

# An Analysis of Water, Energy and Food Nexus: A linear and Nonlinear Granger Causality Approach

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## Abstract

*The nexus between water, energy and food security has drawn attention among researchers and policymakers in recent times. Given that empirical works in the area are scanty, this paper empirically evaluates the water, energy and food security (WEF) relationship using both linear and non-linear Granger causality approach. By employing data for five (5) selected African countries, the results from the linear estimations showed mixed causality between the key variables (Water, Energy, and Food). Evidence of a non-linear causal relationship between the variables was not found because the estimates obtained were predominantly statistically insignificant. The findings of the study indicate the presence of unidirectional linear causality running from Water to Energy, which was found for three countries (Egypt, Nigeria, and South Africa). The study also found the presence of causality running from water to food in South Africa. On the other hand, no evidence of causality between energy and food was found.*

**Keywords:** Water, Energy, Food, Causality.

**JEL Classification :** Q25, Q40, Q10.

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## Introduction

The looming global climate change has raised concerns about the sustainability of environmental quality. Climate change among factors is seen to have exerted pressure on water, energy, food resources and human health globally, thereby bestowing communities with constricted trade-offs and an imminent conflict among these resources, which have dynamic and complex interactions (Magadza, 2000 and Hoff, 2011). Currently, the global environment is presumed to be anguished from extreme climatic conditions such as extreme heat, rainfall shortages, dust storms, harsh geography as well as huge environmental degradation such as ecological footprint (Global Footprint Network, 2013). Therefore, Hayley et al. (2015) expressed that understanding effective and sustainable solutions to challenges on a global level requires in-depth knowledge and understanding of the networks and inter-linkages of Water, Energy, and Food (WEF). According to Endo

et al. (2015), the concept of the WEF nexus was launched in Bonn, 2011, when the German Federal Government organized an international conference with the theme “The Water-Energy and Food Security Nexus—Solutions for the Green Economy” to contribute to the United Nations Conference on Sustainable Development (Rio + 20).

Despite the successful initiation of the idea, the WEF nexus is viewed as rather subjective, as the first two factors (Water and Energy) are considered as inputs in the production process, while the latter (Food) is an output of production (Denis, 2017). Hussey and Pittock (2012) further stated that distinctly, water and energy are recognized as indispensable inputs to modern economies that have undergone rapid reforms mainly driven by the security of supply, environmental sustainability, and economic efficiency. On the sustainability of the WEF nexus, Sharma (2016) stated the need for policy design involving the management of natural resources to achieve efficiency and to minimize the likelihood of inadvertent consequences. Studies such as Golam and Sharma (2015) have suggested that the WEF nexus could be used as an effective adaptation strategy for climate change. They emphasized that the potential synergies and complementarities among the three (WEF) sectors should be used as a framework for an efficient and effective strategy option.

This study has identified that the WEF nexus is still in its developmental stage and the fact that there is a sparse availability of empirical works in the area, possibly due to lack of data, most especially in the African context. Thus, what is known about the WEF nexus is largely concentrated around theoretical studies that review and analyze the significance of the WEF nexus. Based on these gaps, this paper evaluates the WEF inter-linkages across resource changes over time through a quantitative approach. Particularly, the study sorts to achieve this through the use of the econometric tool of linear and nonlinear Granger causality tests. First, the paper verified hypothetically, the claim in the conceptual literature of a Uni-directional/Bi-directional relationship as discussed in section 2.0. This is done using close proxies obtained from the UN data department website and the World Bank’s World Development Indicators. Section 2.0 presents the literature review, which is followed by the methodology (data and model) in section 3.0. The results and discussion are presented in section 4.0, while section 5.0 deals with the conclusion and recommendation of the study.

## Literature Review

Water, energy, and food (WEF) without any doubt are indistinctly linked, thus, access to these resources and their effective management explains the environmental development progress (Heyley et al. 2015). The first serious discussions and analyses of the WEF nexus can be credited to studies of World Economic Forum (2011), Hoff (2011; Rasul 2014). The central focus was on boosting economic growth having less effect on the use of WEF resources and investments to sustain ecosystems' services. The proposition also identified that the WEF nexus is subject to (and also drives) external factors such as global governance failure, economic disparity, and geopolitical conflicts. Also, the authors noted the importance of ecosystem goods and/or services that must be protected to ensure the resilience of WEF sectors.

