Received: 13 April 2023 | Revised: 17 July 2023 | Accepted: 25 July 2023 | Published online: 2 August 2023

Green and Low-Carbon Economy
2024, Vol. 2(4) 259–268
DOI: 10.47852/bonviewGLCE3202948

RESEARCH ARTICLE

Population Growth, Biofuel Production, and Food Security

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Abstract: This study investigates the relationship between population growth and food security, considering the role of biofuel production in 57 developing countries using a panel data approach. By employing the generalized method of moments (GMM) estimator, the analysis reveals that the interaction between population growth and biofuel production has a significant and negative impact on food security. Specifically, the findings suggest that as the population increases, the adverse effects of biofuel production on food security intensify. Furthermore, the study explores this relationship across the four key dimensions of food security: availability, accessibility, utilization, and stability. In each dimension, the negative interaction remains consistent, indicating that population growth exacerbates the detrimental impact of biofuel on food security in all aspects. These findings emphasize the importance of addressing the competing demands of biofuel production and food security, particularly in the context of population expansion. Policymakers must consider these dynamics when formulating strategies to mitigate food insecurity in developing countries.

Keywords: population growth, biofuel production, food security, GMM

1. Introduction

Under the world economy, human beings play a dominant role in structuring economic growth. Human beings are not the only consumer of goods and services, but they also act as a productive factor in the world economy [1]. According to the production function, human beings act as a factor of production that includes human exertion performed in the creation of goods or services. For the most economic sector, labor is required for all forms of economic production, although the number of skills and productivity vary widely from sector to sector, as well as across time and space [2–4]. As the world population continues to grow, the country's economy has the possibility to grow fastest in coming decades due to lower labor cost. Higher population growth would lead to an increment in labor supply and thereby the labor cost (e.g., wages) would fall significantly. Since population growth plays an important role in the overall economic system, the evolution of world population will continue to be putting downward pressure on cost and be a major factor in rising economic productivity [5].

Notwithstanding these benefits, there is growing concern that "too many" people in the world are not always consistent with the principle of economic development. There is a widespread belief that rapid population growth often leads to various problems and one of them is food security problem. This has to do with the relative inequality in patterns of several people and production of food. In respect to past studies, Kinawy and Ahmed [6] as well as Lee et al. [7] have explored the link between population growth and food security. They discover that a significant rise in population causes a rise in water consumption and land use for dwellings, which in turn lowers agricultural output. Food security is seriously threatened by the ongoing fall in crop productivity, which results in food shortages for the population. Food insecurity typically results from an increasing population being unable to consume as much food as is being produced. As a result, it becomes more difficult for food production and distribution networks to meet dietary requirements for people. Likewise, in the 21st century, is aware of population growth may continue to intensify food shortage for millions of people [8, 9]. Every day, more than 200,000 people are added to the world population. By 2050, the earth's population is expected to increase from 7 billion to 9.1 billion and most population growth is expected in developing countries. These demographics shifts imply evolving lifestyles and consumption patterns, which will have significant consequences for food security. Thus, this explosive growth in a few people globally has resulted in acute shortage food.

2. Background of Research

Despite the predicaments caused by the increasing population, the wide use of crops for food production has been one of the most important stimuli of food security. The study observes, alongside the population growth, the availability of crop production has notably increased annually. The historical trend of crop and food production in the selected developing countries who suffer from levels of hunger that are serious is presented in Figure 1 [10].

It shows that total crops production in selected developing countries has been growing between 2011 and 2016, while the total food production has declined in the same period. With the growth of crop production, food production should increase. But the main issue behind the deficit of food production is expected to

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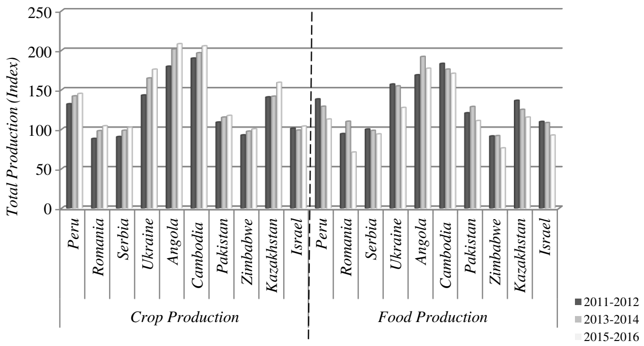
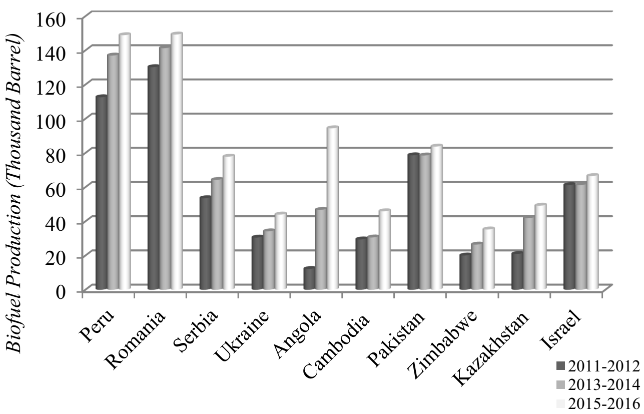
Figure 1
Total food production



