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Biofuels, environmental sustainability, and food security: A review of 51 countries

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ABSTRACT

Biofuels will not only be a solution for a good environmental quality, but may also bring an increase in food production. This scenario, which refers to sufficiently huge supply of biofuels, capable to bring better environmental quality vis-à-vis food security. Biofuels have the potential to offer a win-win opportunity to improve environmental quality, whereby better environmental quality may promote a sizeable increase in food production. Therefore, the objective of this paper is to investigate the impact of biofuels on food security, given the level of environmental quality in 51 developing countries. The results of dynamic generalized method of moments indicate that the interaction term between biofuels and environmental quality has a positive and significant impact on food security. This implies that biofuels will initially bring about a competition to food security but in a later stage it can lead to a favorable condition for agriculture. Therefore, significant expansion and consumption of biofuels could contribute to increment in food security and sustain the environmental quality.

1. Introduction

As a society, we need action to significantly reduce global greenhouse gas (GHG) emission in the coming decades, which primarily comes from the burning fossil fuels. This is because the GHG emission is projected to increase by fifty percent and becomes the fastest growing driver of climate change by 2050. Specifically, this would be far larger in developing countries, in which GHG emission is expected to grow from 63 percent in 2000 to 235 percent by 2050 than in developed countries [1]. Rapid increase in GHG emissions, which is predicted to be the main factor affecting the earth's climate, raises worldwide concern and imposes serious pressure to political leaders to design effective policy that can curb the emissions [2].

Accordingly, international energy agency has introduced renewable energy as part of the possible solutions to reduce GHG emission and ensure a stable climate all over the world [3]. Major types of renewable energy are wind, geothermal, solar, ocean power, hydropower and biomass. Specifically, the share of renewable energy has increased in heating, electricity and transport sectors. Out of various renewable energies, biofuels continue to represent the vast majority of the currently developed and consumed renewable energy. According to Fig. 1, biofuels production has surged from 142.6 mln L to 160.9 mln L in 2019, from which bioethanol made up 78 percent of total biofuels production with the remaining 22 percent accounted for biodiesel. Based on [4], developed countries' production of biofuels has grown progressively in 2019, which is 9.9 mln L greater than in 2015. For developed countries, the main biofuels producer is the United States, driven by the subsidies to bioethanol producer and environmental legislation [5]. While, in developing countries, the production of the renewable energy coming from biofuels has reached 66.3 mln L in 2019. In developing countries, the major biofuels producing countries are Brazil, Indonesia, China, Argentina and Thailand [6,5].

At present, biofuels are liquid fuels (either bioethanol or biodiesel) and mainly produced from agricultural products, leading to a stiff competition or head-aching trade-off between demand for food consumptions and biofuels production. Higher demand for agricultural outputs for biofuel production may adversely affect food availability or supply such as sugarcane, sugar beet, cassava, corn, rapeseed, soya bean, palm oil, wheat and others if they are switched from production of food to biofuels. As a result, it may aggravate the problem of currently insufficient supply of food, leading to acute hunger problem in many areas. Studies on the relationship between food security and biofuels, albeit limited, are sharing almost similar conclusion that the development of biofuels reduces food supplies and increases food

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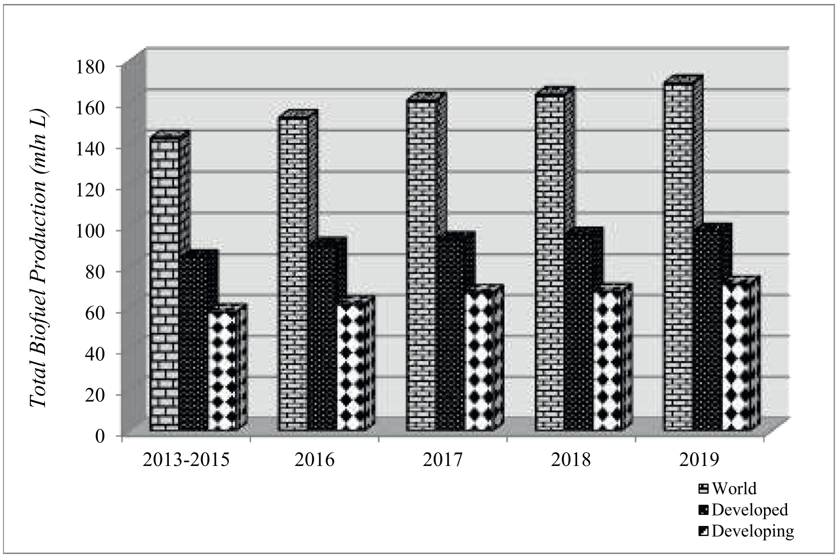

Fig. 1. World biofuels production. Source: [5,7].

prices, thereby worsens food insecurity for the poor [8–11]. The World Bank president, Robert Zoellick states that increasing biofuel production is a significant contributor to soaring food prices around the world in the future [12]. High price of food means that less people are now can afford to buy food. At the same time, [13] state that the use of agricultural commodities (such as cereals) as sources for biofuels will lead to an additional 150 million people at risk of hunger by 2020.

Among the reasons cited as the sources of the conflict are competition for resources, mainly agricultural outputs as well as price of agricultural products. Firstly, in terms of food availability, productive resources such as land, labor, and water are switched from the production of food to biofuels, leaving agricultural sector with less supply of those resources [10,14]. With other developments such as urbanization and industrialization are already seriously affecting the size of land and labor available for agricultural sector, progression of biofuels sector may offer another setback to this sector. Secondly, biofuels are likely to reduce food accessibility because biofuels production is one of the drivers of food commodity prices [15]. While rich people may still be unaffected by the soaring prices of food, the poor may have to satisfy with less food as their real income drops and most likely have to resort to less quality food. Apart from just getting the food, another important aspect which also embedded in the definition of food accessibility is on the quality of food that can support nutrients supply, especially to the poor [16]. High prices of nutrient-contained food may hinder the poor from getting them. Biofuels development is predicted strongly by past studies as having a negative impact on the world agricultural commodity that available to the poor at affordable prices. To further find support, Fig. 2 provides preliminary supporting evidence for the negative impact of biofuels on food consumption. It means that currently, production of biofuels does play a role in diverting the amount of agricultural supply for food productions to biofuels production, leading to shortage of food supply.

With all arguments so far tend to go against the development of biofuels, will that mean we have to abolish biofuels sector? There is actually a forgotten aspect that the development of biofuels is not always in the expense of production or supply of food. The report of Intergovernmental Panel on Climate Change (IPCC) has also supported that biofuels can lead to a substantial reduction in environmental degradation and is projected to contribute to the net reduction of carbon emissions by 94 percent relative to fossil fuels, which is merely at 60 percent [2]. From the fact in Fig. 3, it suggests that the annual greenhouse emissions of developing countries slightly decreased between 2011 and 2016, strongly argued as the positive consequence of biofuels development.

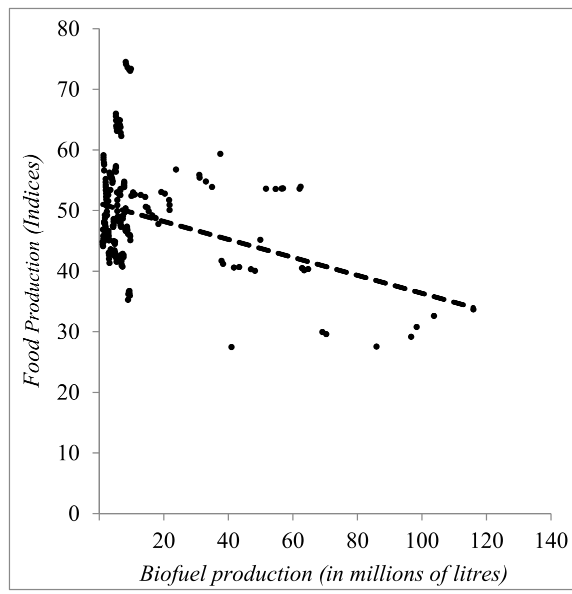

Fig. 2. Total biofuels and food production in 2011 and 2016.[1] Source: [5].

Beyond that, meeting the reduction in GHG emissions due to the biofuels production has the potential to also bring an *increase* in food production to populations. One of the main facts is that an accelerated reduction in greenhouse emissions is likely to recover the current threats to food security. In this case, it is suggested that a reduction in global temperature can potentially increase crop yield, cause better quality and more quantity of crops. According to [18], beyond a certain range of temperatures, warming tends to reduce yields. This is because higher temperatures are likely to impede the ability of plants to use the

[1] Angola, Argentina, Belarus, Bolivia, Brazil, Bulgaria, China, Colombia, Costa Rica, Ecuador, Egypt, El Salvador, Ethiopia, Guatemala, Honduras, India, Indonesia, Kazakhstan, Kenya, Malawi, Mexico, Mozambique, Nicaragua, Pakistan, Panama, Paraguay, Peru, Philippines, Romania, Russian Federation, Rwanda, Serbia, Sudan, South Africa, Thailand, Turkey, Ukraine, United Republic of Tanzania, Uruguay, Viet Nam, Barbados, Croatia, Cuba, Fiji, Iran, Jamaica, Mauritius, Swaziland, The former Yugoslav Republic of Macedonia, Trinidad and Tobago and Zimbabwe.

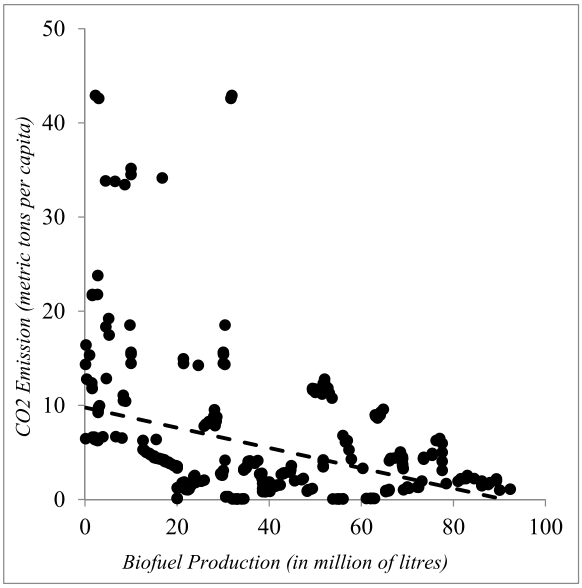

Fig. 3. Biofuels production and CO_2 emission in 2011 and 2016.[2] Source: [5, 17].

moisture. Therefore, increases in temperature with more dryness as a result of the changing climate are harmful to crop cultivation. Thereby, an increase in biofuels is expected to cause lower carbon emission and likely to affect global temperature to be more favorable to food production and supply. These highlight that production of biofuels may play a vital role in reducing greenhouse emission, whereby better environmental quality promotes a sizeable increase in food production. *Hence, this study specifically curious about what is the effect of biofuels production on food security, if biofuels sufficiently promote the level of environmental quality in developing countries.*

The rest of the article is organized as follows: Section 2 reviews past studies, Section 3 provides the research methodology, including model specification and the estimation strategy. The empirical results are reported in Section 4 and finally, Section 5 concludes the article.

