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An Assessment of Water-Energy-Food Nexus for Environmental Sustainability: The Case of Developing Economics

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ABSTRACT

This study examines the water-energy-food nexus for environmental sustainability using panel data of developing economies from 1995-2017. Food index has been constructed using principle component analysis (PCA). Two-step difference generalized method of moment has been employed to estimate four models for assessment of the nexus in 77 developing economies from 1995-2017. Results indicate that the water, energy and food are closely related to each other as one sector affects the productivity of the remaining two sectors. Energy use and food index have strong positive effects on water productivity in developing economies. The environmental degradation of developing economies analyzed through the environmental Kuznets curve hypothesis confirms the inverted U-shaped relationship between environmental pollution and economic growth for developing economies. Study suggests that an integrated policy is required for the management of energy, water and food resources to avoid the water scarcity and food insecurity in the developing world.

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1. Introduction

Food, water, and energy resources are essential components for human development and environmental sustainability. These components are dynamically related to each other as water, energy and food form a nexus and performance of one sector affects the performance of the other sectors (FAO, 2014; Hoff, 2011). In the present day world, most of the energy production depends heavily on availability of water resources and it is also considered as backbone for food production. On the other hand, water extraction, its distribution and treatment entails sufficient supply of energy. This interdependence[1] of these three sectors is called water-energy-food (WEF) nexus (Bazilian et al., 2011; Hussey & Pittock, 2012; Rasul, 2016; Shah, 2010).

This association between these critical resources is the prerequisite for achieving sustainable development (Biggs et al., 2015). Three of the 17 SDGs are related to water-energy and food nexus encompassing SDG 2, 6 and 7 namely; zero hunger, clean water and sanitation, and affordable and clean energy, respectively. The main theme of SDGs is management of these resources i.e. water, energy and food etc.(Mabhaudhi et al., 2018). percent (5.6 billion) of the world population is living in Asia and Africa, also termed as the most developing regions of the world (United Nations (UN), 2017). Annual population growth rate of 1.42 percent in low and lower-middle income countries is three times higher than the 0.56 percent growth in high income countries (World Bank, 2018). Increased population growth has led to increased demand for food production and water availability.

[1] Water requirement for energy and food production, while energy is needed for different purposes of water.

Water is indispensable for human needs in the food production, washing, sanitation and other domestic and industrial expediencies. The demand and supply of water is being effected by various factors, recently, such as population growth, technological growth, urbanization, social factors, intergovernmental relations, climate uncertainties, and political and policy choices (Plappally, 2012). The increase in freshwater withdrawals for agricultural consumption is anticipated to increase up to 10 percent by 2050 (FAO, 2011). Agriculture sector uses 70 percent of total freshwater withdrawals mainly used for production of crops, fisheries and forestry. Water is also used to transport or produce energy in different forms (FAO, 2011).

With the growing water demand, an issue of its scarcity arises which is not only related to quantity of available water but also the water quality. Contaminated water possesses serious health risks as approximately 900 million people in the world suffer from diarrhea due to consumption of polluted water and everyday 340 children under the age of five die due to diarrhea. It is also projected that two third of the world's population may face water shortage by 2025 and this will be a serious problem in near future (UNICEF, 2015).

Food security in the developing regions of Africa and Asia has deteriorated in 2017. The quantum of chronic malnutrition and under-nutrition among population increased to 815 million in 2016 compared to 777 million in 2015, which reflects an alarming situation for food provision (FAO, 2017). The competition for land and water has increased in recent years due to population pressure and urbanization especially in developing countries. This increased pressure on land is also causing degradation in soil fertility reducing agricultural production as cereal yields, agricultural value added, and forest area significantly reduce the food-energy-water poverty and increase the level of economic growth (Ozturk, 2017).