be due to biofuel. Biofuel has reinforced and captured much attention to reduce greenhouse gas emission (GHG), strengthen rural development, and deal with energy security. Accordingly, all countries have been compelled to ramp-up existing capacity to produce biofuel for the attainment of climate change targets and long-term energy security. Visibly, production of biofuel can offer higher income, better access to energy, reduce emissions of greenhouse gases, and rehabilitation of degraded land [11]. Besides that, biofuel has the potential to generate new investment into the agricultural sector and leading to employment opportunities for 2.5 billion people who depend upon agriculture sectors [11]. The environmental benefit of biofuel is the reduction of carbon emissions by 94% to 60% relative to fossil fuels [12]. Due to these advantages, developing nations have looked into the possibility of using biofuels to satisfy their energy needs. This seems more sensible for developing countries due to favorable climate and cheap labors to attract the investor to plan large-scale plantations.

Those opposing biofuel argue that biofuel causes food security problems [13, 14]. So, we specifically post the following questions: why consider biofuel when discussing food shortages? The most important reason is that the main feedstocks of biofuel come from agricultural products. Thus, a drawback of increasing biofuel production is that it puts food production in direct competition with agriculture for agricultural products. In fact, Figure 2 [15] reveals that a rise in production

Figure 2
Biofuel production

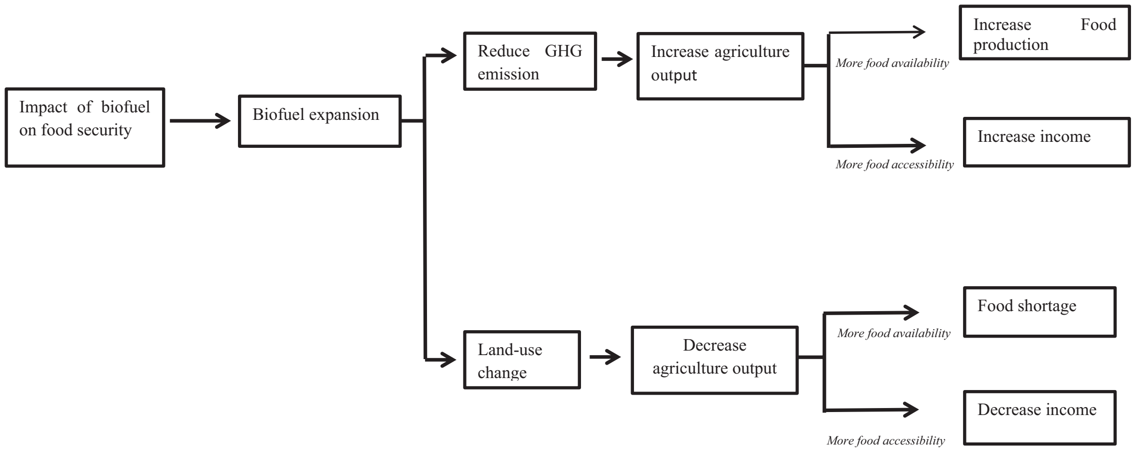


of biofuel can affect the level of food supply to household, whereby the crops are switched from production of food to biofuel. Hence, Figures 1 and 2 clearly indicate that there is a risk that higher production of biofuel may threaten the food availability and supply of the countries, many of whom suffer from acute hunger. It emphasizes the connection between the production of biofuel and food, where large portions of food crops are diverted to the production of biofuel and will continue to be diverted in the future, with grave consequences for food security. The more chronic issue is that the number of people and the percentage of renewable energy coming from biofuel production are also projected to be double by 2050 relative to its level in 2007. Such practices may pose a severe threat to humans, specifically the right supply of food for all. Therefore, it is necessary to ask: if this is true, the natural enquiry to the problem of food security is can the impact of *rapid growth in population on food security worsen given the emergence of biofuel production in developing countries?*

Along these lines, in this paper, we will make further attempts to contribute to this line of enquiry. In this study, we bring into the analysis the role played by biofuel, an aspect that has not been much emphasized. Taking the issue into account, the increase in biofuel production is going to have opportunities or risks in food security. Those favoring biofuel in developing countries viewed it to improve environmental quality and therefore food security. According to Figure 3, the relationship between biofuel and food security has two stages. Initially, the production of biofuel offers emissions reduction and enhances energy security. The environmental benefit of increasing biofuel from 5% to 53% is the reduction of carbon emissions by 60% to 94% relative to fossil fuels [12]. According to Keith et al. [16], biofuel development is the important development strategy in the foreseeable future as it promises to be carbon neutral. Meeting the reduction in GHGs during biofuel production has the potential to bring more agricultural outputs [17, 18]. In this instance, it is hypothesized that lowering GHG emissions along with lowering the global temperature may boost crop productivity, resulting in better quality and more harvests overall. These showed how an increase in agricultural output may be crucial in boosting food security: food availability (such as production), the stability of food supplies, access to food, and food utilization. Therefore, biofuel can be seen as not only a cleaner way to mitigate the impacts of climate as well as to promote more agriculture output and potentially input the food availability.