2. Literature review

In respect to empirical analysis, several factors such as population growth, environmental degradation, arable land and biofuels production have been confirmed theoretically and also by past studies as crucial determinants of food security. Basically, there are four research strands pertaining to determinants of food security.

The role of population in food supplies has been considered one of the basic principles in economics. The pioneering work in this field, which links food security and population growth, can be traced back to [19]. Malthusian theory identifies that food shortages exist due to the presence of too many people compared to the amount of food supply and thus exacerbated long-run food insecurity [19]. Many studies conclude that the rate of population growth determines the rate of food supplies [20–23]. Recently, [24] and [25] find that population affects demand for food, leading to an excessive use of resources. A pressure on limited resources increases the challenge of efforts to adequately meeting sufficient and nutritious food. [26] also discuss the challenges and opportunities in food security as well as maintaining the food supply chain globally. The challenge in food security is the increase in population, putting major adverse impact on food availability and threatening food security. Noticeably, world population plays a vital role in determining food production for a country, specifically in the year 2050 [26–28], especially when world population is projected to reach 9 billion in 2050, which is more than double from 1950. Therefore, rapid increasing number of populations makes securing food for everyone a mounting task [29].

H_1: There is a negative impact of population on food security.

In keeping with original Malthus, neoMalthusians adds land in addition to population size. Land has been set as another important basis for food security. It plays an essential role in production of agricultural crops as well as making more food available for growing population [15, 22, 26, 30]. In this context, availability of more land for the agricultural activities can raise household food security by contributing directly to more food production. Additionally,

[22] and [31] find that increases in land access to the poor can contribute to poverty alleviation and an increase in food security via increasing household accessibility. In this respect, it shifts up the willingness and ability of households to buy food and thereby contributes directly to increased household food security. Therefore, the increment in arable land as a mean of higher resources to promote agricultural outputs and livelihood may help to sustain food productivity and assure household food supplies.[3]

H_2: There is a positive impact of land on food security.

Theoretically, Food Availability Decline (FAD) approach proposes that food insecurity is primarily caused by a decline in food availability that leads to insufficient food to feed the growing population. The theory strongly emphasizes the supply side failure as the source of the problem. As one crucial factor leading to the failure, the FAD suggests that food production is vulnerable to environmental degradation. Empirically, [32, 33, 23, 34, 35, 25, 26, 36, 37, 38], and [39] explore the impacts of environmental degradation on food production. These studies show that environmental degradation has a negative significant impact on food production. Changing in climate is expected to increase temperature unfavorably, thereby reduces crop yield and production in short- and long-term [40, 41]. [34] recognize that flooding is destroying growing seasons, leading to crop loss, low yields, and reduction in the availability of food. There are few literatures investigating the link between food security and environmental degradation in African countries, for instances, [36] for North Africa and Southern Africa, as well as [42] for Southern Africa. Overall, past studies suggest that food security might be negatively affected by environmental degradation.

H_3: There is a positive impact of environmental quality on food security.

In addition, biofuels are another specific factor that has been identified by past studies as important in mitigating climate change and alleviating global energy concern. However, a number of studies namely [8, 43, 44, 45, 9, 10, 11, 46, 47, 48, 49, 50, 51, 52] and [53] claim that rapid growth in biofuel production worsens food security. Increases in production of biofuels lead food supplies to be unlikely sufficient as the production of biofuels require agriculture-feedstock. Biofuels are primarily produced from agricultural products such as corn, oleaginous sugarcane, forest biomass, oil seeds and other crops.

[2] Angola, Argentina, Belarus, Bolivia, Brazil, Bulgaria, China, Colombia, Costa Rica, Ecuador, Egypt, El Salvador, Ethiopia, Guatemala, Honduras, India, Indonesia, Kazakhstan, Kenya, Malawi, Mexico, Mozambique, Nicaragua, Pakistan, Panama, Paraguay, Peru, Philippines, Romania, Russian Federation, Rwanda, Serbia, Sudan, South Africa, Thailand, Turkey, Ukraine, United Republic of Tanzania, Uruguay, Viet Nam, Barbados, Croatia, Cuba, Fiji, Iran, Jamaica, Mauritius, Swaziland, The former Yugoslav Republic of Macedonia, Trinidad and Tobago and Zimbabwe.

[3] It is important to note that the immediate effect of land is expected to be positive but land expansion for agricultural activities will always impose bad repercussions to environmental quality. Similar to the case of biofuels, the final effect of land size on food security could also be ambiguous, depending on how much destruction to the environment the land expansion will offer. Nevertheless, this issue could be beyond the scope of this study and we leave it for future study. In this study, we simply assume, in drawing the hypothesis, that the land expansion is accompanied with environmentally friendly agricultural techniques.

Therefore, [8, 54] and several others suggest the occurrence of negative impact of biofuels development on food production.[4]

H_4: There is a negative impact of biofuels on food security.

Past studies on biofuels-food security nexus tend to oagainst the biofuels development via their negative finding. In other words, these studies argue that biofuels production may aggravate the problem of insufficient supply of food, leading to acute hunger problem in many areas [55, 56]. There is actually a forgotten aspect that the development of biofuels it is not always in the expense of production or supply of food. While there is no specific theory available and capable to link biofuels, environment and food security, the recent statement by [57] argues that producing bioenergy does not have to conflict with food security. [57] views bioenergy as a way to improve energy security and food productivity as well as to ensure household food supplies. Likewise, [8] also raise the question of whether the sustainable development goals of alleviating global hunger can be achieved with the expansion of biofuels production.

One of the main facts is that a reduction in global temperature can potentially increase crop yield, cause better crop quality and more crop quantity [18]. This is because each crop has its own temperature requirement that plays a role in crop development and yields. Plant development decreases as temperature rises beyond the optimum level [58]. Beyond the optimum, higher temperatures adversely affect crop yield, pollination, plant growth and reproductive process [59]. For example, an analysis by [60] indicates that yield growth for chili, eggplant, okra, sweet potato, watermelon would gradually increase with temperature up to 21 °C to 29 °C, but decreases with temperature increase beyond this range. Climate change has been one of the factors affecting sugarcane production through higher temperatures in Brazil and Thailand. The maximum temperature in Brazil was 30.8 °C, which leads to higher evapotranspiration, reduction in the amount of water available in soils and thus higher difficulty of planting sugar cane [27]. Likewise, tomato is grown worldwide with China and India are ranked as the world's top two tomato-producing countries. The optimum temperature for tomato growth is between 21 °C and 24 °C. Temperature, which is above 27 °C leads to the deterioration of tomato quality and quantity. Tomato planting is highly affected by adverse climatic conditions, particularly in India, Egypt and Brazil as currently their temperatures stand at 29.9 °C, 27.8 °C and 30.8 °C, respectively. Tomato is a warm seasonal crop that requires a warm and cool climate, but cannot withstand frost and high humidity. High temperature beyond the favorable degree will therefore significantly influence the growth processes of tomato from seed germination, seed growth, flower and flower set and fruit quality. This is because if temperature rises unfavorably exceeding the optimum range for many crops, plant growth, pollination, reproductive processes and development along with crop yield are adversely affected [59]. As a result, an increase in biofuels is expected to cause decreased carbon emissions and is likely to affect global temperature in food supplies.

Accordingly, this study allows us to emphasize a clear distinction regarding the effect of biofuels production on food security, if biofuels sufficiently promote the level of environmental quality in developing countries, the point that is missing in the previous studies. Most of past studies indicate that biofuels production has received an increasing attention by environmentalists as a mean to mitigate greenhouse gases emissions, particularly to tackle the unprecedented climate change. Thereby, a reduction in emission is likely to affect global temperature to be more conducive for plantation. This highlights that the production of biofuels may play a vital role in reducing greenhouse emission whereby better environmental quality promote a sizeable increase in food production in the long run. This is the missing link in the literature. To our limited knowledge, the outcome of this study may be useful for providing a framework for future development, not only in food production but also in biofuels development.

H_5: There is a threshold effect of biofuels on food security, given the level of environmental quality.

3. Model specification

The Malthusian and neoMalthusian model assume that human population tends to grow in geometric progression, while human substance such food and agriculture-based products only grow in arithmetic progression. In other worlds, population tends to grow at much faster rate than human substances, thereby increases in number of populations leads to shortages of food supplies. The studies by [20] and [61] indicate that food shortages exist due to the presence of too many people compared to the amount of food supply and thus exacerbated food insecurity in the long-run. Since it is widely assumed that rapid population growth leads to the considerably lesser amount of food, the basic food security function can be written as:

$$FS_{i,t} = \alpha + \beta_1 POP_{i,t} + \varepsilon_{i,t} \tag{1}$$

where *FS, POP* and ε represent food security, population growth and error term, respectively. Subscripts i refers to country and t refers to period. In addition, combining the literature, we extend Eq. (1) to also incorporate arable land (*AL*), biofuels production (*BP)* and environmental quality (*EQ*) as controlled variables [24, 25, 35, 25], written as:

$$FS_{i,t} = \alpha + \beta_1 POP_{i,t} + \beta_2 AL_{i,t} + \beta_3 EQ_{i,t} + \beta_4 BP_{i,t} + \varepsilon_{i,t} \tag{2}$$

To examine our central thesis that environmental quality can be the turning factor governing the positive effect of biofuels on food security, we extend Eq. (2) by adding the interaction terms of biofuels and environmental quality. Our final estimating model will then be:

$$FS_{i,t} = \alpha + \beta_1 POP_{i,t} + \beta_2 AL_{i,t} + \beta_3 EQ_{i,t} + \beta_4 BP_{i,t} + \beta_5 (BP_{i,t} {}^* EQ_{i,t}) + \varepsilon_{i,t} \tag{3}$$

Accordingly, Eq. (3) can be simplified as:

$$FS_{i,t} = \alpha + \beta_1 X_{i,t} + \varepsilon_{i,t} \tag{4}$$

where X represents all explanatory variables in Eq. (3). In addition to aggregate measure of food security (FS), we also examine the similar issue for individual of all four dimensions of food security, namely food availability *(FSAVA),* food accessibility *(FSACC),* food utilization *(FSUTI)* and food stability *(FSSTA)*. In doing so, apart from the standard explanatory variables set as X in Eq. (4), for each dimension, we also include several other unique factors to each of them. Firstly, *FSAVA* equation is finalized as follows:

$$FSAVA_{i,t} = \alpha + \beta_1 X_{i,t} + \beta_2 CA_{i,t} + \varepsilon_{i,t} \tag{5}$$

where in Eq. (5), *CA* is credit to agriculture. A number of studies have suggested that credit to agriculture [62] appears to be necessary to maintain and improve the food security. On the set up of *FSACC* function, income inequality (*GINI*) and food prices (*PRI*) are two additional variables as the following Eq. (6):

$$FSACC_{i,t} = \alpha + \beta_1 X_{i,t} + \beta_2 GINI_{i,t} + \beta_3 PRI_{i,t} + \varepsilon_{i,t} \tag{6}$$

[63, 64] and [65] find that income inequality intensifies food insecurity by perpetuating poverty and widening the inequalities in accessibility. Thereby, unlike the poor, riche people would always have enough money to spend on healthy foods and to fulfill their basic needs of life. Besides that, [48] has examined the food security in terms of the relationship between food production and food price. Food price can constrain household purchasing power and force them to resort to less food. For *FSUTI* function, we add two more variables, namely food price

[4] Biofuels are not necessarily agriculture-based. There are second and third generations of biofuels, which if properly and successfully developed, may minimize this issue. Nevertheless, the second (i.e. lignocellulosic feedstocks and municipal solid wastes based.) and third generations (i.e. algal biomass-based) biofuels are still at their infancy stage and therefore, the composition of agriculture-based biofuels dominate the total production of the industry.