Both food and water production (withdrawal, transportation and end use) consume energy in larger amount. About 30 percent of the global energy is consumed in food supply chain (FAO, 2014). On the other hand, water consumption is positively related to energy consumption (Plappaly, 2012). Water-energy and food clearly influence the sustainability of the environment. Natural and exhaustible resources (water and energy) used in production of goods and services are inextricably linked with environmental degradation (Grossman & Krueger, 1995; Syrquin, 1988) The relation of economic activity or economic growth and environmental degradation has been studied extensively from last few decades (Fodha & Zaghdoud, 2010). This relationship is known as environmental Kuznets curve (EKC) hypothesis and predicts an inverted u-shape relationship between economic growth and environmental degradation. According to this hypothesis environmental degradation increases with increase in economic growth until certain level of income is achieved, and then after this threshold level of income or turning point, the environmental degradation decreases with increase in economic growth (Akbostanc, Türüt-Aşık, & Tunç, 2009; Brajer, Mead, & Xiao, 2008; Egli, 2002; Focacci, 2005; Fodha & Zaghdoud, 2010; Grossman & Krueger, 1995; Khanna & Plassmann, 2004; Kuznets, 1955; Roberts & Grimes, 1997; Stern, 2004; Suri & Chapman, 1998).

The above discussion illustrates that food, water and energy are closely related and are heavily dependent upon each other. These resources are currently facing many threats due to climate change, population growth and migration of people which create burden on the economy of developing countries (Ningi, Taruvinga, Zhou, & Ngarava). WEF nexus should be seriously considered in devising appropriate economic policies. There is direct association between food insecurity and energy poverty due to the presence of this nexus (Ningi et al.). WEF nexus is also important for industrial linkages as energy production consuming minimal water should be encouraged and energy efficient investment in the agriculture sector should be encouraged (Yan, Fang, & Mu, 2020).

Rich literature is available on water energy and food nexus (Endo, Tsurita, Burnett, & Orencio, 2017; Galaitsi, Veysey, & Huber-Lee, 2018; Hussey & Pittock, 2012; Plappally, 2012; Weitz, Strambo, Kemp-Benedict, & Nilsson, 2017; Zisopoulou et al., 2018). However, studies including (Galaitsi et al., 2018; Infante-Amate, Aguilera, & de Molina, 2018; Ozturk, 2015; Rasul, 2016; Rasul & Sharma, 2016; Siddiqi & Anadon, 2011; Wa'el A, Memon, & Savic, 2017) are region specific or country specific.

Two studies have empirically discussed the water, energy and food nexus. Ozturk (2015) explored the long term sustainability among BRICS countries by analyzing food, water and energy nexus. Ozturk (2017) examined the water, energy and food poverty nexus along with agricultural sustainability for Sub-Saharan African countries. Current study will be significant contribution in literature in many ways as it discusses the situation of all developing economies. Moreover, current study discusses sustainability in water, energy and food nexus in developing economies using a quantitative approach. This study also tests for the presence of EKC hypothesis in all the developing economies in the presence of constraints of water, energy and food. Thus, the objectives of this study are to estimate the existence of water, energy and food nexus for the case of developing economies, to estimate the dynamic relationship between water productivity, energy consumption and food availability for the case of developing economies and to estimate the relationship between economic growth and CO_2 emissions to comment on the environmental sustainability of the developing economies in the presence of water, energy and food nexus variables.

The rest of the paper is organized as follows; Section 2 discusses the methodology, section 3 presents the results while section 4 concludes the paper with suitable policy recommendations.

2. Data and Methodology

2.1. Data and Variable Description

Panel data set of developing economies from 1995-2017 has been extracted from world development indicators (WDI) published by World Bank. Variables used in the study include water productivity, energy use, economic growth, CO_2 emissions, food index, gross capital formation, industry value added, labor force participation rate, natural resource development, and forest depletion (World Bank, 2019).

Food index is constructed using Principal component analysis (PCA). Agricultural value added, agricultural land under cereal production and agricultural machinery were the variables used for the construction of index. Earlier studies have used these variables for developing such indices (Gebbers & Adamchuk, 2010; Godfray et al., 2010; Wiebe, 2003).