Before the conception of the three resources nexus, what was established was the Water-Energy nexus (see Hardy et al., (2012); Scott et al. (2011); Vilanova et al. (2015) and Viera & Ghisi (2016)); Water-Food nexus (see Antonelli (1998) and Vanham (2016)) and Energy-Food nexus (see Abdelradi & Serra (2015) and Karkacier & Goktolga (2005)). In the water-food nexus, water necessitates food production, especially in the agricultural sector where it serves as a key input for animal and crop production. For water-energy synergy, water also serves as a source of extraction and power generation (hydro-electricity). Lastly, in the energy-food nexus, energy is required for agricultural activities such as harvesting, transportation and storage (White et al. 2017).

Despite its overwhelming significance, the WEF nexus is viewed as a dynamic and complex relationship. Shannak et al. (2018) stated that the resources are complex aggregates formed and influenced by the collection of elements, and managing them relies on several factors such as technology choices, fuel choices, resource availability and market factors, which can all be affected by national resource policies. Shannak et al. (2018) further added that these resources are also interlinked for instance; water is desirable for energy production, as energy is required for extraction, distribution, and treatment of water, whereas, food production relies on both water and energy availability. Hence, it is important to note that there exists a sturdy trade-off among the resources as well as the environmental impacts and economic considerations (Zhang & Velimir, 2017).

Among the empirical studies, only the study by Ozturk (2015) was identified as that which established the Food-Energy-Water nexus for BRICS (Brazil, Russia, India, China, and South Africa) countries. However, the study segmented the model based

on the various sectors. The findings from the study indicate a widened demand and supply gap of energy and water which may pose serious food security problems for the BRICS countries. A study by Xingchen et al. (2020) using the SVAR model, found that food production had a negative impact on energy production as the impact of water supply on food production was weak. But there was evidence of the positive impact of energy on water productivity.

## **Methodology**

### **Types and Sources of Data**

Due to the restriction on measurability and availability of data on energy, water supply, and food productivity, the data used in this paper relied on close proxies such as Gross food production index<sup>1</sup>, energy (total hydro production) and renewable internal freshwater resources per capita<sup>2</sup> (in cubic meters). The first two data mentioned were sourced from United Nations Data Division, while data on the water was sourced from World Development Indicators. Only five (5) African countries were selected for the study mainly due to the availability of data for the countries and advancement in economic activities. These countries include Nigeria, Cote d'Ivoire, Egypt, Ghana and South Africa. The study covers the period 1992 to 2017 based on the available data.

### **Data Analysis**

This study employs the Granger Causality test developed by Granger (1980). Furthermore, there is a possibility that the distribution of the factors may not be normally distributed and could assume a non-linear pattern. To account for this possibility, the study also adopted the nonlinear Granger Causality test of Baek and Brock (1992) to empirically evaluate the argument of a non-linear relationship between the WEF variables. The reason for nonlinearity is based on the fact that the resources are sometimes affected by shocks resulting from extreme climatic conditions such as excessive torrential rainfall and drought among others. These factors have an unintended consequential effect on the distribution and availability of resources. For instance; the presence of drought may negatively affect food productivity, water supply as well as energy production.

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<sup>1</sup> According to the FAO, the Food production index covers food crops that are considered edible and that contain nutrients

<sup>2</sup> There were some missing observations in between the years, thus 2 years moving average was used to generate the missing values.

A variable is said to Granger cause another variable if its lagged values are useful in forecasting the future value of the other variable (Abubakar, 2017). As noted by Huang et al. (2008) this test is widely used to infer causality. The linear Granger causality test equations are expressed:

$$water_t = \alpha + \sum_{i=1}^m \beta_i water_{t-i} + \sum_{j=0}^n \gamma_j food_{t-j} + \mu_t \quad (1)$$

$$food_t = \lambda + \sum_{i=1}^p \phi_i food_{t-i} + \sum_{j=0}^q \omega_j water_{t-j} + \varepsilon_t \quad (2)$$

$$energy_t = \pi + \sum_{i=1}^s \theta_i energy_{t-i} + \sum_{k=0}^u \tau_k water_{t-k} + \nu_t \quad (3)$$

$$water_t = \alpha + \sum_{i=1}^m \beta_i water_{t-i} + \sum_{k=0}^o \delta_k energy_{t-k} + \mu_t \quad (4)$$

$$food_t = \lambda + \sum_{i=1}^p \phi_i food_{t-i} + \sum_{k=0}^r \rho_k energy_{t-k} + \varepsilon_t \quad (5)$$

$$energy_t = \pi + \sum_{i=1}^s \theta_i energy_{t-i} + \sum_{j=0}^t \eta_j food_{t-j} + \nu_t \quad (6)$$

The evidence for the existence of causality is said to be found if the coefficients of the lagged independent value are statistically significant, for example, if  $Y_j$ 's are significant in equation 1. Thus, by estimating the above equations, the causal relationship between the three resources (WEF) is determined.