Table 1
The list of developing countries based on region and income groups.

Region	Income groups	Countries
Asia & Pacific	Lower-Middle Income	Indonesia, The Philippines, Vietnam
	Upper-Middle Income	China, Fiji, Thailand
Europe & Central Asia	Lower-Middle Income	Ukraine
	Upper-Middle Income	Belarus, Bulgaria, Kazakhstan, Romania, Russian Federation, Serbia, Turkey
	High Income	Croatia
Latin America& Caribbean	Lower-Middle Income	Bolivia, El Salvador, Guatemala, Honduras, Nicaragua
	Upper-Middle Income	Brazil, Colombia, Costa Rica, Cuba, Ecuador, Jamaica, Mexico, Paraguay, Peru
	High Income	Argentina, Barbados, Panama, Trinidad and Tobago, Uruguay
Middle East & North Africa	Lower-Middle Income	Egypt
	Upper-Middle Income	Iran
South Asia	Lower-Middle Income	India, Pakistan
	Low Income	Ethiopia, Malawi, Mozambique, Rwanda, Tanzania, Zimbabwe
Sub-Saharan Africa	Lower-Middle Income	Angola, Côte d'Ivoire, Kenya, Sudan, Swaziland
	Upper-Middle Income	Mauritius, South Africa

Table 2
List of variables, definition and sources.

Variables	Definition/ measurement	Sources
POP	Annual population growth rates	[17]
EQ	Carbon dioxide emissions in metric tons per capita	
AL	Land area in percentage of total land	
GDP	GDP per capita in constant 2010 US dollar	
UNE	Unemployment of percentage of total labor force	
GFSI	Global Food Security Index	[74]
BP	Total biofuels production in thousand barrels per day	[5] and [7]
CA	Credit to agriculture as percentage of total credit	[75]
PRI	Food price index	[76]
IE	Income inequality in Gini index	[76] and [7]
TEMP	Temperature	[5]
NUM.DISAS	natural disasters occurrences	[77]
EPI	Environmental Performance Index	[78]

(*PRI*) and income (*GDP*) as follows:

$$FSUTI_{i,t} = \alpha + \beta_1 X_{i,t} + \beta_2 PRI_{i,t} + \beta_3 GDP_{i,t} + \varepsilon_{i,t} \quad (7)$$

A number of studies [66, 32, others] indicates that the more the income, the more food secure the household will be, justifying its inclusion in Eq. (7). Income widens the range of food consumption to include healthy and nutritious food. Finally, *FSSTA* equation is set as Eq. (8) by adding unemployment (*UNE*) as follows:

$$FSSTA_{i,t} = \alpha + \beta_1 X_{i,t} + \beta_2 UNE_{i,t} + \varepsilon_{i,t} \quad (8)$$

Unemployment *(UNE)* is generally accepted to be important to explain food security [67]. This is because unemployment disables the household ability to buy food items in order to meet the food needs of household members. To sum up, *AL, EQ, CA, GDP and BP*EQ* are expected to be positive while *POP, BP, PRI, GINI, UNE* are expected to be negative.

3.1. Marginal effect computation

According to [68], if the model is interactive model, then the attention should pay to the interaction term (*BP*EQ*), rather than individual term (*BPor EQ*). This is because the coefficients β_3 and β_4 only capture the effect of environmental quality (or biofuels production) on food security when biofuels production (or environmental quality) does not exist. On the other hand, as shown in Eq. (9) below, environmental quality function as the mediator and is expected to buffer the effect of biofuels on food security. Thereby, β_5 is expected to be marginally positive or negative depending on the condition of environmental quality. [68] suggest that at margin, the net effect of decreasing (or increasing) food security due to production of biofuels can be calculated by examining the partial derivative of food supply as in Eq. (9):

Table 3
Descriptive statistics of the variables.

	Mean	Std. dev.	Min	Max
FSAVG	43.726	3.701	35.790	59.180
FSAVA	51.939	7.831	35.272	74.506
FSACC	31.500	22.166	6.179	99.486
FSUTI	68.669	12.345	34.919	85.830
FSSTA	22.798	7.124	6.461	42.792
GFSI	53.652	11.658	30.800	80.200
AL	18.740	16.367	0.074	112.184
EQ	90.63	13.70	2.28	99.86
POP	1.204	1.051	−1.191	3.721
BP	2.811	4.008	0.086	7.398
CA	0.056	0.051	0.020	0.227
GINI	39.826	9.211	24.000	75.700
CPI	173.352	111.833	38.492	788.684
GDP	6.851	7.076	3.690	3.677
UNE	7.975	6.928	0.160	31.380

Note: GDP (per capita) and BP are in thousand.

$$\frac{\partial FS_{it}}{\partial BP_{it}} = \beta_4 + \beta_5 EQ \quad (9)$$

To evaluate the significance of the marginal effect, we need to compute the new standard error. Accordingly, the mean, minimum and maximum values of these levels are used to compute the t-statistics to evaluate the significant of the marginal effect.

3.2. Econometric methodology: generalized method of moments

Our empirical models, as pointed out, have been estimated with panel data methodology. Panel data has advantages that it can control for some unobserved heterogeneity and to model individual dynamics. Like heterogeneity, endogeneity also may affect the estimates and at the same time, it is hard to assume strict exogeneity of all the independent variables [69]. To control for the potential endogeneity, generalized method of moments (GMM) estimation is employed. Specifically, we utilize dynamic panel specification which characterized by the presence of lagged dependent variables among the regressors [69]. Hence, Eq. (4), following benchmark specification for GMM estimation will be as follows:

$$FS_{i,t} = \alpha + \beta X_{i,t} + \gamma FS_{i,t-1} + \mu_i + \nu_{i,t} \quad (10)$$

where μ_i is the individual effect and $\nu_{i,t}$ is the error term in Eq. (10). The GMM approach is usually considered the work of [70], but they in fact popularized the work of [71]. It is based on the notion that the instrumental variables approach noted above does not exploit all information available in the sample. Therefore, we may construct more efficient estimates of the dynamic panel data model via GMM. Initially, [70] propose using extra moment conditions in matrix form:

Table 4
Correlation analysis.

Variable	FSAVG	FSAVA	FSACC	FSUTI	FSSTA	GFSI	AL	ENV_QUA	POP	BP	CA	GINI	CPI	GDP	UN
FSAVG	1.000														
FSAVA	0.124	1.000													
FSACC	0.281	−0.811	1.000												
FSUTI	0.661	0.430	−0.317	1.000											
FSSTA	0.272	0.754	−0.792	0.558	1.000										
GFSI	0.236	0.601	−0.475	0.363	0.575	1.000									
AL	0.122	0.093	0.083	0.022	0.076	0.112	1.000								
EQ	0.055	−0.268	0.298	−0.203	−0.133	0.265	−0.093	1.000							
POP	−0.093	−0.353	0.345	−0.187	−0.421	−0.729	−0.186	−0.276	1.000						
BP	−0.078	−0.211	0.170	−0.058	−0.113	−0.209	−0.098	0.007	−0.120	1.000					
CA	0.136	0.135	0.133	0.136	0.251	−0.385	0.224	−0.245	0.176	−0.156	1.000				
GINI	−0.031	−0.330	0.287	−0.189	−0.245	−0.138	−0.297	−0.036	0.339	0.149	−0.178	1.000			
CPI	−0.052	−0.137	−0.178	−0.141	−0.225	−0.387	0.074	−0.113	0.326	−0.074	0.408	−0.140	1.000		
GDP	0.214	0.553	0.326	0.270	0.354	0.797	−0.174	0.409	−0.330	0.146	−0.329	−0.113	−0.304	1.000	
UNE	−0.257	−0.039	−0.053	−0.113	−0.134	0.008	−0.160	0.145	0.016	0.018	−0.157	0.261	−0.117	0.017	1.000

Table 5
Regression analysis [DV = *LFS*].