2.2. Econometric Model

Basic Cobb-Douglas production function framework was used for estimation of dynamic relationship among water, energy and food variables for the panel of developing economies. The following framework by Ozturk (2015) puts forwarded the functional relationship as in equation 1;

$$Y_{it} = A_{it}^{\beta 0} W_{it}^{\beta 1} K_{it}^{\beta 2} H_{it}^{\beta 3} L_{it}^{\beta 4} M_{it}^{\beta 5} e_{it}^{\mu} \quad (1)$$

Y represents water, energy and food variables, technology and error term (equation 1). A_{it}, W_{it}, K_{it}, H_{it}, L_{it}, M_{it} and e_{it} represent the technology level, GDP, gross capital formation, per capita health expenditure, labor force participation rate, control variables (net forest depletion, improved water sources, natural resource depletion and industrial value added) and error term, respectively. To estimate the parameters in elasticity form, study has transformed equation (1) into natural logarithmic form (equation 2);

$$Ln(Y)_{it} = \beta_0 + \beta_1 ln(W)_{it} + \beta_2 ln(K)_{it} + \beta_3 ln(H)_{it} + \beta_4 ln(L)_{it} + \beta_5 ln(M)_{it} + \mu_{it} \quad (2)$$

Where *Ln* presents natural log while the μ denotes the error term. To evaluate the dynamic relationship among water, energy and food variables, three simultaneous models are introduced in this study which are presented as

2.1.1. Model 1: Energy Use

$$\ln(ENRG_{i,t} - ENRG_{i,t-1}) = \beta_0 + \beta_1 ln(GDP_{it} - GDP_{i,t-1}) + \beta_2 \ln(CO_{2_{it}'} - CO_{2_{i,t-1}'}) + \beta_3 \ln(GCF_{i,t} - GCF_{i,t-1}) + \beta_4 (LFPR_{i,t} - LFPR_{i,t-1}) + \beta_5 ln(HEXPPC_{it} - HEXPPC_{i,t-1}) + \sum_{h=1}^{4} \delta W_{h,it-1} + n_i + \varepsilon_t + \mu_{it} \quad (3)$$

Energy use model estimates the effect of independent and control variables on energy use. Where ENRG represents energy use, GDP refers to gross domestic product, CO_2 represents CO_2 emissions, HEXPPC reflects per capita health expenditure, LFPR represents labor force participation rate, GCF corresponds to gross capital formation, while W depicts all control variables including; industrial value added, natural resource depletion, net forest depletion. ε_t is the time specific effect, and n_i represents country specific effect while μ_{it} is the error term (equation 3).

2.1.2. Model 2: Food Index

$$\ln(FIND_{i,t} - FIND_{i,t-1}) = \beta_0 + \beta_1 ln(GDP_{it} - GDP_{i,t-1}) + \beta_2 \ln(CO_{2_{i,t}'} - CO_{2_{i,t-1}'}) + \beta_3 \ln(GCF_{i,t} - GCF_{i,t-1}) + \beta_4(LFPR_{i,t} - LFPR_{i,t-1}) + \beta_5 ln(HEXPPC_{i,t} - HEXPPC_{i,t-1}) + \sum_{h=1}^{4} \delta W_{h,it-1} + n_i + \varepsilon_t + \mu_{it} \quad (4)$$

Model 2 in equation 4 estimates the effect of regressors and control variables on food index. This model estimates the situation of food security in developing economies using different logical variables. Various studies analyzed food security issue and estimated the food index with similar variables as in this study except a few with different variables (Gebbers & Adamchuk, 2010; Godfray et al., 2010; Wiebe, 2003).

2.1.3. Model 3: Water Productivity

$$\ln(WPRO_{i,t} - WPRO_{i,t-1}) = \beta_0 + \beta_1 ln(GDP_{it} - GDP_{i,t-1}) + \beta_2 \ln(CO_{2_{i,t}'} - CO_{2_{i,t-1}'}) + \beta_3 \ln(GCF_{i,t} - GCF_{i,t-1}) + \beta_4(LFPR_{i,t} - LFPR_{i,t-1}) + \beta_5 ln(HEXPPC_{i,t} - HEXPPC_{i,t-1}) + \sum_{h=1}^{4} \delta W_{h,it-1} + n_i + \varepsilon_t + \mu_{it} \quad (5)$$

Water productivity in equation 5 is explained by different explanatory variables and helps to comment on the water scarcity issue of the developing economies. Model 4 in equation 6 exhibits environmental degradation measured with CO_2 emissions and explains the existence of EKC in developing economies.

