta_3 Ln(Tem)_t \\ + \beta_4 Ln(Co2)_t + \beta_5 Ln(Engc)_t + \beta_6 Ln(Fuel)_t \\ + \beta_7 Ln(Hdt)_t + \varepsilon t \end{aligned} \quad (1)$$

Model 2: The impact of environmental factors on cereal production

$$\begin{aligned} Ln(Cerl)_t = \beta_0 + \beta_1\ Ln(Cerl)_{t-1} + \beta_2 Ln(Rnf)_t + \beta_3 Ln(Tem)_t \\ + \beta_4 Ln(Co2)_t + \beta_5 Ln(Engc)_t + \beta_6 Ln(Fuel)_t \\ + \beta_7 Ln(Hdt)_t + \varepsilon t \end{aligned} \quad (2)$$

Model 3: The impact of environmental factors on vegetables production

$$\begin{aligned} Ln(Vege)_t = \beta_0 + \beta_1\ Ln(Vege)_{t-1} + \beta_2 Ln(Rnf)_t + \beta_3 Ln(Tem)_t \\ + \beta_4 Ln(Co2)_t + \beta_5 Ln(Engc)_t + \beta_6 Ln(Fuel)_t \\ + \beta_7 Ln(Hdt)_t + \varepsilon t \end{aligned} \quad (3)$$

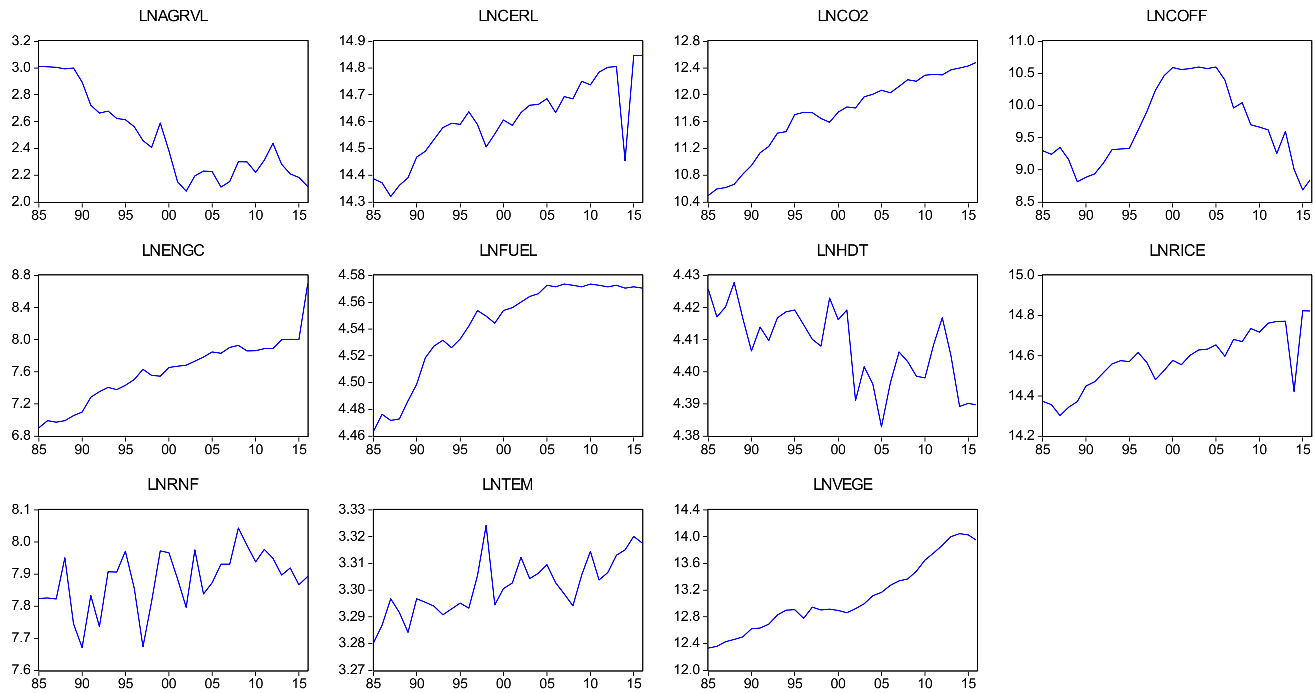

Fig. 1 Trends of the study variables

Model 4: The effect of environmental factors on coffee production

$$Ln(Coff)_t = \beta_0 + \beta_1\ Ln(Coff)_{t-1} + \beta_2 Ln(Rnf)_t + \beta_3 Ln(Tem)_t + \beta_4 Ln(Co2)_t + \beta_5 Ln(Engc)_t + \beta_6 Ln(Fuel)_t + \beta_6 Ln(Hdt)_t + \varepsilon t \quad (4)$$