	FS DIFF-GMM	SYS-GMM	FSAVA DIFF-GMM	SYS-GMM	FSACC DIFF-GMM	SYS-GMM	FSUTI DIFF-GMM	SYS-GMM	FSSTA DIFF-GMM	SYS-GMM
Constant	–	4.7132***	–	4.9346***	–	3.2420***		4.3222***	–	2.7461***
		[17.24]		[17.27]		[13.07]	-	[16.63]		[14.05]
LFS_{t-1}	−0.0019*	−0.0174***	0.0014	−0.0023***	−0.5956***	−0.4678**	−0.9774***	−0.8216***	3.465*** [13.21]	−1.2068***
	[−1.77]	[−2.66]	[1.34]	[−3.65]	[−7.86]	[−2.78]	[−9.23]	[−3.95]		[−15.35]
LAL	−0.0043	0.0143***	0.0022***	0.0038***	0.0455***	0.0475***	–	–	0.0396	0.0282**
	[−1.63]	[5.86]	[6.22]	[2.88]	[5.41]	[3.13]			[1.44]	[2.09]
LEQ	0.0031***	0.0361**	0.0015***	0.0090***	0.0297***	0.0261***	0.1506***	0.2129***	0.740***	0.0201**
	[2.73]	[2.12]	[10.42]	[10.74]	[12.93]	[7.28]	[10.66]	[5.65]	[2.61]	[9.56]
LPOP	0.7301***	−1.1399***	−0.0204***	−0.1463***	−0.7455***	−1.4080***	−1.3273***	−1.2716***	−0.1695	−0.1228*
	[6.74]	[−4.02]	[−2.56]	[−4.74]	[−16.20]	[−10.09]	[−19.25]	[−7.83]	[−1.20]	[−1.84]
LBP	−0.1761***	−1.3493***	−0.0703***	−0.1701***	0.7512***	0.6773***	−0.8123***	−0.6832***	−0.4742***	−0.5766***
	[−2.95]	[−2.91]	[−4.84]	[−15.60]	[7.22]	[6.98]	[−14.83]	[−8.55]	[−3.87]	[−8.40]
*LBP*LEQ*	0.1735***	1.3973***	0.0748***	0.0948***	0.7548***	0.7046***	0.8650***	0.7237**	0.5188***	0.6334***
	[2.94]	[3.01]	[5.15]	[5.15]	[17.22]	[7.29]	[15.93]	[8.60]	[4.24]	[8.88]
LCA	0.0368***	0.0216*	0.0039*	0.0167***	–	–	–	–	–	–
	[3.89]	[1.77]	[1.78]	[3.93]						
LGINI	−0.0257*	−0.9421***	–	–	−1.2531***	−0.6591***	–	–	–	–
	[−1.71]	[−2.53]			[−3.66]	[−10.79]				
LPRI	−0.0293*	−0.5729***	–	–	−0.0194	−0.0778*	−0.3187***	−0.294***	–	–
	[−1.99]	[−2.80]			[−1.10]	[−1.87]	[−13.18]	[−5.72]		
LGDP	0.0374*** [2.66]	0.1325*	–	–	–	–	0.0268***	0.0226***	–	–
		[1.99]					[14.13]	[8.64]		
LUNE	−0.0237**	−0.0944***	–	–	–	–	–	–	−0.1378***	−0.1383***
	[−2.03]	[−2.55]							[−5.73]	[−6.96]
	Model criteria									
Hansen	0.589	0.469	0.557	0.722	0.178	0.643	0.823	0.665	0.399	0.505
AR(1)	0.087*	0.008***	0.001***	0.050**	0.068*	0.006***	0.008***	0.022**	0.001***	0.022**
AR(2)	0.208	0.121	0.376	0.977	0.198	0.176	0.372	0.111	0.252	0.271
Difference-Hansen	–	0.917	–	0.191	–	0.997	–	0.983	–	0.917
#instruments	33	33	33	33	33	33	33	33	33	33
#Groups	56	56	56	56	56	56	56	56	56	56
#Obs	336	336	336	336	336	336	336	336	336	336
	Marginal effect									
Mean	0.6005	4.9052	0.2645	0.0647	4.1298	3.8312	3.0595	2.5562	1.8481	2.2586
Min	−1.5835	−12.6838	−0.6771	−0.9391	−5.3715	−5.0382	−7.8290	−6.5536	−4.6825	−5.7146
Max	0.9176	7.4590	0.4012	0.4275	5.5093	5.1190	4.6405	3.8789	2.7962	3.4162
Threshold	2.7593	2.6265	2.5596	6.0153	0.3696	0.3824	2.5576	2.5703	2.4944	2.4851

Note: Asterisks *, **, and*** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [] stand for t-statistic. The values of the Hansen and AR tests stand for the p-value. The model is estimated using the two-step model with robust estimation.

$$\begin{bmatrix} FS_{i1} & 0 & 0 & \dots & 0 & \dots & 0 \\ 0 & FS_{i1} & FS_{i2} & \dots & 0 & \dots & 0 \\ \cdot & \cdot & \cdot & \dots & \cdot & \dots & \cdot \\ 0 & 0 & 0 & \dots & FS_{i1} & \dots & FS_{iT-2}, \end{bmatrix}, \tag{11}$$

where rows in Eq. (11) correspond to the first-differenced equations for the period $t = 3, 4, \ldots, T$ for individual, and exploit the moment condition as shown in Eq. (12) below:

$$E\,[Z_i' \Delta v_i] = 0 \; for \;\; i = 1,\, 2,\, \ldots, N \tag{12}$$

While the deail can be obtained from [70], based on the moment conditions, GMM minimizes the discrepancy between the sample moments and the values in probability, giving the GMM estimator for β as follows:

$$\hat{\beta}_d = (\Delta FS_{-1}' Z W_N Z' \Delta FS_{-1})^{-1} \Delta FS_{-1}' Z W_N Z' \Delta FS$$

Using the optimal weight matrix expressed as in Eq. (13) :

Table 6
Regression analysis [DV = *LGFSI*].

	DIFF-GMM	SYS-GMM
Constant	–	2.6364***
		[15.16]
LGFSI$_{t-1}$	−0.51976***	−0.64137***
	[−11.37]	[−10.45]
LAL	0.1471*	0.1834*
	[1.86]	[1.4]
LEQ	2.2723***	0.93995*
	[3.03]	[1.82]
LPOP	−11.7475*	−5.4903***
	[−1.80]	[−3.43]
LBP	−2.8202**	−3.6374*
	[−2.31]	[−1.85]
*LBP*LEQ*	1.0474**	1.7137***
	[2.23]	[2.66]
LCA	2.7863***	0.5438*
	[6.13]	[1.69]
LGINI	−0.0452*	- 2.1715***
	[−2.02]	[−2.88]
LPRI	−3.4069***	−1.0570*
	[−3.30]	[−1.98]
LGDP	5.8985***	2.9953***
	[3.13]	[6.27]
LUNE	−3.9855**	−0.2159*
	[−2.19]	[−1.92]
	Model criteria	
Hansen	0.899	0.263
AR(1)	0.010***	0.001***
AR(2)	0.129	0.610
Difference-Hansen	–	0.869
#instruments	33	33
#Groups	44	44
#Obs	264	264
	Marginal effect	
Mean	0.4493	1.7119
Min	−10.055	−15.4753
Max	3.7824	7.1654
Threshold	14.7696	8.3523

Note: Asterisks *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [] stand for t-statistics. The values of the Hansen and AR tests stand for the p-value. The model is estimated using the two-step model with robust estimation.

$$W_N = \left[\frac{1}{N}\sum_{i=1}^{N}(Z_i'\Delta\hat{\nu}_i\Delta\hat{\nu}_i'Z_i)\right]^{-1} \tag{13}$$

This is known as two-step GMM estimator. Besides that, under the homoscedasticity of the error disturbances, the particular structure of the first-differenced model implies that an asymptotically equivalent GMM estimator can be obtained in one-step using the weight matrix as Eq. (14):

$$W_{1\,N} = \left[\frac{1}{N}\sum_{i=1}^{N}(Z_i'HZ_i)\right]^{-1}, \tag{14}$$

where H is a *(T-2)* square matrix with 2′s on the main diagonal, −1′s on the first off-diagonal and zero elsewhere. Notice that W_{1N} does not depend on any estimated parameters.

It is also important to take note that the generated instruments could be extremely weak, which leads to the well-known weak instrumental problems of inconsistency and inaccurate inference. For an example, if *FS* is extremely persistent, the lagged level of *FS* will be weak instruments for ΔFS in first- difference GMM. This problem can be solved using system GMM approach by [73]. Their modification of the estimator includes lagged level as well as lagged differences instead of transforming the regressors as instruments to make it exogenous on the fixed effect. The additional moment's conditions for the system GMM are as Eq. (15) and Eq. (16):

$$E\,[(FS_{i,t-s} - FS_{i,t-s-1})(\mu_i + \nu_{i,t}) = 0 \ \text{for}\, s = 1 \tag{15}$$

$$E\,[(X_{i,t-s} - X_{i,t-s-1})(\mu_i + \nu_{i,t}) = 0 \text{ for } s = 1 \tag{16}$$

The additional moment conditions are employed to generate consistent and efficient parameter estimates based on GMM procedure. Moreover, for either first-difference GMM or system GMM, the degree of serial correlation of ν will determine the validity of instruments based upon the dependent variable. [70] devise a test of serial correlation based on first-difference moment conditions. Under serial correlation test, rejection of the null of the absence of the first-order serial correlation AR (1) and failure to reject the absence of the second-order serial correlation AR (2) are valid and the models are correctly specified. Secondly, given the surfeit of instruments, it is natural to consider overidentification test. The overidentification restriction is verified with Hansen test [72].

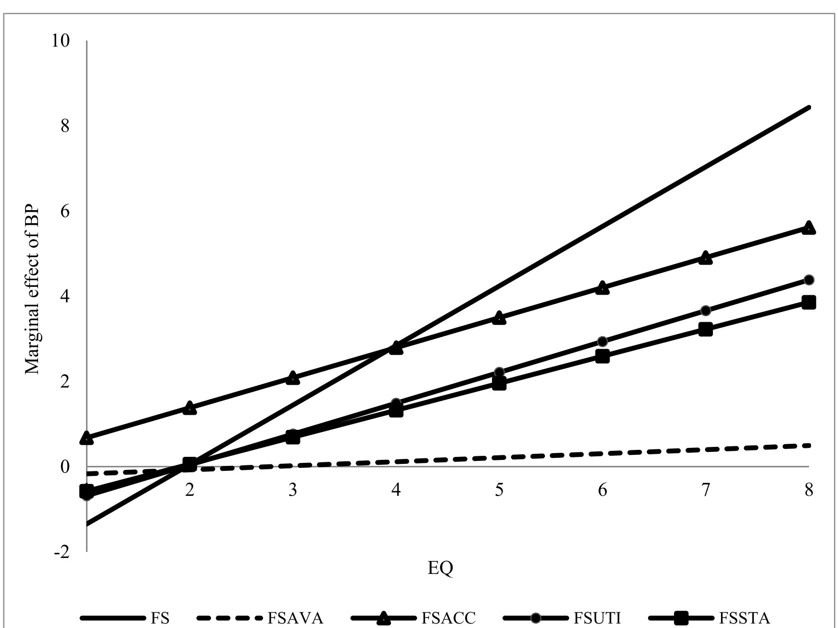

Fig. 4. The marginal effect of *BP* on *FS,* conditional upon *EQ*.

3.3. Data sources

In this study, we employ a panel sample of 51 developing countries over the period 2011 to 2016 dictated by the availability of data on food security and biofuels production. The list of developing countries is taken from [17] are shown in Table 1.

Additionally, the present study uses various data sources to obtain the datasets of developing countries from 2011–2016 as summarized in Table 2.

On the measurement of each variable, the percentage of population growth is used as a proxy for population. We utilize the percentage of land area and biofuels production as measures of arable land and biofuels, respectively. As for the other control variables, we use the percentage share of total credit to proxy credit to agriculture, the index of GINI for income inequality, the price of food for price, *real GDP* for economic growth, and the percentage of total labor force for unemployment. For environmental quality, instead of directly apply CO_2 emission metric tons per capita, we reverse the measurement so that it can reflect environmental quality, by which the higher EQ will imply better quality. In doing so, we design the following Eq. (17):

$$EQ_{CO2} = \left(1 - \frac{CO_2}{World\ Worst\ CO_2}\right) \times 100 \tag{17}$$

where *World Worst* CO_2 is represented by the world highest emission level of 10,357 million metric tons in China in year 2017.