2.1.4. Model 4: Environmental Sustainability

$$ln(CO_{2_{i,t}'} - CO_{2_{i,t-1}'}) = \beta_0 + \beta_1 ln(GDP_{it} - GDP_{i,t-1}) + \beta_2 \ln(GCF_{i,t} - GCF_{i,t-1}) + \beta_3(LFPR_{i,t} - LFPR_{i,t-1}) + \beta_4 ln(HEXPPC_{i,t} - HEXPPC_{i,t-1}) + \sum_{h=1}^{4} \delta W_{h,it-1} + n_i + \varepsilon_t + \mu_{it} \quad (6)$$

Generalized methods of moment (GMM) is suitable econometric technique to obtain results in the presence of panel endogeneity through instrumental variables and reduction of small sample bias. The rule of thumb to apply GMM is when T< N (where, T denotes time period= 22 years), and N denotes the cross-sections (77 countries).

Arellano-Bond for dynamic panel estimation is used as this dynamic modeling design is used for following situations; (i) When T<N, where T refers time period, N refers individuals, (ii) When functional relationship is linear, (iii) When any dependent variable is dynamic in nature depending on its lag values, (iv) Independent variable is not strictly exogenous, (v) When autocorrelation and heteroscedasticity is present in data, and (vi) when fixed individuals effects are present in data (Roodman, 2009). In Arellano-Bond estimation, all regressors are transformed by differencing method and generalized method of moment is used for it is known as difference GMM.

Difference in Hansen Test (DHT) evaluated the exogeneity of instruments. The acceptance of null hypothesis is necessary for the validity of test. Sargan test of over-identifying restrictions (OIR) postulates the validity of over-identifying restrictions through the null hypothesis. Hence, the acceptance of null hypothesis refers as the instruments of model are uncorrelated with error term and explanatory variables have only effect on endogenous variable through the mechanism of endogenous variables.

Autocorrelation of models has been checked by the Arellano-Bond test. The null hypothesis of test is that no autocorrelation exists. As the AR (1) is applied on difference residuals so test statistic should be significant and reject the null hypothesis. The equations 7 and 8 show Arellano-Bond test.

$$\Delta\mu_{i,t} = \mu_{i,t} - \mu_{i,(t-1)} \quad (7)$$
$$\Delta\mu_{i,(t-1)} = \mu_{i,(t-1)} - \mu_{i,(t-2)} \quad (8)$$

3. Results and Discussion

Table 1 depicts the summary of descriptive statistics by mean, standard deviation, minimum and maximum value of variables.

Table 1: Summary of Descriptive Statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Labor Force Participation Rate	1,771	61.76	10.82	36.95	86.23
Improved Water Source	1,771	63.14	24.44	4.74	98.94
Natural Resource Depletion	1,771	4.59	5.96	0.00	36.87
Net Forest Depletion	1,771	3.21	4.92	0.00	36.87
Food Index	1,771	21.39	1.76	17.49	26.66
GDP(constant)	1,771	7.72	0.96	5.21	9.61
CO_2 emissions	1,771	0.23	1.26	0.04	15.64
Gross Capital Formation	1,762	22.82	2.14	-9.50	4.79
Industrial Value Added	1,771	22.92	2.09	18.23	29.18
Energy Use	1,771	4.84	0.63	.870	6.78
Per Capita Health Expenditure	1,771	7.72	0.96	5.21	9.61
GDP^2	1,771	50.11	3.78	41.95	61.37
Water Productivity	1,771	6.81	8.08	1.73	26.65

3.1. Results of Difference GMM

Table 3 presented the results obtained from difference GMM for four defined models. For every model there are two estimates GMM-I and GMM-II, respectively. The second and third column present the results of model 1 and evaluate the impact of independent variables on energy use. The results show significant parameters of health expenditure, GDP, CO_2, improved water sources, Gross capital formation, Industry value added, and labor force participation, NRD and NFD.

Health expenditures, improved water sources, NRD and NFD have negative impact on energy, whereas, GDP, CO_2, GCF, Industry value added and labor force participation have positive impact on energy demand in developing countries.

While column 3 presents the results of second equation of first model. The second model is estimated by excluding some control variables and including first lags of all dependent variables. Column 2 results indicate that energy use and food index are negatively related, while the total water productivity is positively linked with energy use. With every 1 percent increase in per capita health expenditures there is 0.4 percent decrease in energy use.