On the other hand, as reflected in Figure 3, those opposing biofuels argue that biofuel causes environmental problems and deteriorates food security. It is possible to observe a tendency toward a rise in the production of biofuel which can lead to substantial land-use change [19, 20]. Directly, land-use change occurs when unproductive land is converted to grow biofuel crops (e.g., biofuel companies), while indirect land-use change occurs when the diversion of current feed crops and croplands to produce biofuel. In Brazil, the production of biofuels leads to indirect land-use change, as around 45% of the land converted to sugarcane between 2007 and 2008 was previously utilized as rangeland [21]. Increasing land-use change can lead to greenhouse emission gases such as CO_2, CH_4, and N_2O when the natural habitats or unused or used land is converted to the production of biofuel. Subsequently, global warming resulting from greenhouse emission gases (GHG) is expected to negatively affect agricultural production. The decline in agriculture production threatens millions of people's food security with the growing risk of food shortages. Thus, it shows that it is possible to observe that the

Figure 3
Biofuel production routes for food security



production of biofuel is the changeable subject for developing countries.

Our study, therefore, aims to investigate the impact of population growth on food security, given the level of biofuel. In this case, we examine 57 developing countries using data that span over the period from 2011 to 2019 via generalized method of moments (GMM) estimation approach. The FAO defines food security as requiring simultaneous fulfillment of all four dimensions. As a result, the goal of this study is to investigate the impact of population growth on all dimensions of food security, namely availability, access, utilization, and stability, considering the level of biofuel.

The remainder of this paper is structured as follows: Section 2 describes the research context, and Section 3 describes the method, which includes model formulation and estimating procedure. Section 4 reports the empirical findings, and Section 5 concludes this paper and discusses the implications.

3. Methods

In this study, we adopt a standard relation between population growth and food security and incorporated biofuel production and the interaction term of population growth and biofuel production, written as

$$lnFS_{i,t} = \alpha_0 + \beta_1 lnPOP_{i,t} + \beta_2 lnBP_{i,t} + \beta_3 ln(POP_{i,t} * BP_{i,t}) + \beta_4 lnAL_{i,t} + \beta_5 lnCO2_{i,t} + \varepsilon_{i,t} \quad (1)$$

Hence, the model is reconstructed as follows:

$$lnFS_{i,t} = \alpha_0 + \beta lnX_{i,t} + \varepsilon_{i,t} \quad (2)$$

where subscripts i and *t* refer to time series and cross-section, respectively, and the prefix *ln* is the natural logarithm. *FS* is the food security (index) measuring the level of food security, based on availability (FS_{AVA}), access (FS_{ACC}), utilization (FS_{UTI}), and stability (FS_{STA}). *X* is a set of independent variables, including a measure *POP* is the population growth (annual %), BP is the biofuel production (thousand barrels per day), *AL* is the arable land (% of land area), and CO_2 is the environmental degradation (CO_2 emission metric tons per capita).

Most empirical studies such as Rosegrant and Cai [22], Lutz and Qiang [23], Faisal and Parveen [24], Cohen [25], and others reveal that rapid population growth tends to have higher levels of food insecurity. The latest research by Godber and Wall [26] as well as Meyers and Kalaitzandonakes [27] points out that continued rates of growth in population are responsible for both food supply and demand where it can be made these food availability trends impose a burden on food security and worsening the level of hunger. For biofuel, a number of studies by Yang et al. [28], Subramaniam and Al-Mulali [29], Ajanovic [30], Nonhebel [31], and Negash and Swinnen [32] indicate that production of biofuel may adversely affect food security through demand-side effects. According to the demand-side effect, biofuel may induce price increases for food as it competes for agricultural commodities for food and biofuel production process. In addition, these studies [6, 9, 33, 34] imply that for food insecure countries, constraints on the land area have the greatest role in determining food security. The impact of arable land on food security can be identified through climate change with a reduction in agriculture yields, availability of arable land and fresh water. Besides these, environmental degradation also may influence food security [35, 36]. Since climate change reduces rainfall and growing seasons in the tropical and subtropics to less than 120 days required by cereal crops, it is likely to reduce agriculture production to meet the food consumption.