The non-linear Granger causality test of Baek and Brock (1992) being a nonparametric method employs the correlation integral which is an estimator measuring spatial probabilities across time to examine the causal relationship between variables (Heimstra & Jones, 1994). To illustrate the test, consider two series  $X_t$  and  $Y_t$  where the superscript  $m$  is the length of the lead of the variable  $X$  and the subscripts  $Lx$  and  $Ly$  are the lengths of the lags of variables  $X$  and  $Y$  respectively. The distance between the lead and lag vectors of a variable is represented by the term  $e$ .

The variable  $Y$  does not Granger cause variable  $X$ , if for the given values of  $Lx$ ,  $Ly$  and  $m \geq 1$ , and  $e > 0$ :

The probability,  $\Pr(\|X_t^m - X_s^m\| < e \mid \|X_{t-Lx}^{Lx} - X_{s-Lx}^{Lx}\| < e, \|Y_{t-Ly}^{Ly} - X_{s-Ly}^{Ly}\| < e) = \Pr(\|X_t^m - X_s^m\| < e \mid \|X_{t-Lx}^{Lx} - X_{s-Lx}^{Lx}\| < e)$  (7)

From equation 7,  $\|\cdot\|$  denotes the maximum norm, and the left-hand side of the equation denotes that the conditional probability that two  $m$ -length lead vectors of  $X$  are within a certain distance (represented by)  $e$  of each other, given that the corresponding lag vectors of  $X$  and  $Y$  are within the distance  $e$  of each other. Similarly, the right-hand side of the equation denotes that the conditional probability that two  $m$ -length lead vectors of  $X$  are within a certain distance (represented by)  $e$  of each other, given that the corresponding lag vectors of  $X$  are within the distance  $e$  of each other (see Heimstra & Jones, 1994). The arbitrary variables  $X$  and  $Y$  in equation 7 can be replaced by any pair from the study's Water, Energy and Food variables.

## **Empirical findings and Discussions**

### **Descriptive Statistics**

The result from the descriptive statistics in Table 1.0 indicates that all the variables for the countries, except for energy in South Africa, are not normally distributed as indicated by the Jarque-Bera statistics. The estimates also indicated that Egypt had the highest hydro energy production of 15510kwh, though; they had the lowest renewable internal freshwater resources of 18.52 cubic meters.

**Table 1.0 Summary of Descriptive Statistics**

<i>Variable</i>	<i>Mean</i>	<i>Max.</i>	<i>Min.</i>	<i>Std. Dev.</i>	<i>Skewness</i>	<i>Kurtosis</i>	<i>Jarque-Bera</i>
<b><i>Cote d'Ivoire</i></b>							
<i>ENERGY</i>	1657.74	2131.00	1048.00	239.18	-0.65	3.20	1.88
<i>FOOD</i>	99.53	129.02	69.02	18.27	0.08	2.14	0.83
<i>WATER</i>	4338.91	5997.31	3130.99	833.50	0.39	2.10	1.54
<b><i>Egypt</i></b>							
<i>ENERGY</i>	12932.77	15510.00	8540.00	1546.01	-0.74	4.01	3.50
<i>FOOD</i>	96.11	127.96	60.11	21.56	-0.22	1.70	2.04
<i>WATER</i>	24.27	30.68	18.52	3.63	0.14	1.89	1.42
<b><i>Ghana</i></b>							
<i>ENERGY</i>	6137.96	8387.00	3727.00	1237.63	-0.19	2.76	0.22
<i>FOOD</i>	102.09	154.69	54.51	33.36	0.21	1.71	2.01
<i>WATER</i>	1431.90	1935.69	1030.61	273.74	0.26	1.89	1.63
<b><i>Nigeria</i></b>							
<i>ENERGY</i>	6137.96	8387.00	3727.00	1237.63	-0.19	2.76	0.22
<i>FOOD</i>	91.57	119.94	60.02	18.60	-0.07	1.82	1.52
<i>WATER</i>	1635.11	2206.43	1149.53	321.69	0.18	1.84	1.61
<b><i>South Africa</i></b>							
<i>ENERGY</i>	3814.77	5845.00	772.00	1101.50	-1.13	4.42	7.72
<i>FOOD</i>	100.79	125.85	71.96	16.03	-0.07	1.79	1.61
<i>WATER</i>	948.98	1158.44	781.37	108.38	0.27	2.07	1.24