Model 5: The influence of environmental factors on agriculture value added

$$Ln(Argvl)_t = \beta_0 + \beta_1\ Ln(Argvl)_{t-1} + \beta_2 Ln(Rnf)_t + \beta_3 Ln(Tem)_t + \beta_4 Ln(Co2)_t + \beta_5 Ln(Engc)_t + \beta_6 Ln(Fuel)_t + \beta_6 Ln(Hdt)_t + \varepsilon t \quad (5)$$

where Rice signifies rice production, Cerl denotes cereal production, Vege represents vegetables production, Coff means coffee production, Agrval represents agriculture value added, Rnf represents rainfall, Tem represents temperature, CO_2 denotes carbon dioxide emissions, Engc means energy consumption, Fuel signifies fossil fuel emission, Hdt stands for humidity, t-1 represents the lag value, Ln is the natural logarithm, εt indicates error term, and t refers to time period from 1985 to 2016.

Results and Discussion

In this section of the study, we present the empirical results of the descriptive statistics of the variables (Table 1), correlation between the variables and GMM technique for simultaneous equation modelling. The statistics show that all the variables of agriculture production (rice, cereal, vegetables, and coffee production and agriculture value added) exhibit positive mean values, which also exceed their standard deviations. Besides, the highest (14.60) and lowest mean value (2.47) were observed in cereal production and agriculture value added, respectively. The Kurtosis value of all the variables is less than three, except for energy consumption, whose distribution is leptokurtic. Other variables are normally distributed, positively and negatively skewed. Figure 2 reveals the data trend at first difference, which depicts the productivity of the variables.

Table 2 presents the correlation matrix of agriculture production and environmental factors in Malaysia based on five different models. The results indicated that all environmental factors except humidity positively affect agriculture productions (rice, cereal, vegetables, and coffee) and agriculture value added in Malaysia. However, rainfall was observed to be weakly associated with agriculture production as opposed to other factors such as temperature, CO_2 emissions, energy consumption and fossil fuel energy consumption. On the other hand, a negative effect of environmental factors (rainfall, temperature, CO_2 emission, energy consumption, and fossil fuel energy use) was observed on agriculture value added in model 5, given their coefficient values of – 0.383, – 0.754, – 0.917, – 0.895, and – 0.948, respectively. The GMM estimates of the five models are presented in Table 3.

Table 1 Descriptive statistics

	LNRICE	LNCERL	LNVEGE	LNCOFF	LNAGRVL	LNRNF	LNTEM	LNCO2	LNENGC	LNFUEL	LNHDT
Mean	14.578	14.601	13.090	9.665	2.472	7.880	3.301	11.699	7.605	4.542	4.408
Maximum	14.823	14.846	14.043	10.596	3.012	8.043	3.324	12.492	8.698	4.573	4.427
Minimum	14.302	14.320	12.332	8.687	2.080	7.671	3.280	10.497	6.904	4.463	4.382
Std. Dev	0.143	0.145	0.518	0.628	0.309	0.090	0.011	0.603	0.395	0.035	0.011
Skewness	−0.127	−0.160	0.503	0.261	0.571	−0.639	0.189	-0.630	0.130	−1.032	−0.363
Kurtosis	2.209	2.227	2.160	1.720	2.005	2.940	2.451	2.240	3.299	2.725	2.141
Observations	32	32	32	32	32	32	32	32	32	32	32

Author's calculation

Table 3 depicts the relationship between rainfall, temperature, CO_2 emissions, total energy consumption, fossil fuel energy consumption, humidity, and rice production in Malaysia. The study found that CO_2 emissions have statistically significant influence on rice production in Malaysia. The study also indicated that a negative and significant relationship exists between temperature and rice production, thus suggesting that a 1% increase in temperature will correspondingly reduce rice production by 2.46%. It also showed that rainfall, fossil fuel consumption, and humidity have negative effects on rice production but statistically insignificant.