In addition, this study intends to investigate the impact of population on food security, given the level of biofuel, by separating food security into four dimensions, namely FS_{AVA}, *FSACC*, FS_{UTI}, *and* FS_{STA}, as follows:

Food Availability

$$lnFS_{AVA\,i,t} = \alpha_0 + \beta_1 lnX_{i,t} + \beta_2 lnTR_{i,t} + \beta_3 lnCA_{i,t} + \varepsilon_{i,t} \quad (3)$$

where *TR* is the trade in agriculture products (US dollar at constant prices) and *CA* is the credit to agriculture (% share of total credit). A number of studies suggest that trade [37–39] and credit to agriculture [40–42] appear to be necessary to maintain and improve the food security. These studies demonstrate that farmers' access to financial resources greatly contributes to the fight against food insecurity by providing a financial guarantee fund to pay for seasonal harvest inputs and to invest in agricultural technology. There is a tendency in the literature that trade will become important in terms of ensuring food security via balancing the deficit of net importers with the surplus of net food exporters.

Food Accessibility

$$lnFS_{ACCi,t} = \alpha_0 + \beta_1 lnX_{i,t} + \beta_2 lnGINI_{i,t} + \beta_3 lnPRI_{i,t} + \varepsilon_{i,t} \quad (4)$$

Recently, a few studies by Swinnen [43] and Martinez et al. [44] have examined the nexus between food production and income inequality (*GINI,* GINI index). Food insecurity is exacerbated by unequal income distribution because it perpetuates poverty and extends the accessibility gap. As a result, only the wealthiest individuals may have enough resources to afford healthy foods and fulfill their basic needs, while others struggle to obtain sufficient nutrition for an active and healthy lifestyle. Moreover, rising food prices, as measured by the food price index (PRI), can have a significant impact on food security by constraining household purchasing power and forcing individuals to compromise on the quality or quantity of their food choices, which can negatively impact their health and well-being [45–47].

Food Utilization

$$FS_{UTIi,t} = \alpha_0 + \beta_1 lnX_{i,t} + \beta_2 lnPRI_{i,t} + \beta_3 lnGDP_{i,t} + \varepsilon_{i,t} \quad (5)$$

where *GDP* is the economic growth (constant 2010 US$). The empirical studies by Elzaki [48] as well as Rahman and Mishra [49] reveal that economic growth widens the range of food consumption, improves diets, and satisfies food preferences by increasing the capabilities of households. Thus, economic growth is necessary for reduction in hunger and malnutrition for an active and healthy life and resulting in positive impact on food security status.

Food Stability

$$lnFS_{STAi,t} = \alpha_0 + \beta_1 lnX_{i,t} + +\beta_2 lnUN_{i,t} + \beta_3 lnEX_{i,t} + \varepsilon_{i,t} \quad (6)$$

Unemployment *(UN)* (% of total labor force) and exchange rate *(EX)* (index) are typically seen as crucial to understanding food security [50–53]. Exchange rates are believed to be important sources of imports that can affect countries abilities to import. Accordingly, the rising exchange rate is expected to contribute to higher prices for imports, thereby reducing the countries' ability to import and closely affecting food availability and access. Besides that, the exchange rate also leads to internal inflation and thus reduces the household's real income and purchasing power of households resulting in food insecurity. For unemployment, it is found to have a significant negative impact on food security. This is because unemployment disables the household ability to buy food items to meet the food needs of household members. Consequently, it may directly raise poverty that runs a continually high risk of inability to fulfill their basic needs of life. Hence, Table 1 provides the list of variables and sources.

We employ dynamic panel GMM approaches to achieve the intended goal. Following Arellano and Bond [54], the first differences are required to wipe out the country-specific effect or any time-invariant country-specific variable. To deal with this econometric problem, Arellano and Bond [54] specify a few steps to overcome and the use of instrumental variables are required. The initial step is to eliminate the time effect by subtracting cross average in period *t* of each variable and then transforming the variables into first difference to eliminate the individual effect. The lagged levels of the endogenous variables are instrumented under the condition that the disturbance term is not serially correlated, and the level of the explanatory variable is weakly exogenous [54]. However, the primary issue with the first difference GMM estimator is that it overlooks potential information in the level connection and the correlations between the levels and the first differences. To solve the issue, Blundell and Bond [55] suggest constructing a system estimator by merging the difference estimator and level estimator. The Hansen and serial correlation tests are used to evaluate the validity of the GMM estimator [55]. The null hypothesis that the used instruments are associated with the residuals is what the Hansen test is intended to evaluate. The estimated regression residuals are examined using the serial correlation test to see whether they are first-order correlated but not second-order correlated.