The measurement of food security index is a bit complicated as FAO does not provide a single index to represent its definition of food security. In this study, we construct the index based on the average of four components or dimensions of food security defined by FAO, namely the index of food availability (*FSAVA*), food accessibility (*FSACC*), food utilization (*FSUTI*), and food stability (*FSSTA*). Each dimension has its own but different set of elements. For instance, food availability (*FSAVA*) has 5 elements. Before we can construct the food security index based on the 4 dimensions, we have to ensure that all elements in each dimension are in the same format. To do so, we establish each dimension in the form of index. To summarize, food security index is the average index of 4 food security dimensions and each dimension is an average index of all elements under each of the dimensions. The detail explanation is available in Appendix A.

Although there are other food security index such as the Global Food Security Index (GFSI) by DuPont, this study opts for FAO framework but with slight modification. The GFSI index score is based on the four broad dimensions that measure consumers' ability to purchase food, availability that measures the sufficiency of the national food supply, quality and safety that measures variety and nutritional quality of average diets and safety of the food supply and natural resources that ensures country's exposure to the impacts of changing climate. However, [79] indicate that GFSI does not describe the real food security situation. This is because GFSI tends to measure the conditions for food security or an enabling environment for food security instead of actual food security level [79]. Besides that, according to FAO definition, food security is people-centered, while GFSI is country-centered and fails to provide information about food security status of vulnerable households [79]. Among the modification that we introduce in constructing FS index based on FAO framework is to remove imports component and political stability.

According to the descriptive statistics indicated in Table 3, the largest food security index (*FSAVG*) is 59.180 and could be represented by the case of Thailand in 2013, whereas the lowest food security is observed at 35.79 and potentially refers to Sudan in 2011. What is interesting to note is the relatively huge gap between the measure constructed by this study, which is *FSAVG* and global food security index (*GSFI*) by World Bank. *GSFI* tends to underestimate the severity of the issue as the mean demonstrates that the level of food security is likely to be at satisfactory level if above average or more than 50 percent rule is applied.[5] Another important point is about the huge discrepancy among the dimensions of food security, with food utilization has the highest mean (68.7) and food stability has been at critical condition with mean of 22.8 only. In addition, Brazil is the largest producer of biofuels as described by the maximum score of biofuels (7.398) relative to the lowest size of biofuels production (0.086) in Bosnia and Herzegovina in 2012. What intriguing point is that the mean of biofuels production is merely 2.811, skewed towards lower end of the production level. This may imply that there is still huge potential for the industry to grow as well as the incapability of biofuels to effectively improve the environmental quality.

Besides that, the correlation matrix for the key variables is offered in Table 4. As estimated, food security has a positive correlation with arable land, which supports the existing literature that arable land, is among the main resources to farmers in order to produce more food. On the other hand, the correlation between food security and population growth, environmental degradation, biofuels production is highly negatively. In summary, we do not see any serious issue of multicollinearity in this study.

4. Results and discussions

The results of GMM estimates of the dynamic equation are shown in Table 5. The validity of instruments that give a set of over-identifying restriction has been verified with the standard Hansen test, which confirm that in all cases our set of instruments are valid. The correct statistical specification of the models has been additionally checked with tests for the presence of first and second order residual autocorrelation. The results of AR9(1) and AR(2) indicate that there is evidence of first order but not second order autocorrelation, implying that the models are correctly specified. Besides that, the results of the *Difference-Hansen* statistic also reported as a test of the additional moment conditions used in the system GMM estimators relative to the corresponding first-difference GMM estimator. The *Difference-Hansen* shows that system GMM estimates appear to be reasonable than first-GMM.

In respect to environmental quality, the results in Table 5 demonstrate that environmental quality has a significant positive impact on food security in all models, which are supported by the past studies [23, 35, 25]. Reduction in carbon dioxide emissions have been associated with a decrease in global temperature, and will have favorable impacts on agricultural production. Under optimum temperature regime, the growing seasons, soil moisture conditions and quality of the yield will be positively affected. Beyond that, to the extent that food production is increased by better environmental quality, price of food will decrease [23, 35, 25]. In the presence of lower food price, the buying power of people will be higher and allow people to obtain food regularly. An increase in accessibility of food would also mean higher intake of nutritious food. Improved environmental quality may also decrease the pressure on food stability due to little uncertainty in phenomena such as flooding, hurricanes, and drought, associated with greater risks of landslide and erosion [34].

Meanwhile, the effect of biofuels on food security is observed to be significantly negative in all models, as expected and consistent with [11, 47, 48], to mention only few. Although biofuel development has received growing attention as a mean to reduce carbon dioxide emission and support energy security all over the world, one of the most critical problems with biofuel production is that it poses threat to food security. This is because biofuels are primarily produced from food crops such as sugar cane, maize, rapeseed and others, where it may reduce the of proportion of agricultural resources for food productions and food-related uses [47, 48]. Consequently, the overall availability of

[5] This reminds us the need to relook at the measurement of food security index. GSFI is still used for robustness test in this study, albeit the issue.

food is affected by an increment in demand for agricultural crops by biofuel production. Competition between biofuels and food production will also trigger food price to go up. The conversion of high quality and suitable food crop to biofuels production may adversely affect the ability to consume nutrient food, and in turn would result in increasing undernourishment and lower food utilization. Therefore, the development of biofuels may substantially reduce global food security.

When biofuels industry is currently threatening food security level, should we propose that biofuels production should be abandoned? As shown in Table 3, most developing countries have small and negligible size of biofuels industry. The current size of biofuels industry or production may not be able to produce the desirable outcome, in terms of reduction in CO_2. But it is expected to be more successful in lowering the CO_2, and eventually preserving climate from further deteriorating or unfavorable to crop productions, should the volume can be extended [8, 57]. As been discussed about the effect of environmental quality on food security, once the size of biofuels can minimize CO_2 emission and environmental quality is at higher possible level, climate condition can be promoted or maintained, then crop productions are expected to be supporting food security problem. The results of interaction term between biofuels and environmental quality (*LBP*LEQ*) are found to be positively significant in all models, justifying the validity of out intuition. The positive and statistically significant coefficient of the interaction term between measure of biofuels production and environmental quality indicates that the relationship between biofuels and food supply varies across countries depending on the degree to which the biofuels sector is developed and the resulted environmental quality. These results point out to the significant moderating effect of environmental quality on the relationship between biofuels and food supply. In other words, the negative effect of biofuels production may disappear as country's environmental quality increases.

When examining the relationship between biofuels and food security conditional upon the level of environmental quality, it is essential to compute the turning point. This is important in order to explain why there is a substantial difference in minimum threshold values that need to be achieved by developing countries in order to transform the negative effect of biofuels on food supplies into positive influence. The estimated threshold values are summarized at the bottom of Table 5 and these threshold values are quite different among the dimensions of food security. The threshold values of biofuels in developing countries, for example, implies that the negative impact of biofuels can be transformed into positive impact if the environmental quality has achieved a minimum improvement level of 2.75 percent. Thus, the positive impact of biofuels production is not unconditional, but is likely to depend upon the improvement of the environmental quality.

Having established the existence of a moderating effect, the following step is to compute the marginal effect [80]. We compute the new standards error to evaluate the significance of the marginal effect of changes in food supply due to changes in biofuels production. Fig. 4 illustrates the increasing marginal effects for the four dimensions of food security, namely the index of food availability (*FSAVA*), food accessibility (*FSACC*), food utilization (*FSUTI*), and food stability (*FSSTA*) as well as the aggregate measure of food security *(FS)*. All dimensions in Fig. 4 demonstrates that when the level of environmental quality improves, partly could be due to biofuels production, the marginal effect of biofuels is getting positively higher. The marginal effect reported in Table 4 shows that biofuels production and environmental quality are positive at mean and maximum levels, and statistically significant but weak at the minimum level where marginal effect is negative. For example, each additional percentage point of biofuels benefits 0.60 percentage points of annual growth in food supply at mean level. More essentially, the marginal effect at the maximum level has a greater beneficial effect of biofuels on food security, which is 0.91 and greater than when environmental quality is at the mean level. This implies that the higher level of biofuels production tends to increase food supply as high biofuels will also contribute to preservation of environmental quality.

The other variables are also found to have their results as expected. We do not discuss them here to conserve space. The full-length original working paper, which includes detail explanation on each result is available upon request. While we disagree with GSFI, we still employ it as an alternative measure of food security to check the consistency and robustness of the above results. Using the alternative measure of food security, our results in Table 6 confirm that the negative impact of biofuels can be transformed into a positive one as country's environmental quality improves. Turning to the threshold results themselves, we find evidence of a significant threshold for biofuels production. The outcomes again highlight a better level of environmental quality is required before the benefits of biofuels can be realized. Overall, the result of alternative measure of food security is consistent with findings reported in Table 5 and in line with the notion that environmental quality plays a greater role in moderating the negative effect of biofuels on food supply.

We further check the robustness of the results by: (i) using full elements introduced by FAO in Table B.1, (ii) using various indicators of environmental quality, namely methane (*CH_4*), nitrous oxide (*N_2O*) and fluorinated gases (*FGAS*) in Table B.2 for the aggregate FS and in Table B.3 for each domain of FS, (iii) using consistently all explanatory variables in the dimensional models in Table B.4 , (iv) adding two additional explanatory variables, namely temperature and natural disaster in Table B.5, and (v) using Distance Approach in Table B.6. The findings are similar to the earlier results and shown in Appendix B.

5. Conclusion

This paper examines the effect of biofuels production on food security, given the level of environmental quality in developing countries for the period between 2011 and 2016. We carry out an empirical investigation using GMM estimator, where food security is measured by a total of 18 indicators grouped in 4 dimensions. More specifically, this study empirically examines whether food security increases as the level of biofuels production is at a stage of capable to improve environmental quality. Our analysis provides supporting evidence that the coefficient of *BP*EQ* is positive and statistically significant. This result implies that the negative effect of biofuels production on food security declines as a country's environmental quality improves. As a result, it is important to promote biofuel development as it can bring better environment quality and greater production of food.

In this regard, government in developing countries may need to ensure that any policies promoting biofuels are consistent with reducing emission as well as making a contribution to food production. For example, government can initiate the development of the biofuel sector by setting up, for instance, a government-linked company or to offer significant incentives to private sectors to get involved in the development process. In addition, developed countries should continue to provide financial support to developing countries for the adaptation and use of biofuels and other new environmental friendly technologies to move developing countries away from food insecurity problem [3]. The easiest way to do this is by encouraging multinational corporations (MNCs) to join the projects, particularly to those developing countries which own huge reserves of resources related to biofuels production. Government should also promote development of second and third generations of biofuels, which certainly free from food competition as well as capable in preserving environmental quality, and support agriculture production. Although the second and third generations of biofuels are showing no significant progress so far in the case of developing countries, this study partly hints that the two generations need be taken up seriously especially when the assumption of environmental friendly agricultural practices are violated.