This demonstrates that humidity, temperature, and rainfall all have an effect on crop yields. This backs up the claims made by Solaymani (2018); Malhi et al. (2021); Mahato (2014); Challinor et al. (2014); and Sok et al. (2021) that extreme heat and rainfall have an impact on crop production and consequently impede food availability and accessibility. Although climate change is projected to have a detrimental effect on crop productivity globally, the effects will differ by crop type and geographic region (Zhao et al. 2017). According to Dabi and Khanna (2018) and Islam et al. (2021), high temperature has a deleterious influence on the rice plant's reproductive phase, resulting in a shorter crop length and decreased rice output. Mahmood et al. (2012) and Zulkafli et al. (2021) established that variations in rainfall patterns reduced rice productivity during the reproductive and ripening stages of rice growth. Abbas and Mayo (2021) discovered that rainfall has a damaging effect on rice plants throughout

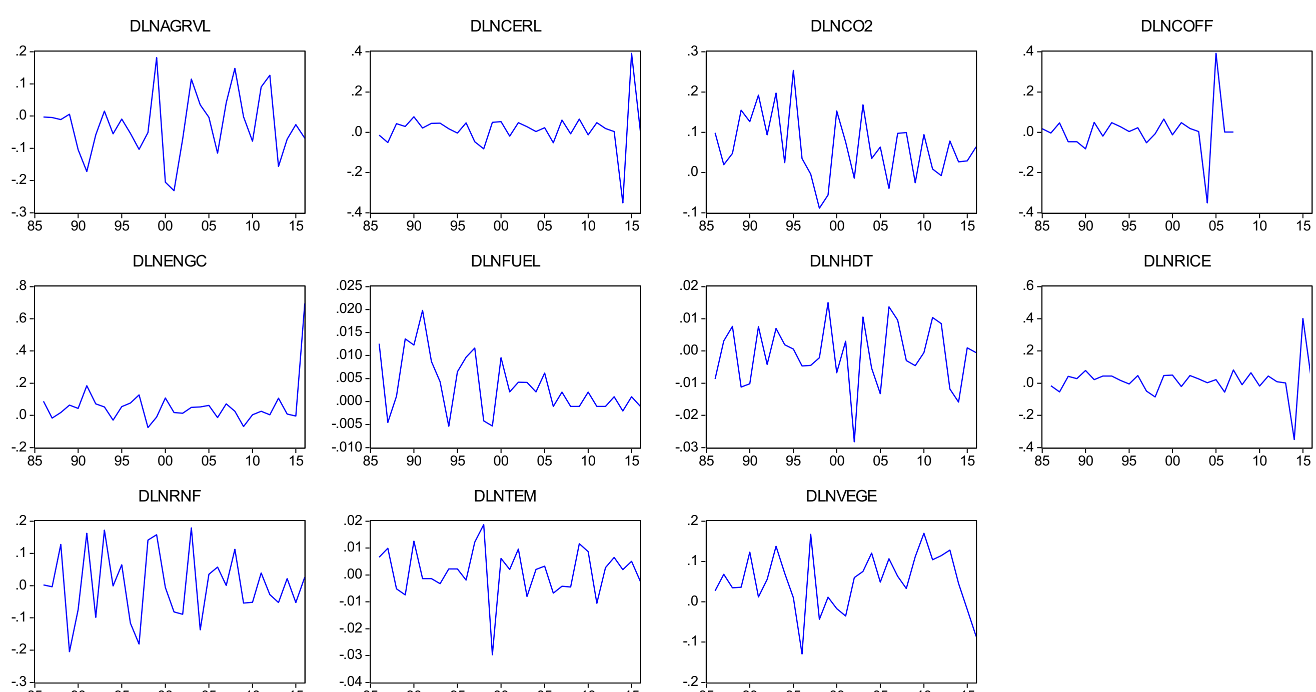

Fig. 2 Data trend at their first difference. D represents the difference

Table 2 Correlation matrix

	LNRICE	LNRNF	LNTEM	LNCO2	LNENGC	LNFUEL	LNHDT
Model 1: The effect of environmental factors on rice production							
LNRICE	1.000						
LNRNF	0.416*	1.000					
LNTEM	0.578***	0.087	1.000				
LNCO2	0.878***	0.482**	0.738***	1.000			
LNENGC	0.851***	0.419**	0.743***	0.950**	1.000		
LNFUEL	0.844**	0.428*	0.719**	0.971**	0.909***	1.000	
LNHDT	−0.544***	−0.023	−0.722**	−0.682*	−0.713**	−0.678**	1.000
	LNCERL	LNRNF	LNTEM	LNCO2	LNENGC	LNFUEL	LNHDT
Model 2: The association between environmental factors and cereal production							
LNCERL	1.000						
LNRNF	0.416*	1.000					
LNTEM	0.596***	0.087	1.000				
LNCO2	0.888***	0.482**	0.738***	1.000			
LNENGC	0.861***	0.419*	0.743***	0.950**	1.000		
LNFUEL	0.857***	0.428*	0.719***	0.971**	0.909***	1.000	
LNHDT	−0.555	−0.023	−0.722**	−0.682*	−0.713***	−0.678***	1.000
	LNVEGE	LNRNF	LNTEM	LNCO2	LNENGC	LNFUEL	LNHDT
Model 3: The impact of environmental factors on vegetables production							
LNVEGE	1.000						
LNRNF	0.435*	1.000					
LNTEM	0.724***	0.087	1.000				
LNCO2	0.910***	0.483**	0.738***	1.000			
LNENGC	0.887***	0.419*	0.743***	0.950**	1.000		
LNFUEL	0.812***	0.428*	0.719***	0.971**	0.909***	1.000	
LNHDT	−0.635***	−0.023	−0.722**	−0.682*	−0.713***	−0.678***	1.000
	LNCOFF	LNRNF	LNTEM	LNCO2	LNENGC	LNFUEL	LNHDT
Model 4: The correlation between environmental factors and coffee production							
LNCOFF	1.000						
LNRNF	0.267	1.000					