Table 1
Variables name, symbol, and sources

Variables	Symbol	Sources
Population growth	*POP*	World Bank (2023)
Arable land	*AL*	
Environmental degradation	CO_2	
Income inequality	*GINI*	
Economic growth	*GDP*	
Trade	*TR*	
Biofuel production	*BP*	
Unemployment	*UN*	
Food price	*PRI*	UNDATA (2023)
Credit to agriculture	*CA*	FAOSTAT (2023)
Food security	*FS*	

4. Results and Discussions

Table 2 shows the descriptive statistics of the variable employed in our estimations. The mean *FS* of developing countries for the period from 2011 to 2016 is recorded as 43.726. The largest food security is in Israel in 2016 whereas the lowest in Rwanda in 2016. It is also reported that the mean value of *POP* is 1.204 and recorded highest for Sudan followed by United Republic of Tanzania and Angola. World Bank and Population Information Centre report shows that Sudan's population increased by approximately 2.38% compared to the previous year due to high and low birth and death rate, respectively. Moreover, for *BP*, Brazil has the highest level in 2011, whereas Bosnia and Herzegovina are the smallest producer of biofuel in 2011 and 2012. According to International Energy Agency, the Brazilian biofuel sector, particularly ethanol, has the bright future than the USA, though there are challenges to overcome.

Tables 3 and 4 display the results for the baseline specification, which was estimated using food security (*FS*) as well as the four dimensions of food security: FS_{AVA}, FS_{ACC}, FS_{UTI}, and FS_{STA}. Firstly, Sargan fails to reject the over-identification restrictions, indicating that our instruments are valid. Second, the serial correlation test fails to reject the null hypothesis of no second-order autocorrelation while rejecting the null hypothesis of no first-order autocorrelation.

The estimation results, presented in Tables 2 and 3, provide support for our hypothesis that the availability of arable land is a crucial factor in determining food security. This suggests that the availability of land, which connects roughly to food production, can provide access to a sufficient supply of food. This result could be explained by the fact that arable land is the most fundamental resource in the agriculture development in terms of farmers' income and agricultural production. With this resource, it is possible to guarantee food security in developing countries to maintain current and future food consumption levels. In addition, the outcome supports the findings obtained by Garzón Delvaux

Table 2
Descriptive of variables

Variable	Mean	Std. Dev.	Min	Max
lnFS	43.726	3.701	35.790	59.180
$lnFS_{AVA}$	51.939	7.831	35.272	74.506
$lnFS_{ACC}$	31.500	22.166	6.179	99.486
$lnFS_{UTI}$	68.669	12.345	34.919	85.830
$lnFS_{STA}$	22.798	7.124	6.461	42.792
lnAL	18.740	16.367	0.074	112.184
$lnCO_2$	4.155	5.973	0.063	42.921
lnPOP	1.204	1.051	−1.191	3.721
lnBP	2.811	4.008	0.086	7.398
lnTR	1.96E+10	3.53E+10	4.68E+07	2.45E+11
lnCA	0.056	0.051	0.000	0.227
lnGINI	39.826	9.211	24.000	75.700
lnCPI	173.352	111.833	38.492	788.684
lnGDP	6.851	7.076	3.690	3.677
lnUN	7.975	6.928	0.160	31.380
lnEX	117.979	22.881	68.332	205.943

Note: *GDP* and *BP* are in 000(thousand)

Table 3
Regression analysis [DV = *FS*]

	DIFF-GMM		SYS-GMM	
	One-step	Two-step	One-step	Two-step
$lnFS_{t-1}$	0.181***	0.108***	0.803***	0.935**
	[2.53]	[2.52]	[3.69]	[2.16]
lnAL	0.084*	0.185**	0.027*	0.517***
	[1.92]	[2.38]	[2.16]	[2.51]
$lnCO_2$	−0.121**	−0.147	−0.058**	−0.753***
	[−2.37]	[−1.63]	[−2.21]	[−2.40]
lnPOP	−0.271***	−0.159***	−0.037**	−0.871**
	[−2.73]	[−2.83]	[−2.29]	[−2.27]
lnBP	−0.047*	−0.031*	−0.031*	−0.036*
	[−1.93]	[2.00]	[−1.81]	[−1.85]
*ln (POP*BP)*	−0.013*	−0.020*	−0.028*	−0.025*
	[−2.09]	[−1.87]	[−2.49]	[−2.05]
lnTR	0.051*	0.025*	0.020*	0.027*
	[1.94]	[1.98]	[1.79]	[1.76]
lnCA	0.058**	0.469***	0.0401**	0.278***
	[2.07]	[3.09]	[2.13]	[3.71]
lnGINI	−0.681***	−0.274***	−0.010*	−0.166**
	[−3.19]	[−3.11]	(−1.82)	(−2.16)
lnPRI	−0.366***	−0.144***	−0.073***	−0.411***
	[−2.85]	[−2.65]	[−2.29]	[−2.40]
lnGDP	0.220**	0.388***	0.091***	0.109*
	[2.17]	[3.16]	[2.72]	[1.82]
lnUNE	−0.332***	−0.051*	−0.212***	−0.057*
	[−3.10]	[−1.76]	[−3.08]	[−1.84]
lnEX	−0.041***	−0.030	−0.037*	−0.091**
	[−2.06]	[−1.46]	[−2.06]	[−2.19]
Model criteria				
Sargan	0.559	0.201	0.221	0.223
AR(1)	0.046**	0.008***	0.039**	0.061**
AR(2)	0.236	0.277	0.142	0.154

Note: Asterisks *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [ ] stand for *t*-statistics.
The values of the Sargan and AR tests stand for the *p*-value.

and Gomez y Paloma [56], Soko et al. [57], and Mulusew and Hong [58]. Beyond meeting food production needs, arable land also has important links to accessibility, as increased availability of arable land can result in greater agricultural activities and employment, leading to higher income levels. This income may raise households' willingness and ability to purchase food, thus resulting in an improvement in food security for the entire household. Hence, in this case, the increment in arable land as a means of resources and livelihood may sustain or maintain food productivity and ensure household food supplies.