This is counterfactual, but the high hydro energy production could be attributed to the presence of the Nile River in the country. Ghana also had the highest gross food productivity (154.69 points), while Nigeria had the lowest (60.02)-

### Unit Root Test Result

To determine the Stationarity of the variables, the Augmented Dickey-Fuller (ADF) and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) were employed to test the variables. The KPSS test can determine if a time-series is stationary around a mean or linear/deterministic trend. The estimates of the KPSS test presented in Table 2.0 indicates that all the variables are stationary at levels implying the constancy of the mean and variance around its deterministic trend. This also implies the suitability of the series for the Granger causality test.

**Table 2.0 Unit root Test result**

Country	Variables	ADF	Level	KPSS	Level
Cote d' Ivoire	<i>Food</i>	-3.536*	<i>I(0)</i>	0.081***	<i>I(0)</i>
	<i>Energy</i>	-4.431***	<i>I(0)</i>	0.273***	<i>I(0)</i>
	<i>Water</i>	-9.909***	<i>I(0)</i>	0.190***	<i>I(0)</i>
Egypt	<i>Food</i>	-5.009***	<i>I(0)</i>	0.132***	<i>I(0)</i>
	<i>Energy</i>	-3.539**	<i>I(1)</i>	0.394***	<i>I(0)</i>
	<i>Water</i>	-5.634***	<i>I(2)</i>	0.186***	<i>I(0)</i>
Ghana	<i>Food</i>	-5.046***	<i>I(0)</i>	0.150***	<i>I(0)</i>
	<i>Energy</i>	-2.697*	<i>I(1)</i>	0.200***	<i>I(0)</i>
	<i>Water</i>	-7.063***	<i>I(0)</i>	0.202***	<i>I(0)</i>
Nigeria	<i>Food</i>	-3.255*	<i>I(0)</i>	0.085***	<i>I(0)</i>
	<i>Energy</i>	-2.697*	<i>I(0)</i>	0.200***	<i>I(0)</i>
	<i>Water</i>	-4.580***	<i>I(2)</i>	0.204***	<i>I(0)</i>
South Africa	<i>Food</i>	-6.281***	<i>I(1)</i>	0.126***	<i>I(0)</i>
	<i>Energy</i>	-3.490**	<i>I(0)</i>	0.472***	<i>I(0)</i>
	<i>Water</i>	-5.129***	<i>I(2)</i>	0.167***	<i>I(0)</i>

**Note:** \*, \*\* and \*\*\* indicates statistical significance at 10, 5 and 1 per cent respectively

Source: *Author's computation*

### Non-Linear and Linear Granger Causality Test

The estimates from the nonlinear Granger causality presented in Table 4.0 were generally insignificant, indicating the acceptance of all the null hypotheses that there is no causal relationship between the variables. Though the Granger test may be hypothetical, and thus one needs to thread with caution in the interpretations of the results. However, the linear Granger causality result presented in Table 3.0

looks more robust than the nonlinear estimates, as the later predominantly had very low F-statistics and high probability values, depicting statistical insignificance. This invalidates our earlier assumption of the existence of non-linearity among WEF.