According to the theory in early stages of development the demand for energy increases so the energy use rises but later on this demand is fulfilled by energy mix (Heidari & Omid, 2011). The results confirm the theory that GDP has positive effect on energy use while GDP^2 is negatively linked with energy use. Due to this transformation of growth, LFPR intensifies the energy use while the CO_2 emissions increase the energy use, to keep the environmental sustainability.

Whenever the depletion of natural resources increases in any developing economy, the energy use decrease. According to the results, if natural resource depletion and net forest depletion increase by 1 percent then energy use decreases by 0.007 percent. Although coefficient is very small but still it has statistically significant impact on developing economies. The relation of variables in first model conforms with Ozturk (2017).

The column 4 and 5 contain the result of second model which has estimated the impact of independent variables on food index constructed by Principle component analysis (PCA). Results for all the variables are significant. Energy use worsens the food security in developing economies while the total water productivity (WPRO) and improved water sources (IWS) contribute to food security because water is primary factor in agriculture productivity (Liu et al., 2015).

The Food index (FIND) increases with the health expenditures, GDP, CO_2, Gross capital formation, labor force participation and NRD. It refers to the conclusion that an increase in these variables will increase the food production and consumption in developing countries. While the food index is negatively affected due to increase in NFD and industry value added (IND).

Model 3 results have been presented in column (6) and (7) of Table 3. Water productivity is taken as dependent variable. Energy use positively affects the WPRO, as due to the use of energy, water can be used efficiently in every sector. While food index negatively affects the water productivity.

In initial stages of economic growth (GDP), the water productivity reduces due to the process of industrialization. NRD, NFD and GCF worsens the water productivity, because depletion of natural resources including forests affects the ground water (Liu et al., 2015). Health expenditures, improved water sources, industry value added and labor force participation have direct impact on water productivity of developing nations.

Column 8 of Table 3 presents results of model 4, estimated to check the existence of EKC in the developing countries. As income (GDP) increase in developing economies, CO_2 emissions increase while after a certain point the increase in income (GDP^2) has negative impact on pollution. These results confirm the existence of EKC in developing economies. These results conform with the previous studies (Carson, Jeon, & McCubbin, 1997; Fodha & Zaghdoud, 2010; Grossman & Krueger, 1995; Kuznets, 1955)).

Table 3: Difference GMM

Variable	**ln ENRG**		**LnFIND**		**WPRO**		**CO_2**
	GMM I	GMMII	GMMI	GMMII	GMM I	GMM II	GMM
$(lnENRG)_{t-1}$	0.594 (0.000)	0.555 (0.000)	-	-0.206 (0.000)	-	0.118 (0.000)	-
$(LnFIND)_{t-1}$	-	-0.0684 (0.000)	0.558 (0.000)	0.556 (0.000)	-	0.139 (0.000)	-
$(WPRO)_{t-1}$	-	0.0644 (0.000)	-	0.032 (0.117)	0.020 (0.115)	-0.101 (0.000)	-
$(LnCo_2)_{t-1}$	-	-	-	-	-	-	0.379 (0.000)
LHEXPPC	-0.478 (0.000)	0.7656 (0.000)	0.306 (0.000)	2.356 (0.000)	0.123 (0.000)	0.178 (0.000)	1.280 (0.000)
$(LnGDP)_{t-1}$	0.179 (0.000)	-	-0.530 (0.000)	-	-0.198 (0.000)		1.990 (0.000)
$LnGDP^2$	0.072 (0.001)	-0.0594 (0.000)	0.149 (0.000)	-0.129 (0.000)	0.102 (0.000)	0.035 (0.001)	-0.515 (0.000)
$LnCO_2$	0.094 (0.000)	0.0408 (0.000)	0.036 (0.000)	-0.044 (0.000)	-0.067 (0.000)	-0.067 (0.000)	-
IWS	-0.014 (0.000)	-	0.009 (0.000)	-0.063 (0.000)	0.004 (0.000)	-	0.002 (0.000)
LnGCF	0.090 (0.000)	-	0.022 (0.000)	-	-0.008 (0.000)	-	0.028 (0.250)
LnIND	-0.062 (0.000)	-0.073 (0.000)	-0.039 (0.000)	-0.064 (0.000)	0.019 (0.000)	0.012 (0.138)	0.335 (0.000)
LFPR	0.005 (0.164)	0.029 (0.000)	0.010 (0.000)	0.042 (0.000)	0.026 (0.000)	0.024 (0.000)	-0.071 (0.000)
NRD	-0.007 (0.000)	-0.011 (0.000)	0.002 (0.000)	-0.004 (0.000)	-0.001 (0.022)	0.001 (0.000)	-0.004 (0.000)
NFD	-0.007 (0.000)	-	-0.015 (0.000)	-	-0.004 (0.000)	-	0.011 (0.000)
AR(1)	0.032	0.038	0.003	0.004	0.014	0.001	0.094
AR(2)	0.366	0.500	0.425	0.683	1.000	0.695	0.254
Sargan OI	0.112	0.008	0.087	0.436	0.000	0.896	0.000
Hansen OI	0.659	0.613	0.561	0.550	0.622	0.652	0.281
IV(year, eq(diff)) Hansen test excluding group:	0.703	0.598	0.558	0.517	0.589	0.620	0.259
Difference (null H = exogenous)	0.133	0.457	0.347	0.806	0.854	0.888	0.563
Fisher	26823.89 (0.000)	57989.9 (0.000)	13047.23 (0.000)	9970.69 (0.000)	28889.30 (0.000)	10311.59 (0.000)	1392.70 (0.000)
Observation	1617	1617	1617	1617	1617	1617	1607
Countries	77	77	77	77	77	77	77
Instruments	76	76	76	76	76	76	61