Second, CO_2 emission is found to have a statistically significant and negative impact on food security. Climate change threatens food security by altering rainfall, dry and wet events, and the availability of land, water, and biodiversity. The decline in rainfall and extreme wet and dry events can reduce crop yields due to high evapotranspiration and affect long-term food production. As a result, decline in per capita food production threating food security and experience further food shortages. This indicates that in sub-Saharan Africa, climate change significantly changes rainfall patterns and temperature and thus shortened growing seasons and impede people's ability to grow food [59, 60]. Hence, the findings show that the problem of food security could be as large as the projected increase in climate change.

The estimated coefficient of trade had a positive sign, which suggests that there is an increment in food availability in developing countries. In this case, the results confirm that trade plays an essential role in safeguarding food security because any changes in the degree of trade can ensure food availability and accessibility. This finding is in line with Hanjra and Qureshi [61], Fellmann et al. [62], Brooks and Matthews [38], and Méthot and Bennett [63], who demonstrated that increased trade could enhance imports and contribute to a greater quantity and variety of food available through improved specialization and productivity. Besides that, growth in exports and inflow of foreign direct investment may contribute to higher income in competitive sectors through greater employment. In turn, this increased income enables households to buy food items and ultimately affects food security status.

The empirical analysis about the variable capturing the income inequality indicates the coefficient of IE is negative and significant. The results are consistent with the findings of Lee et al. [7] for sub-Saharan Africa and South Asia, Otsuka [64] for Asia countries, Martinez et al. [44] for the United States, and Grzelak [65] for OECD countries. This notion confirms that the lower level of food supply is accompanied by an unequal distribution of income. For instance, income inequality widens the inequalities in accessibility and thereby only high-earning people would have enough money to spend on foods. Therefore, high-income inequality indirectly signals the presence of many low-income earners suffering food insecurity.

This study observes that the control variable of credit to agriculture does exert a significant effect on food security and the estimated coefficient is positive. Accordingly, an increase of 1% in the agricultural credit increases food security by 0.278%. Credit to agriculture has a positive effect on food security by providing financial guarantee fund to pay seasonal harvest inputs, to invest in agricultural technology and expansions [66, 67]. Thus, there is evidence that higher agricultural credit significantly ensures food security in developing countries.

Moreover, there is evidence of negative link between food security and food price [46, 47]. Higher food prices lead to lower purchasing power and ultimately reflect the effects of food intakes on nutritional and health of households. In this context, changes in food price would make "too little" food consumption that leads to under-nutrition, starvation, and death. Hence, the rise in food price is one of the important factors that result in decreasing

Table 4
Regression analysis [DV = FS_{AVA}, FS_{ACC} FS_{UTI}, FS_{STA}]