Nevertheless, our finding should also be treated cautiously as our study is meant to justify the need to continue the effort to promote biofuel industry as one of the renewable energies without sacrificing food security issue. In doing so, we put a strict assumption that agricultural activities, which are the main source of food security, are conducted in the most environmental friendly. The real fact is that deforestation or expansion of agricultural land will always be accompanied by various environmental issues [81]. Hence, government should also pay attention on improving agricultural techniques so that it would be more environment-promoting.

Dedclaration of Competing Interest

The authors declare that they have no conflict of interest.

Appendix A

To provide a more accurate measurement of food security, this study excludes two elements in the calculation of food security.[6] In constructing the index of food security, there are three steps. Firstly, we need to transform each element within each of the four major dimensions (i.e. availability, accessibility, utilization and stability) of food security by FAO to be similar in range, which is set to be between 0 and 100. To normalize the scores, we refer to the methodology employed by United Nation in the construction of human development index as follows:

$$FS_{element} = \frac{Country\ Index - World\ Minimum}{World\ Maximum - World\ Minimum} \times 100$$

The world maximum value will be proxied by the United States (US) by an assumption that the US is the world most secured country in terms of food. The world minimum will be represented by Sudan as Sudan is the world hungriest country (World Bank, 2018).

Secondly, we create four separate indices for each of the four dimensions. This is done by taking the average of all indices of elements, which belong to each dimension. For instance, as shown in Table A.1, food availability index (*FSAVA*) comprises 5 elements and therefore, the index is represented by the average of 5 indices as the equation below:

$$FSAVA = (FS_{element1} + FS_{element2} + \ldots)/5$$

The last step is to calculate the composite food security index by taking the average of four dimensions as follows:

$$FS = (FSAVA + FSACC + FSUTI + FSSTA)/4$$

where *FSACC* is food accessibility index, *FSUTI* stands for food utilization index and *FSSTA* denotes food stability index. In this case, we add all these four dimensions together and then divid by 4 (total dimensions). Therefore, the food security index is expressed as a value between 1 and 100, where the higher the value of food security, the better the level is.

Table A.1
The FAO framework of food security.

Dimension	Source
Availability	
Average dietary energy supply adequacy	FAOSTAT
Average value of food production	FAOSTAT
Share of dietary energy supply derived from cereals, roots and tubers	FAOSTAT
Average protein supply	FAOSTAT
Average supply of protein of animal origin	FAOSTAT
Access	
Gross domestic product per capita (in purchasing power equivalent)	World Bank
Prevalence of undernourishment	FAOSTAT
Depth of the food deficit	FAOSTAT
Stability	
Food per capita	FAOSTAT
Percent of arable land equipped for irrigation	FAOSTAT
Political stability and absence of violence/terrorism	World Bank
Per capita food production variability	FAOSTAT
Per capita food supply variability	FAOSTAT
Utilization	
Percentage of population with access to improved drinking water sources	World Bank
Percentage of population with access to sanitation facilities	World Bank
Prevalence of obesity in the adult population (18 years and older)	GHO
Prevalence of anemia among women of reproductive age (15–49 years)	World Bank

Note: FAOSTAT indicates the food and agriculture organization corporate statistical database; GHO indicates Global Health Observatory.

[6] Nevertheless, we still provide the results based on complete FAO framework for stability test in Appendix B.

Appendix B

Tables B.1–B.6

Table B.1
Regression results based on complete FAO framework [DV = LFS].

	FSAVG		FSAVA		FSACC		FSUTI		FSSTA	
	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM
Constant	–	0.045***	–	0.092***	–	0.014***	–	0.0319***	–	0.0993***
		[2.02]		[3.95]		[2.71]		[7.28]		[10.23]
LFS_{t-1}	−0.067**	0.067***	1.508***	0.2465***	6.947**	1.922**	2.129**	0.593*	0.182*** [7.87]	0.1900***
	[2.84]	[2.89]	[2.75]	[9.81]	[2.15]	[2.27]	[2.17]	[1.93]		[8.79]
LAL	0.709***	0.710***	1.555	0.145*	0.975*	0.741*	–	–	0.515*	0.897*
	[5.29]	[5.46]	[1.78]	[1.99]	[1.98]	[1.97]			[1.94]	[1.89]
LEQ	0.348	0.349**	0.193*	3.763***	0.363**	0.103**	4.152***	3.719***	0.740***	0.079**
	[1.71]	[2.39]	[1.84]	[2.51]	[2.12]	[2.31]	[3.17]	[3.59]	[2.61]	[2.25]
LPOP	0.118***	−0.113*	−1.151***	−0.904**	−0.366**	−0.229***	−0.174	−0.589***	−0.825***	−0.767***
	[6.48]	[−1.87]	[−2.47]	[−2.30]	[−2.11]	[−2.53]	[−1.65]	[−6.47]	[−2.78]	[−2.74]
LBP	−0.281**	−0.254**	−0.096**	−0.135***	0.217***	0.153**	−0.465	−0.293***	−0.352*	−0.323***
	[−2.23]	[−2.15]	[−2.10]	[−3.55]	[2.52]	[2.32]	[−1.78]	[−2.42]	[−2.09]	[−2.55]
*LBP*LEQ*	0.196*	0.919***	0.064**	0.087***	0.199*	0.619***	0.294**	0.271**	0.182*	0.182***
	[1.89]	[8.53]	[2.10]	[4.33]	[2.02]	[5.33]	[2.03]	[2.15]	[1.86]	[3.29]
LTR	0.295***	0.299**	1.421	3.421*	–	–	–	–	–	–
	[4.98]	[2.37]	[1.51]	[1.91]						
LCA	0.160**	0.158***	0.145***	0.162**	–	–	–	–	–	–
	[2.19]	[3.10]	[2.99]	[2.10]						
LGINI	−0.031***	−0.032***	–	–	−2.730	−4.194***	–	–	–	–
	[−11.91]	[−3.95]			[−1.56]	[−9.42]				
LPRI	−0.108***	−0.116***	–	–	−0.2567**	−0.450***	−0.101***	−0.420***	–	–
	[−5.07]	[−2.68]			[−2.10]	[−4.14]	[−2.97]	[−2.42]		
LGDP	0.105	0.103***	–	–	–	–	0.788*	0.237***	–	–
	[1.70]	[3.88]					[1.93]	[2.76]		
LUNE	−0.153***	−0.160***	–	–	–	–	–	–	−0.123***	−0.123***
	[−3.77]	[−2.55]							[−3.78]	[−3.71]
LEX	−0.133***	−0.130***	–	–	–	–	–	–	0.865	−0.688*
	[−3.02]	[−4.09]							[1.68]	[−2.24]
Model criteria										
Hansen	0.492	0.501	0.223	1.000	0.178	0.212	0.227	0.225	0.191	0.139
AR(1)	0.015***	0.009**	0.084*	0.037**	0.097*	0.097*	0.039**	0.014**	0.035**	0.017***
AR(2)	0.143	0.284	0.681	0.996	0.748	0.830	0.859	0.120	0.187	0.890
Difference-Hansen	–	0.479	–	0.980	–	0.938	–	0.961	–	0.995
#instruments	33	33	33	33	33	33	33	33	33	33
#Groups	56	56	56	56	56	56	56	56	56	56
#Obs	336	336	336	336	336	336	336	336	336	336
Marginal effect										
Mean	0.5963	3.8594	0.1905	0.2544	0.6737	2.9236	0.8509	0.9177	0.4626	0.4916
Min	−1.8709	−7.7087	−0.6152	−0.8407	−1.3972	−4.8682	−2.8500	−2.4936	−1.8283	−1.7993
Max	0.545	5.5391	0.3074	0.4134	1.4714	4.0550	13,883	1.4130	0.7953	0.8243
Threshold	4.1938	1.3183	4.4817	4.7195	0.3360	0.7810	4.8627	2.9482	6.9178	5.8985

Note: Asterisks *, **, and*** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [] stand for t-statistic. The values of the Hansen and AR tests stand for the p-value. The model is estimated using the two-step model with robust estimation.

Table B.2
Regression analysis for various indicators of environmental quality [DV = *LFS*].

	FSAVG *EQ = CH4*	*EQ = N2O*	*EQ = FGAS*
Constant	3.0441***	2.9226***	1.1948***
	[11.40]	[14.57]	[4.98]
LFS_{t-1}	−0.8051***	−0.7956***	−0.7989***
	[−21.36]	[−20.75]	[−22.38]
LAL	0.0020*	0.0037*	0.0017*
	[1.74]	[1.85]	[1.62]
LEQ	0.0122***	0.0133***	0.0063***
	[4.61]	[4.94]	[2.82]
LPOP	−0.1009***	−0.1171***	−0.0656***
	[−3.80]	[−4.81]	[−2.64]
LBP	−0.0226***	−0.0233***	−0.0093***
	[−5.28]	[−5.29]	[−2.70]
*LBP*LEQ*	0.0113**	0.0098***	0.0091***
	[2.76]	[2.89]	[2.84]
LCA	0.0064*	0.0073*	0.0043*
	[1.75]	[1.96]	[1.81]
LGINI	−0.0645***	−0.0727***	−0.0343
	[−2.49]	[−3.21]	[−1.51]
LPRI	−0.0208*	−0.0180*	−0.0158*
	[−2.06]	[−1.73]	[−1.75]
LGDP	0.0104*	0.0154***	0.0196*
	[1.68]	[2.23]	[1.85]
LUNE	−0.0106*	−0.0103*	−0.0172***
	[−1.87]	[−1.87]	[−3.27]
	Model Criteria		
Hansen	0.161	0.124	0.192
AR(1)	0.000***	0.000***	0.000***
AR(2)	0.145	0.150	0.173
Difference-Hansen	0.827	0.915	0.958
#instruments	33	33	33
#Groups	56	56	56
#Obs	336	336	336
	Marginal effect		
Mean	0.0138	0.0181	0.0200
Min	−0.1143	−0.1028	−0.0831
Max	0.0486	0.0385	0.0481
Threshold	7.3891	10.7785	2.7787

Note: Asterisks *, **, and*** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [] stand for t-statistic. The values of the Hansen and AR tests stand for the p-value. The model is estimated using the two-step model with robust estimation.

Table B.3
Regression analysis of dimensional model for various indicators of environmental quality [DV = *LFS*].