Arellano and Bond test of first order AR (1) and second order AR (2), Sargan and Hansen test of over-identified restrictions are basically used for the validity of results as diagnostic tests. The results depict that for AR (1) is significant in all the models and AR (2) is insignificant. Therefore, null hypothesis cannot be rejected and autocorrelation does not exist in any model.

Sargan test of over-identification is only insignificant in energy and food model. Hansen test of over identification and test for instruments are also insignificant in all the regressions which indicates the validity for instruments by failing to reject the null hypothesis. The instruments in four regressions are less than countries. F-statistic reflects that overall model is statistically significant. The results are strongly significant in each regression.

4. Conclusion and Policy Recommendations

This paper examined the water-energy-food nexus in panel of developing economies. The interdependency of water, energy and food sectors on each other is called water-energy-food nexus. The Food variable in this study has been constructed using three variables, namely; agricultural machinery, agricultural value added and land under cereal production using principle component analysis (PCA). The study also commented on existence of environmental sustainability in developing economies.

The generalized method of moment was employed for estimations, which is considered as preferred measure in panel estimations. Further, study selected two-step difference generalized method of moments to estimate the four models of water energy, food and environmental sustainability.

The results suggest that water, energy and food are closely related to each other as one sector affects the productivity of remaining two sectors. Results finds that WPRO and FIND influence the energy use in developing economies. Energy use is negatively affected by HEXPPC while GDP effects the energy use according to the development theory.

While the food sector is also heavily effected by energy use due the mechanization and processing of food, water productivity and improved water sources are directly linked with the food index. Natural resource and forests resource depletion worsens the food security situation of developing economies.

It is evident that ENRG and FIND have strong positive effect on WPRO in developing economies. NRD and NFD affect the water sector negatively, water productivity is also influenced by the improved water sources and gross capital formation. The environmental degradation of developing economies is tested through the EKC hypothesis and study comments that EKC exist in the case of selected panel of developing economies.

Integrated policies are required to manage the resources of water, energy and food. The integrated management is mainly required in developing economies. Integrated management refers to as the management of water resources to command and control different water sectors e.g. commercial, household, agriculture and others, and integration of governance of various water bodies e.g. groundwater, sea, rivers and lakes. While integrated energy policy postulates the management of production and consumption of different kinds of energy resources such as gas, fuel, coal, oil, renewable energy, hydro-power and nuclear energy.

The management of these resources is need of hour because sustainable development demands such kind of management in developing economies. Water scarcity and food insecurity are burning global issues and our study will help the policymakers in setting up policies to help manage the water and energy resources.

Our analysis is limited to only the nexus among water-energy and food. As these three issues are burning global issues due to the projection of population growth and raising demand of water energy and food. The further study should be on how to deal with energy to produce food efficiently and to improve productivity of food sector, and how both water and energy can help in achieving the green revolution in developing economies. For future research, this study recommends to carry out comparative analysis of water-energy-food nexus between developed and developing economies.

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