LNTEM	0.215	0.087	1.000				
LNCO2	0.294	0.482**	0.738**	1.000			
LNENGC	0.235	0.419*	0.743***	0.950	1.000		
LNFUEL	0.449**	0.428*	0.719***	0.971**	0.909***	1.000	
LNHDT	−0.183	−0.023	−0.722**	−0.682*	−0.713***	−0.678***	1.000
	LNAGRVL	LNRNF	LNTEM	LNCO2	LNENGC	LNFUEL	LNHDT
Model 5: The impact of environmental factors on agriculture value added							
LNAGRVL	1.000						
LNRNF	−0.383**	1.000					
LNTEM	−0.754***	0.087	1.000				
LNCO2	−0.917***	0.483**	0.738***	1.000			
LNENGC	−0.895***	0.419*	0.743***	0.950**	1.000		
LNFUEL	−0.948***	0.428**	0.719***	0.971**	0.909**	1.000	
LNHDT	0.736***	−0.023	−0.722**	−0.682*	-0.713*	−0.678***	1.000

Author's calculation

The asterisks (***), (**), and (*) signify 1%, 5%, and 10% significance levels, respectively

the heading and flowering stages. Likewise, Ibrahim et al. (2014), Firdaus (2015), Tang (2019), and Vaghefi et al. (2016) revealed that climate change lowers the yields of paddy and other agricultural crops in Malaysia.

Table 4 shows that CO_2 emissions have a positive and significant impact on cereal production in Malaysia, in agreement with the findings of Ahsan et al. (2020). While climate change is expected to have a negative influence on

Table 3 The impact of environmental factors on rice production (GMM test on model 1)

Variable	Coefficient	Std. error	*t*-statistic	Prob
C	33.13860	14.19841	2.333965	0.0287
LNRICE(-1)	−0.069692	0.193107	−0.360901	0.7215
LNRNF	−0.105296	0.090942	−1.157827	0.2588
LNTEM	−2.463506	1.238924	−1.988424	0.0588
LNCO2	0.354066	0.097042	3.648598	0.0013
LNENGC	0.016170	0.122538	0.131962	0.8962
LNFUEL	−1.791025	1.401640	−1.277807	0.2141
LNHDT	−1.067980	2.204886	−0.484370	0.6327
R^2	0.762555	Adjusted R^2		0.6902
D.W statistics	2.252705	J-statistic		2.4204

Author's calculation

Dependent variable includes Ln (RICE); the lag value of explanatory variables constitutes the instrumental list; LN is the natural logarithm; RNF, TEM, CO2, ENEC, FUEL, and HDT are environmental factors; and RICE is rice production

Table 4 The impacts of environmental factors on cereal production (model 2)

Variable	Coefficient	Std. error	*t*-statistic	Prob
C	31.22048	14.43195	2.163289	0.0412
LNCERL(-1)	−0.107233	0.180672	−0.593526	0.5586
LNRNF	−0.097567	0.088092	−1.107555	0.2795
LNTEM	−2.170048	1.371891	−1.581794	0.1274
LNCO2	0.338902	0.098530	3.439585	0.0022
LNENGC	0.024492	0.116770	0.209743	0.8357
LNFUEL	−1.461462	1.404407	−1.040626	0.3089
LNHDT	−1.050486	2.206081	−0.476178	0.6384
R^2	0.781382	Adjusted R^2		0.7148
D.W statistics	2.234929	J-statistic		2.4227