	FS_{AVA}				FS_{ACC}				FS_{UTI}				FS_{UTI}			
	DIFF-GMM		SYS-GMM		DIFF-GMM		SYS-GMM		DIFF-GMM		SYS-GMM		DIFF-GMM		SYS-GMM	
	One-step	Two-step	One-step	Two-step	One-step	Two-step	One-step	Two-step	One-step	Two-step	One-step	Two-step	One-step	Two-step	One-step	Two-step
$lnFS_{t-1}$	1.358**	0.801***	0.791***	0.872***	0.736***	0.529***	0.916***	0.818***	0.674***	0.476***	0.844***	0.824***	0.269***	0.279**	0.269***	0.904***
	[2.28]	[2.59]	[5.66]	[7.89]	[3.11]	[8.43]	[4.89]	[6.25]	[2.54]	[6.51]	[10.03]	[6.33]	[2.76]	[2.10]	[2.76]	[6.55]
lnAL	0.039*	0.174***	0.022**	0.189**	0.141*	0.042	0.160**	0.078***	–	–	–	–	0.080**	0.062	0.080**	0.074*
	[1.76]	[2.46]	[2.18]	[2.22]	[1.89]	[1.62]	[2.14]	[2.92]					[2.36]	[1.12]	[2.36]	[2.02]
$lnCO_2$	−0.047**	−0.085	−0.011*	−0.026*	−0.518***	−0.322**	−0.049*	−0.071*	−0.127*	−0.120*	−0.476***	−0.394**	−0.131**	−0.276*	−0.131**	−0.637**
	[−2.16]	[−1.54]	[−1.78]	[−1.83]	[−2.90]	[−2.13]	[−1.76]	[−1.85]	[−2.02]	[−1.76]	[−3.43]	[−2.33]	[−2.26]	[−2.09]	[−2.26]	[−2.20]
lnPOP	−0.143**	−0.155***	−0.042***	−0.180***	0.284*	−0.033*	−0.013**	−0.0231***	−0.025*	−0.023***	−0.074*	−0.079***	−0.44**	−0.093*	−0.442**	−0.110***
	[−2.21]	[−2.76]	[−2.47]	[−3.96]	[2.05]	[−1.87]	[−1.96]	[−2.61]	[−1.95]	[−2.59]	[−2.07]	[−2.51]	[−2.16]	[−1.91]	[−2.16]	[−2.77]
lnBP	−0.081**	−0.189**	−0.060**	−0.160**	−0.753**	−0.167**	0.129***	0.291***	−0.077***	−0.158**	−0.419**	−0.170***	−0.085**	−0.120***	−0.085**	−0.134***
	[−2.12]	[−2.35]	[−2.26]	[−2.26]	[−2.60]	[−2.17]	[2.05]	[2.44	[−2.53]	[−2.26]	[−2.45]	[−2.40]	[−2.15]	[−2.61]	[−2.15]	[−2.96]
*ln(BP*POP)*	−0.015**	−0.099*	−0.038**	−0.139***	−0.632***	−0.302***	−0.109*	−0.573***	−0.055**	−0.153**	−0.250***	−0.140*	−0.258***	−0.064***	−0.258***	−0.074***
	[−2.18]	[−1.83]	[−2.17]	[−3.28]	[−2.79]	[−2.46]	[−2.08]	[−3.93]	[−2.34]	[−2.38]	[−2.68]	[−2.13]	[−2.58]	[−2.70]	[−2.58]	[−2.63]
lnTR	0.015**	0.058	0.013*	0.037*	–	–	–	–	–	–	–	–	–	–	–	–
	[2.35]	[1.33]	[1.77]	[2.07]												
lnCA	0.026**	0.390***	0.027**	0.074*	–	–	–	–	–	–	–	–	–	–	–	–
	[2.29]	[2.97]	[2.28]	[2.05]												
lnGINI	–	–	–	–	−0.470***	−0.022	−0.597***	−0.026*	–	–	–	–	–	–	–	–
					[−2.40]	[−1.42]	[−2.52]	[−1.93]								
lnPRI	–	–	–	–	−0.904***	−0.386**	−0.169**	−0.481*	−0.061**	−0.029	−0.013*	−0.029	–	–	–	–
					[−2.42]	[−2.35]	[−2.20]	[−2.05]	[−2.25]	[−1.33]	[−1.99]	[−1.33]				
lnGDP	–	–	–	–	–	–	–	–	0.041**	0.110**	0.333***	0.110**	–	–	–	–
									[2.12]	[2.36]	[2.95]	[2.36]				
lnUNE	–	–	–	–	–	–	–	–	–	–	–	–	−0.525***	−0.035	−0.525***	−0.058**
													[−2.83]	[−1.70]	[−2.83]	[−2.06]
lnEX	–	–	–	–	–	–	–	–	–	–	–	–	−0.142	−0.151**	−0.142	−0.232**
													[−1.41]	[−2.15]	[−1.41]	[−2.26]
									Model criteria							
Sargan	0.612	0.145	0.121	0.177	0.254	0.335	0.522	0.145	0.652	0.826	0.838	0.913	0.962	0.438	0.403	0.517
AR(1)	0.043**	0.086*	0.069*	0.033**	0.042**	0.007*	0.032**	0.000***	0.094*	0.001***	0.071*	0.000***	0.007***	0.015**	0.004***	0.019**
AR(2)	0.991	0.111	0.879	0.872	0.829	0.289	0.829	0.515	0.413	0.270	0.672	0.313	0.313	0.218	0.104	0.164

Note: Asterisks *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [ ] stand for *t*-statistics.

Table 5
Two-stage least squares (2SLS) analysis [DV = FS, FS_{AVA}, FS_{ACC} FS_{UTI}, FS_{STA}]