	FSAVA			FSACC			FSUTI			FSSTA		
	CH4	*N2O*	*FGAS*	*CH4*	*N2O*	*FGAS*	*CH4*	*N2O*	*FGAS*	*CH4*	*N2O*	*FGAS*
Constant	2.0763***	1.5302***	2.2651***	1.6394***	1.5188***	2.8793***	1.0798***	1.8693***	1.1746***	2.7499***	2.8596***	1.7165***
	[4.89]	[4.29]	[4.48]	[2.62]	[2.53]	[2.59]	[2.98]	[4.24]	[4.61]	[4.68]	[3.48]	[2.67]
LFS_{t-1}	- 1.0103***	−1.0218***	−0.9886***	−0.9693***	−0.9274***	−0.9270***	−0.9123***	−0.4969***	−0.4636***	−0.5106***	−0.5330***	−0.4022***
	[−16.49]	[−18.69]	[−4.06]	[−6.77]	[−5.17]	[−9.57]	[−2.35]	[−16.79]	[−16.59]	[−17.41]	[−19.14]	[−14.54]
LAL	0.0030***	0.0032***	0.0006	0.0156***	0.0248***	0.0209***	–	–	–	0.1884***	0.2199***	0.1023***
	[5.54]	[5.34]	[1.54]	[12.42]	[6.34]	[4.79]				[5.86]	[6.09]	[2.74]
LEQ	0.0063**	0.0049***	0.0067***	0.0036***	0.0019*	0.0043*	0.0973***	0.0783***	0.1472***	0.1487***	0.0381***	0.2876***
	[8.69]	[5.77]	[8.44]	[4.29]	[2.05]	[1.84]	[4.95]	[6.20]	[4.08]	[5.09]	[2.48]	[5.34]
LPOP	−0.0451***	−0.0396***	−0.0164***	−0.0916***	−0.0775***	−0.1047***	−0.5015*	−0.6150***	−0.5747*	−0.8949***	−0.4645***	−0.2336*
	[−11.09]	[−8.36]	[−3.08]	[−2.81]	[−2.38]	[−2.69]	[−2.18]	[−3.06]	[−2.15]	[−5.09]	[−2.28]	[−1.87]
LBP	−0.0075***	−0.0073***	−0.010**	0.0292***	0.0284***	0.0269***	−0.1639***	−0.1527***	−0.1835**	−0.0281***	−0.0180*	−0.0434***
	[−8.6]	[−6.80]	[−10.03]	[3.36]	[3.82]	[4.35]	[−4.38]	[−5.24]	[−3.66]	[−3.88]	[−1.80]	[−4.34]
*LBP*LEQ*	0.0099***	0.0063**	0.0082*	0.0120*	0.0132***	0.0124***	0.1076*	0.0980**	0.1089*	0.0185***	0.0096***	0.0199*
	[2.57]	[2.99]	[2.48]	[1.96]	[4.08]	[3.56]	[2.14]	[2.32]	[1.87]	[2.00]	[2.72]	[1.93]
LCA	0.0095***	0.011***	0.0026***	–	–	–	–	–	–	–	–	–
	[6.85]	[7.21]	[4.29]									
LGINI	–	–	–	−0.1432***	−0.1647*	−0.1488***	–	–	–	–	–	–
				[−5.56]	[−6.27]	[−5.43]						
LPRI	–	–	–	−0.0183*	−0.0125*	−0.0230*	−0.3548***	−0.3638***	−0.3054***	–	–	–
				[−1.84]	[−1.78]	[−1.74]	[−3.38]	[−3.97]	[−2.79]			
LGDP	–	–	–	–	–	–	0.0560*	0.0803*	0.0113 [1.57]	–	–	–
							[1.85]	[1.84]				
LUNE	–	–	–	–	–	–	–	–	–	−0.0778*	−0.0963*	−0.0837*
										[−1.90]	[−1.73]	[−1.75]
	Model criteria											
Hansen	0.482	0.377	0.226	0.671	0.701	0.742	0.231	0.174	0.253	0.187	0.421	0.191
AR(1)	0.003***	0.002***	0.001***	0.047**	0.087*	0.074*	0.005***	0.005***	0.003***	0.004***	0.010**	0.012**
AR(2)	0.333	0.112	0.406	0.200	0.206	0.311	0.410	0.364	0.668	0.677	0.153	0.767
Difference-Hansen	0.640	0.999	0.759	0.826	0.519	0.884	0.725	0.914	0.824	0.900	0.898	0.996
#instruments	33	33	33	33	33	33	33	33	33	33	33	33
#Groups	56	56	56	56	56	56	56	56	56	56	56	56
#Obs	336	336	336	336	336	336	336	336	336	336	336	336
	Marginal effect											
Mean	0.0145	0.0130	0.0164	0.0679	0.0709	0.0668	0.1827	0.1630	0.1673	0.0315	0.0129	0.0207
Min	−0.0878	−0.0584	−0.0765	−0.0682	−0.0787	−0.0737	−1.0367	−0.9476	−1.0669	−0.1782	−0.0959	−0.2048
Max	0.0549	0.0324	0.0417	0.1048	0.1116	0.1051	0.5144	0.4651	0.5030	0.0885	0.0425	0.0820
Threshold	2.1331	3.1859	3.3855	0.0877	0.1163	0.1143	4.5870	4.7501	5.3926	4.5673	6.5208	8.8543

Note: Asterisks *, **, and*** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [] stand for t- statistic. The values of the Hansen and AR tests stand for the p-value. The model is estimated using the two-step model with robust estimation.

Table B.4
Regression analysis of dimensional model for all control variables [DV = *LFS*].

	FSAVA		FSACC		FSUTI		FSSTA	
	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM
Constant	–	.298 ***	–	3.2420***	–	4.3222***	–	2.7461***
		[17.27]		[13.07]		[16.63]		[14.05]
LFS_{t-1}	0.646***	0.923 ***	0.956 ***	0.997***	0.061***	0.985***	0.372*** [5.50]	0.918***
	[3.51]	[9.23]	[16.77]	[15.48]	[2.78]	[14.79]		[18.17]
LAL	0.001 ***	0.002*	0.010 *	0.003**	0.005**	0.049**	0.007*** [2.95]	0.009*
	[2.56]	[1.71]	[1.72]	[2.30]	[2.15]	[2.29]		[1.82]
LEQ	0.004 *	0.013 *	0.005*	0.045***	0.030*	0.008**	0.006***	0.052*
	[1.89]	[1.97]	[1.51]	[2.42]	[1.86]	[2.20]	[2.40]	[1.96]
LPOP	−0.040 ***	−0.020 *	−0.011***	−0.022***	−0.008*	−0.034**	−0.121	−0.035*
	[−5.34]	[−2.03]	[−2.51]	[−3.15]	[−1.97]	[−2.16]	[−1.83]	[−2.09]
LBP	−0.009 ***	−0.042 ***	0.038**	0.040***	−0.008**	−0.002***	−0.189*	−0.305***
	[−2.89]	[−2.37]	[2.22]	[4.08]	[−2.31]	[−2.72]	[−1.77]	[−2.54]
*LBP*LEQ*	0.013 ***	0.039 **	0.033*	0.038***	0.022***	0.012**	0.173*	0.312***
	[1.69]	[2.29]	[1.92]	[3.79]	[5.24]	[2.17]	[1.87]	[2.61]
LEXP	−0.007***	−0.002 ***	−0.013***	−0.004***	−0.042***	−0.051***	−0.007**	−0.002**
	[−2.95]	[−2.65]	[−3.11]	[−2.70]	[−3.24]	[−5.63]	[−2.24]	[−2.09]
LCA	0.002 ***	0.010 ***	0.085***	0.001*	0.002**	0.050**	0.009**	0.079***
	[3.24]	[4.18]	[2.51]	[1.81]	[2.17]	[2.30]	[2.38]	[3.69]
LGINI	−0.021**	−0.054***	−0.037**	−0.010**	−0.091***	−0.075***	−0.353**	−0.003**
	[−2.33]	[−3.00]	[−2.19	[−2.23]	[−5.91]	[−3.37]	[−2.15]	[−2.10]
LPRI	−0.017***	−0.007***	−0.021*	−0.004*	−0.056**	−0.076***	−0.018**	−0.018**
	[−3.79]	[−2.94]	[−2.02]	[−2.04]	[−2.18]	[−3.55]	[−2.23]	[−2.31]
LGDP	0.005*	0.032	0.036**	0.006*	0.120***	0.051**	0.069***	0.008*
	[1.96]	[3.11]	[2.29]	[1.69]	[8.98]	[2.37]	[2.75]	[2.13]
LUNE	−0.003***	−0.001***	−0.008***	−0.003***	−0.004***	−0.001***	−0.179*	−0.010*
	[−4.59]	[−2.27]	[−3.30]	[−2.93]	[−2.97]	[−3.39]	[−1.82]	[−2.08]
	Model criteria							
Hansen	0.438	0.239	0.282	0.472	0.153	0.379	0.461	0.418
AR(1)	0.006 ***	0.002 ***	0.039**	0.003***	0.001***	0.021**	0.081*	0.044**
AR(2)	0.154	0.162	0.478	0.652	0.831	0.308	0.788	0.235
Difference-Hansen	–	0.977	–	0.999	–	0.999	–	0.920
#instruments	33	33	33	33	33	33	33	33
#Groups	56	56	56	56	56	56	56	56
#Obs	336	336	336	336	336	336	336	336
	Marginal effect							
Mean	0.0491	0.1326	0.1857	0.2101	0.0905	0.0517	0.5853	1.0915
Min	−0.1145	−0.3584	−0.2297	−0.2682	−0.1865	−0.0993	−1.5923	−2.8359
Max	0.0729	0.2038	0.2460	0.2795	0.1307	0.0736	0.9015	1.6618
Threshold	1.9983	2.9355	0.3162	0.3490	1.4385	12,214	2.9814	2.6580

Note: Asterisks *, **, and*** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [] stand for t-statistic. The values of the Hansen and AR tests stand for the p-value. The model is estimated using the two-step model with robust estimation.

Table B.5
Regression analysis for additional controlled variables [DV = *LFS*].