Author's calculation

Dependent variable is represented by LN (CERL); instrumental list includes the lag value of independent variables; RNF, TEM, CO2, ENEC, FUEL, and HDT are environmental factors; and CERL denotes cereal production

crop productivity worldwide, the effects will vary by crop and geographical region. Hence, climate variables such as rainfall, temperature, fossil fuel consumption, and humidity were observed to have a detrimental effect on cereal output albeit statistically insignificant. This finding is congruent with that of Deutsch et al. (2018), who showed a decrease in the yields of three cereal grains (rice, maize, and wheat) and projected an additional loss of 10–25% if the global mean surface temperature climbed by 1 °C. Similarly, a meta-analysis study discovered that temperature variance as a result of climate change considerably reduces wheat, rice, maize, and soybean yields (FAO 2017). Pickson et al. (2020) reported that average temperature and temperature variability have a long-term negative effect on cereal output. As a result, policymakers should develop cohesive adaptation and mitigation policies to address the already observed effect of climate change on agriculture in order to rebuild robust and sustainable agriculture output in Malaysia.

Table 5 depicts the significant negative effect of total energy consumption on vegetable production in Malaysia. This implies that a 1% increase in energy consumption results in a 0.28% decrease in vegetable yield. Although rainfall, temperature, fuel consumption, and humidity also exhibit an inverse relationship with vegetable production, they are not statistically significant. This finding is in line with the earlier studies of Wang et al. (2015) and Xu et al. (2016), who found that climatic fluctuations differently affect various crop types. Overall, vegetables are more sensitive to environmental stresses including high temperatures and water stress. Carbon dioxide, a primary greenhouse gas, affects plant growth and development. Crop failures, low yields, poor quality, and increased insect and disease problems are typical in changing climates, making vegetable farming unprofitable (Naik et al. 2017). Agriculture output must be adapted to climate change to ensure nutritional security in underdeveloped nations.

Table 6 shows that CO_2 has a negative and significant effect on coffee production in Malaysia, thus suggesting that a 1% reduction in carbon dioxide emission will decrease coffee production by 1.09%. While rainfall also exhibits an inverse relationship, it is not statically significant. This result agrees with the findings of Gay et al. (2006) that climatic factors affect coffee yield in Veracruz, Mexico. Wagner et al. (2021) also affirmed that excess rainfall influences coffee production during flowering, maturation, and harvest stages. Rising temperatures will cause drought, as well as an

Table 5 The impacts of environmental factors on vegetable production (model 3)

Variable	Coefficient	Std. error	*t*-statistic	Prob
C	14.61127	18.35541	0.796020	0.4342
LNVEGE (−1)	0.974063	0.085654	11.37206	0.0000
LNRNF	−0.079289	0.176271	−0.449815	0.6571
LNTEM	−1.279271	2.164574	−0.591004	0.5603
LNCO2	0.260074	0.237309	1.095931	0.2845
LNENGC	−0.285593	0.086426	−3.304493	0.0031
LNFUEL	−0.932884	2.469927	−0.377697	0.7091
LNHDT	−1.360897	1.756758	−0.774664	0.4464
R^2	0.982741	Adjusted R^2		0.9774
D.W statistics	1.977035	J-statistic		3.9038

Author's calculation

LN (VEGE) is the dependent variable; the lag value of independent variables constitutes the instrumental list; RNF, TEM, CO_2, ENEC, FUEL, and HDT make up the environmental factors; and VEGE represents vegetable production increase in the frequency of diseases and the extinction of large swaths of the insects that pollinate coffee trees. According to Bongase (2017), over half of the land currently used to produce high-quality coffee may become unproductive by 2050.

Table 7 shows that temperature, energy consumption, and fuel consumption have negative and significant impacts on agriculture value added in Malaysia. This result is consistent with the study of Qureshi et al. (2016). The results indicate the varying influence of environmental factors on agriculture value added, given the indirect relationship between temperature, energy consumption, fossil fuel consumption, and the agriculture's contribution to GDP. Besides, the coefficient value suggests that a 1% rise in temperature, energy consumption, and fossil energy will result in the reduction of agriculture value added by 4.03%, 0.11%, and 5.41%, respectively. This indicates the major influence of temperature, energy consumption, and fossil energy in reducing agricultural yield in the country. This can also mean that increase dependence on fossil fuel energy will heighten food insecurity, which is consistent with the report that implicate the anthropogenic GHG emission in the rising global food–fuel prices amid dwindling food production (Woods et al. 2010). West and Marland (2003) also noted that poor management practices could impede the crop yields and land productivity. Hence, as concluded by Zaman-Allah et al. (2015), poor agriculture production significantly contribute to the global food inequality and insecurity.