	FS	FS_{AVA}	FS_{ACC}	FS_{UTI}	FS_{STA}
lnAL	0.012***	0.044***	0.026***	–	−0.023*
	[4.00]	[7.05]	[4.90]		[−2.00]
$lnCO_2$	−0.006*	−0.032***	−0.012***	−0.051***	−0.016**
	[−2.01]	[−6.52]	[−9.94]	[−2.79]	[−2.18]
lnPOP	−0.051***	−0.011*	−0.033***	−0.021***	−0.049***
	[−3.36]	[−1.80]	[−2.71]	[−5.70]	[−2.52]
lnBP	−0.042*	−0.055**	−0.026**	−0.024***	−0.037***
	[−1.93]	[−2.26]	[−2.24]	[−2.90]	[−2.81]
*ln(BP*POP)*	−0.035***	−0.049**	−0.016*	−0.012***	−0.023***
	[−2.56]	[−2.30]	[−2.05]	[−3.36]	[−3.29]
lnTR	0.026*	0.091***	–	–	–
	[1.86]	[4.32]			
lnCA	0.026*	0.005**	–	–	–
	[1.84]	[2.14]			
lnGINI	−0.014*	–	−0.010***	–	–
	[−1.92]		[−3.44]		
lnPRI	−0.065***	–	−0.006*	−0.014***	–
	[−2.78]		[1.96]	[−4.14]	
lnGDP	0.018***	–	–	0.017***	–
	[2.87]			[2.61]	
lnUNE	−0.010**	–	–	–	−0.033***
	[−2.30]				[−3.97]
lnEX	−0.067***	–	–	–	−0.027**
	[−3.92]				[2.34]
R^2	0.840	0.644	0.8047	52.31	74.80
F-statistic	14.42	31.52	27.26	71.03	70.05
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: Asterisks *, **, and *** denote the 10%, 5%, and 1% levels of significance, respectively. Figures in [ ] stand for *t*-statistics.

consumer ability to obtain food and can be problematic for a country as it is difficult to provide adequate nutrition and health.

Unemployment has an important role in household food security and is found to be negatively influencing food security. In the current study, unemployment exacerbates food instability by reducing the sustainability of the production system and investment in human capital due to unstable income [51, 68–70]. Increasing unemployment is a means to drop human capital development that worsens the economic status of households, ultimately leading to impede food security. As a result, higher unemployment is found to be a critical socioeconomic problem in developing countries that are trapped with the problem of food security and does not guarantee food security for poor households.

One of our contributions in this study is the impact of population growth on food security given the level of biofuel production. The findings highlight that the coefficient of POP*BP has negative and significant impact on food security in developing countries. The negative impacts of the interaction term worsen the already existing negative relationship between population growth and food security. This means that rapid population growth as well as growth in biofuel increases the challenge of adequately meeting basic and nutritional needs and implies a very huge effect on food security. Since the production of biofuel depends on the type of food crops, an increasing number of people often drives up the demand for food. This results in additional food consumption, which may increase the competition between biofuel and food. The competition in food crops demand for food and biofuel can cause lack of adequate food for healthy and active life, and thereby pushing more people into hunger. Such practices can create massive food shortages and leave millions of people without enough food to eat and in turn decline food security in developing countries. This result suggests that the negative effect of population growth on food security worsens as a country's population increases. In turn, this limits the availability, accessibility, and stability of food, making it increasingly challenging to ensure food security for growing populations because driving biofuel production amplifies the strain on resources and agricultural capacity. As a result, considering the expected population growth as well as the competition of biofuel production by the year 2050, the problems regarding hunger and food insecurity can increase dramatically in developing countries.

Moreover, we use two-stage least squares (2SLS) to assess the results' robustness, and the outcomes are shown in Table 5. The outcomes again highlight that the effects of biofuel on food security worsen, as the population grows. Overall, the outcomes of the 2SLS are consistent with those shown in Table 4.[1]

5. Conclusion

This paper examines the role of biofuel in the population-food security nexus for 57 developing countries. Our empirical findings allow us to conclude that the impact of biofuel on food security worsens as population growth increases. This suggests that as the population grows, the conflict between the production of food and biofuels escalates, as more people need food to survive while also increasing the demand for biofuels as an alternative energy source. Due to the fact that land and water, which could be used

[1]We do not discuss them here to conserve space.

for food production, are instead allocated to biofuel cultivation, this dynamic puts a burden on agricultural resources.

The policy suggestions in this paper are as follows, based on the empirical findings:

1) The third generation of biofuel is better for the environment. In this sense, the government should encourage the creation of second and third-generation biofuels, which are undoubtedly free from food competition and capable of maintaining environmental quality, supporting the growth of agriculture.
2) Employ integrated resource management strategies that emphasize the sustainable and efficient use of land, water, and other agricultural resources. To guarantee the availability of resources for both food production and the cultivation of biofuels, this entails supporting sensible land-use planning, optimizing irrigation systems, and implementing water conservation measures.
3) Encourage integrated planning and policy coordination among sectors, such as agriculture, energy, environment, and population, to solve the complex issues brought on by population expansion and the development of biofuels. This entails encouraging cross-disciplinary cooperation, stakeholder involvement, and evidence-based decision-making to create comprehensive policies that consider the interdependencies between food security, energy, and environment.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by the author.

Conflicts of Interest

The author declares that she has no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Yogeeswari Subramaniam: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration.

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How to Cite: Subramaniam, Y. (2024). Population Growth, Biofuel Production, and Food Security. *Green and Low-Carbon Economy*, *2*(4), 259–268. https://doi.org/10.47852/bonviewGLCE3202948