	FSAVG			FSAVA			FSACC			FSUTI			FSSTA		
	(1)	*(2)*	*(3)*	*(1)*	*(2)*	*(3)*	*(1)*	*(2)*	*(3)*	*(1)*	*(2)*	*(3)*	*(1)*	*(2)*	*(3)*
Constant	0.840***	1.661 ***	0.880**	0.024*	0.716**	0.263***	0.108***	0.202***	0.443***	0.082***	0.305***	0.312***	0.177***	2.148***	1.916***
	[2.69]	[7.52]	[2.30]	[2.00]	[2.21]	[5.43]	[2.86]	[5.75]	[5.18]	[11.00]	[6.82]	[3.22]	[2.62]	[3.69]	[2.60]
LFS_{t-1}	0.952***	0.536 ***	0.832***	1.016***	0.996***	0.966***	1.004***	0.962***	0.915***	0.979***	0.937***	0.965***	0.865***	0.697***	0.894***
	[18.02]	[11.30]	[14.60]	[16.76]	[17.63]	[18.15]	[9.72]	[12.06]	[8.48]	[16.65]	[14.75]	[16.87]	[12.89]	[6.49]	[12.57]
LAL	0.027***	0.087 ***	0.021*** [4.84]	0.001*	0.001***	0.001*	0.001	0.004	0.002*	–	–	–	0.003	0.047	0.137***
	[5.25]	[9.30]		[1.80]	[6.65]	[1.97]	[1.42]	[1.63]	[1.95]				[1.24]	[1.40]	[3.13]
LEQ	0.006*	0.029***	0.010*	0.041***	0.005**	0.006***	0.002***	0.014***	0.009***	0.026**	0.014***	0.001***	0.006***	0.538***	0.018*
	[1.91]	[4.29]	[1.79]	[2.72]	[2.23]	[2.55]	[4.52]	[2.60]	[2.52]	[2.13]	[4.51]	[1.96]	[2.65]	[3.61]	[1.85]
LPOP	−0.001*	−0.020 ***	−0.004***	−0.001***	−0.009***	−0.003	−0.001**	−0.017	−0.002	−0.002***	−0.211	−0.129***	−0.007***	−0.004	−0.014
	[−2.86]	[−2.78]	[−4.19]	[−3.79]	[−4.80]	[−1.60]	[−2.38]	[−1.69]	[−1.66]	[−4.85]	[−1.57]	[−2.73]	[−1.86]	[1.25]	[−1.23]
LBP	−0.001*	−0.088***	−0.109***	−0.003***	−0.001*	−0.070**	0.003***	0.058***	0.006**	−0.014***	−0.008***	−0.009**	−0.011***	−0.260***	−0.140***
	[−2.84]	[−8.72]	[−7.90]	[−5.34]	[−1.82]	[−2.26]	[4.35]	[6.78]	[2.10]	[−4.17]	[−3.81]	[−2.28]	[−3.05]	[−2.79]	[−1.75]
*LBP*LEQ*	0.080***	0.087***	0.089***	0.021***	0.005***	0.073**	0.002***	0.053***	0.003*	0.013*	0.009***	0.008***	0.046***	0.256***	0.166***
	[4.15]	[8.90]	[4.78]	[2.35]	[3.21]	[2.31]	[4.32]	[6.62]	[2.05]	[1.87]	[4.86]	[5.01]	[3.16]	[3.05]	[5.36]
LCA	0.001	0.028***	0.002***	0.039***	0.016***	0.005***	–	–	–	–	–	–	–	–	–
	[1.43]	[3.29]	[2.75]	[2.67]	[7.89]	[4.17]									
LGINI	−0.006***	−0.011	−0.041***	–	–	–	−0.011***	−0.029**		−0.044***	–	–	–	–	–
	[−2.99]	[−1.59]	[−3.58]				[−2.66]	[−6.22]		[−5.36]					
LPRI	−0.028***	−0.004***	−0.018***	–	–	–	−0.003***	−0.006**	−0.006***	−0.001***	−0.002***	−0.005***	–	–	–
	[−4.24]	[−3.58]	[−3.61]				[−3.03]	[−2.23]	[−3.06]	[−2.48]	[−2.60]	[−2.60]			
LGDP	0.017***	0.048***	0.030***	–	–	–	–	–	–	0.001*	0.007***	0.003	–	–	–
	[8.31]	[6.34]	[6.44]							[1.79]	[4.18]	[1.56]			
LUNE	−0.004**	−0.010*	−0.011***	–	–	–	–	–	–	–	–	–	−0.021 ***	−0.007***	−0.006***
	[−2.33]	[−1.74]	[−4.16]										[−9.79]	[−3.84]	[−3.59]
TEMPE	–	−0.017**	–	–	−0.013***	–	–	−0.010**	–	–	−0.013***	–	–	−0.042*	–
		[−2.07]			[−6.57]			[−2.10]			[−5.93]			[−1.78]	
NUM.DISAS	–	–	−0.015***	–	–	−0.002***	–	–	−0.009***	–	–	–	–	–	−0.134***
			[−4.10]			[−2.82]			[−5.75]						[−4.55]
Model criteria															
Hansen	0.499	0.498	0.518	0.391	0.673	0.662	0.210	0.645	0.330	0.243	0.675	0.334	0.485	0.270	0.474
AR(1)	0.016**	0.072*	0.035**	0.016**	0.046**	0.005***	0.014**	0.036**	0.009***	0.097*	0.009***	0.007***	0.036**	0.097*	0.032**
AR(2)	0.550	0.340	0.334	0.407	0.134	0.324	0.256	0.383	0.305	0.432	0.346	0.36	0.588	0.168	0.474
Difference-Hansen	0.499	0.639	0.928	0.992	0.999	0.953	0.993	0.973	0.953	0.964	0.992	0.951	0.999	0.960	0.996
#instruments	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
#Groups	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56
#Obs	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336
Marginal effect															
Mean	0.3571	0.3014	0.2894	0.0910	0.0214	0.2567	0.0120	0.2952	0.0194	0.0442	0.0322	0.0268	0.1949	0.8859	0.6030
Min	−0.6499	−0.7937	−0.8310	−0.1733	−0.0416	−0.6622	−0.0132	−0.3719	−0.0183	−0.1195	−0.0810	−0.0739	−0.3841	−2.3366	−1.4866
Max	0.5033	0.4604	0.4520	0.1294	0.0305	0.3902	0.0156	0.3921	0.0249	0.0679	0.0487	0.0414	0.2790	1.3537	0.0906
Threshold	1.0126	2.7497	3.4031	1.1536	1.2214	2.6088	0.2231	0.3348	0.1353	2.9356	2.4322	3.0802	1.2701	2.7610	2.3243

Note: Asterisks *, **, and*** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [] stand for t- statistic. The values of the Hansen and AR tests stand for the p-value. The model is estimated using the two-step model with robust estimation. (1) EQ = Environmental Performance Index (EPI); (2) EQ = Temperature and (3) EQ = number of natural disasters occurrences.

Table B.6
Regression analysis based on distance approach [DV = *LFS*].

	FS DIFF-GMM	SYS-GMM	FSAVA DIFF-GMM	SYS-GMM	FSACC DIFF-GMM	SYS-GMM	FSUTI DIFF-GMM	SYS-GMM	FSSTA DIFF-GMM	SYS-GMM
Constant		1.063***		1.998***		1.017***		1.048***		0.640***
		[7.48]		[18.20]		[4.42]		[5.08]		[4.87]
LFS_{t-1}	0.800***	0.195***	0.3014***	1.998***	0.846***	0.846***	1.101***	0.991***	0.165*** [5.46]	0.482***
	[16.71]	[4.09]	[5.54]	[18.20]	[15.98]	[15.78]	[17.98]	[13.33]		[17.93]
LAL	0.008	0.057***	0.001***	0.082***	0.0455***	0.003***	–	–	0.986***	0.060**
	[1.63]	[5.03]	[2.68]	[5.32]	[5.41]	[4.25]			[6.65]	[2.00]
LEQ	0.015*	0.280***	0.073***	0.046***	0.069***	0.069***	0.053***	0.002***	0.741***	0.058**
	[2.04]	[5.54]	[2.76]	[7.48]	[2.59]	[2.50]	[2.78]	[5.59]	[3.31]	[2.34]
LPOP	−0.003***	−0.004***	−0.012***	−0.006***	−0.045	−0.045*	−0.021**	−0.001***	−0.1695	−0.055*
	[−6.75]	[−3.23]	[−1.84]	[−8.66]	[−1.50]	[−1.95]	[−2.28]	[−3.33]	[−1.20]	[−9.60]
LBP	−0.050***	−1.349***	−0.206***	−0.130***	0.047***	0.027***	−0.104*	−0.004***	−0.088***	−0.415***
	[−2.89]	[−2.91]	[−2.56]	[−6.82]	[3.73]	[3.43]	[−1.90]	[−3.57]	[−4.64]	[−2.83]
*LBP*LEQ*	0.059***	1.297***	0.212***	0.0948***	0.040***	0.020*	0.092**	0.009**	0.210*	0.455***
	[3.29]	[3.01]	[2.57]	[5.15]	[2.72]	[1.92]	[2.20]	[8.80]	[1.90]	[3.61]
LCA	0.012***	0.009***	0.132****	0.0167***	–	–	–	–	–	–
	[8.16]	[2.99]	[6.95]	[3.93]						
LGINI	−0.060*	−0.099***	–	–	−0.163***	−0.163***	–	–	–	–
	[−3.50]	[−3.51]			[−5.03]	[−5.08]				
LPRI	−0.040***	−0.030***	–	–	−0.051	−0.051***	−0.003***	−0.002***	–	–
	[−6.34]	[−4.25]			[−4.13]	[−4.43]	[−4.77]	[−4.13]		
LGDP	0.003*	0.219***	–	–	–	–	0.007***	0.006***	–	–
	[1.88]	[5.14]					[3.68]	[5.64]		
LUNE	−0.015**	−0.005	–	–	–	–	–	–	−0.076***	−0.054***
	[−2.04]	[1.52]							[−2.57]	[−4.80]
	Model criteria									
Hansen	0.723	0.296	0.543	0.471	0.587	0.792	0.691	0.498	0.558	0.287
AR(1)	0.030**	0.069*	0.010***	0.001**	0.038***	0.038**	0.005***	0.084*	0.082*	0.039**
AR(2)	0.425	0.369	0.203	0.262	0.638	0.638	0.613	0.349	0.758	0.117
Difference-Hansen	–	0.821	–	0.191	–	0.981	–	0.948	–	0.999
#instruments	33	33	33	33	33	33	33	33	33	33
#Groups	56	56	56	56	56	56	56	56	56	56
#Obs	336	336	336	336	336	336	336	336	336	336
	Marginal effect									
Mean	0.2141	4.4563	0.7429	0.2943	0.2260	0.1165	0.3078	0.0363	0.8520	1.6216
Min	−0.5286	−11.870	−1.9257	−0.899	−0.2775	−0.1352	−0.8503	−0.0770	−1.7915	−4.1059
Max	0.3219	6.8269	1.1304	0.4676	0.2991	0.1531	0.4759	0.0527	1.2358	2.45318
Threshold	2.3338	2.8292	2.6424	3.9404	0.3088	0.2592	3.0970	1.5596	1.5204	2.4895

Note: Asterisks *, **, and*** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [] stand for t- statistic. The values of the Hansen and AR tests stand for the p-value. The model is estimated using the two-step model with robust estimation.

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