**Table 3.0 Linear Granger Causality Estimates**

<b>Hypothesis</b>	<b>Cote d'Ivoire</b>	<b>Egypt</b>	<b>Ghana</b>	<b>Nigeria</b>	<b>South Africa</b>
	<i>F-Stat.</i>	<i>F-Stat.</i>	<i>F-Stat.</i>	<i>F-Stat.</i>	<i>F-Stat.</i>
<i>ENERGY does not Granger Cause FOOD</i>	0.14	0.39	0.67	0.83	1.66
<i>FOOD does not Granger Cause ENERGY</i>	0.11	0.74	0.11	1.41	0.17
<i>WATER does not Granger Cause FOOD</i>	1.68	0.79	0.31	0.70	5.45***
<i>FOOD does not Granger Cause WATER</i>	0.38	1.35	0.08	2.77*	0.23
<i>WATER does not Granger Cause ENERGY</i>	0.30	4.50**	2.54	2.84*	7.93***
<i>ENERGY does not Granger Cause WATER</i>	2.37	0.87	1.37	1.11	0.44

\*, \*\* and \*\*\* indicates statistical significance at 10, 5 and 1 per cent respectively

Source: *Author's computation*

While estimates from the linear causality test showed that water Granger causes food productivity in South Africa, the estimates for Nigeria indicated that food productivity Granger cause water supply in Nigeria. Though this is counter-intuitive because it may be quite difficult to establish causation from food to water. The unidirectional causality running from water supply to food productivity implies that the availability of fresh water is very vital for food production in South Africa. However, the most consistent and significant results found was that water Granger causes energy productivity in 3 countries (Egypt, Nigeria, and South Africa) out of the 5 countries sampled, implying that the availability of water bodies in these countries is very important for hydropower generation. The result supports the situation of Nigeria which relies to a great extent on hydro-electric energy, though supplemented with gas. Similarly, Egypt's high production of hydro-electric energy could be attributed to the presence of and utilization of the Nile River. The absence of causality running from the water to energy productivity in Cote d' Ivoire and

Ghana are not surprising because power generation is largely sourced from fossil fuel.

Other interesting findings from the estimates are the consistency of non-Granger causality moving from Energy to Water; Energy to Food and Food to Energy based on variables used as proxies for the analysis. But this is open to debate within several contextualizations of the variables, with the possibility of having diverse results from the nexus.

**Table 4.0 Nonlinear Granger Causality Estimates**

Hypothesis	Cote d'Ivoire	Egypt	Ghana	Nigeria	South Africa
	<i>F-Stat.</i>	<i>F-Stat.</i>	<i>F-Stat.</i>	<i>F-Stat.</i>	<i>F-Stat.</i>
<i>ENERGY does not Granger Cause FOOD</i>	0.003	-0.33	0.0001	-0.019	-0.01
<i>FOOD does not Granger Cause ENERGY</i>	-0.0003	-0.42	-0.0003	-0.002	0.003
<i>WATER does not Granger Cause FOOD</i>	-0.219	-0.04	-0.01	-0.007	-0.018
<i>FOOD does not Granger Cause WATER</i>	-0.034	-	-0.024	-0.017	-0.028
<i>WATER does not Granger Cause ENERGY</i>	-0.00001	-0.01	-0.0004	-0.007	-0.004
<i>ENERGY does not Granger Cause WATER</i>	-0.017	-	-0.0003	-0.005	-0.018

**Note:** \*, \*\* and \*\*\* indicates statistical significance at 10, 5 and 1 per cent respectively

Source: *Author's computation*

### Conclusion and Recommendations

This study empirically evaluated the water, food and energy nexus as proposed in WEF (2011), Hoff (2011) and Rasul (2014). The study argued that though the nexus exists, it may not follow the assumption of a normal distribution of the variables. But given the contextual issues associated with variables such as extreme climatic

conditions such as drought, flood and excessive torrential rainfall, one could assume the likelihood of a non-linear association among the variables. This informed the study in adopting the linear and nonlinear Granger causality test to verify the hypothetical existence of the WEF nexus using data from five (5) African countries. The result of the linear Granger test indicates a strong link from water to energy in three (3) countries (Egypt, Nigeria and South Africa), implying a unidirectional flow. There is also a significant unidirectional flow from water to food in South Africa. The estimates for these countries further indicate that energy production is highly dependent on water supply, though, with Egypt having the highest productivity in terms of Hydro energy production. Another key finding is the absence of a directional relationship between energy and food production. This may also be since most finished food produced in these countries are being imported. Thus, may not have any significant direct link. However, the study was not able to empirically verify the trade-offs that were assumed to have existed among the resources. The remaining countries had not significant Granger causal relationship and hence, much cannot be said about them.

The study, therefore, recommends the need for future research in this area involving panel data analysis and besides, the need to explore other alternative measures of water, food and energy to further establish empirically the WEF link, thereby identifying the existing trade-offs among them.

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