Table 7 The influence of environmental factors on agriculture value added (model 5)

Variable	Coefficient	Std. Error	t-statistic	Prob
C	28.15356	19.59157	1.437024	0.1642
LNAGRVL(-1)	0.401405	0.125519	3.197963	0.0040
LNRNF	−0.137034	0.154350	−0.887813	0.3838
LNTEM	−4.039905	2.351363	−1.718112	0.0992
LNCO2	0.194899	0.131041	1.487312	0.1505
LNENGC	−0.116703	0.052448	−2.225127	0.0362
LNFUEL	−5.406068	1.405096	−3.847473	0.0008
LNHDT	2.474579	2.869527	0.862365	0.3974
R^2	0.944300	Adjusted R^2		0.9273
D.W statistics	1.402014	J-statistic		3.1979

Author's calculation

Dependent variable includes LN (AGRVL); instrumental list is comprised of the lag value of independent variables; RNF, TEM, CO_2, ENEC, FUEL, and HDT are the environmental factors; and AGRVL represents agriculture value added

Conclusion

According to the findings of the study, it is evident that climatic factors pose significant challenges to various agricultural production, which ultimately lowers agriculture value added (as a percentage of GDP) in Peninsular Malaysia. This implies that the climatic factors will weaken the economic performance of Malaysia in the short and long run. The findings revealed the association existing between climate change and agriculture production, suggesting that climatic factors threaten global food security. With the current level of global warming, existing strategies might be inadequate and inefficient to neutralize its consequences. In order to restore robust and sustainable agricultural output in Malaysia, policymakers need to design unified adaptation and mitigation policies to address the already observed effect of climate change on agriculture. Hence, Malaysia needs to revisit its adaptive strategies towards climate change by considering the following: First, meteorologists, policymakers, and researchers should come up with effective strategies and synthesize comprehensive policy to address the problems of climate change. This will ensure long-term improvement of the country's self-sufficiency levels (SSL) and food security. Second, the country should emphasize the enhancement of farmers' adaptive capacity against the effect of climate change on their agricultural activities. Third, the Malaysian government should implement policy-based adaptations through agricultural research. Besides, national policy on agriculture adaptation against climate change is yet to be developed in Malaysia. Lastly, there is a need to revise certain strategies and programmes in the current policy. As an instance, the use of SSL as a measure of food security might be irrelevant owing to the multifaceted nature of food security.

Table 6 The impacts of environmental factors on coffee production (model 4)

Variable	Coefficient	Std. error	*t*-statistic	Prob
C	−128.1702	33.83964	−3.787575	0.0010
LNCOFF(-1)	0.876419	0.073378	11.94382	0.0000
LNRNF	−0.048797	0.470572	−0.103697	0.9183
LNTEM	7.981249	4.435633	1.799349	0.0851
LNCO2	−1.096928	0.484015	−2.266313	0.0332
LNENGC	0.425050	0.326515	1.301776	0.2059
LNFUEL	15.49116	5.424959	2.855534	0.0089
LNHDT	9.670811	5.250154	1.842005	0.0784
R^2	0.907209	Adjusted R^2		0.8789
D.W statistics	2.411574	J-statistic		5.0197

Author's calculation

Dependent variable includes LN (LNCOFF); instrumental list is comprised of the lag value of independent variables; RNF, TEM, CO2, ENEC, FUEL, and HDT are environmental factors; and COFF refers to coffee production

Author contribution Masud wrote the introduction and literature review, while Akhtar contributes the methodology, results, and conclusion parts.

Funding The authors would like to thank the Universiti Malaya for the continuous support and the UM Living Lab Grant Programme-SUS (Sustainability Science) under grant no. LL057-2021.

Data availability The datasets generated during and/or analysed during the current study are available in World Development Indicators (WDI): https://databank.worldbank.org/source/world development-indicators and Department of Statistics Malaysia: https://www.dosm.gov.my/.

Declarations

Ethics approval and consent to participate This article does not use human participants and informed consent is not applicable.

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

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