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An Empirical Analysis of Water-Energy-Environment Nexus: The Case of Developing Economies

Faisal Mehmood Mirza[1], Abre-Rehmat Qurat-ul-Ann[2], Syed Badar-ul-Husnain Rizvi[3], Wajeeha Arshad[4]

[1] Professor, Department of Economics, University of Gujrat, Pakistan. Email: faisal.mirza@uog.edu.pk
[2] Assistant Professor, Department of Economics, University of Gujrat, Pakistan. Email: abre.rehmat@uog.edu.pk
[3] Assistant Professor, Department of Economics, University of Gujrat, Pakistan. Email: badarrizvi@uog.edu.pk
[4] MPhil Scholar, Department of Economics, University of Gujrat, Pakistan. Email: wajihaarshad1@gmail.com

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ABSTRACT

Water, energy, and environment play a significant role in the economic growth and sustainable development of an economy. Energy and water resources rely on each other as energy is derived from water and water can be extracted with the use of energy, and environmental quality is affected by the use of energy and water. Current research examines this nexus using panel data of developing economies. Ecological Footprint (EF) has been used to measure environmental quality, environmental degradation and its sustainability in developing economies. Empirical results based on two-step difference generalized method of moments indicate that water, energy and environment are closely related to each other. Water productivity influences energy consumption and both energy use and water productivity have strong effects on climate change in case of developing economies. Integrated policy actions are required for water, energy and environmental management to avoid water scarcity and environmental degradation in developing economies.

Corresponding Author's Email: abre.rehmat@uog.edu.pk

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1. Introduction

Water, energy, and environment are crucial for economic growth and sustainable development. Energy and water resources are synergetic as energy can be produced from water and water can be extracted with the use of energy (Moadel, Amidpour, Abedi, & Kani, 2022; Stillwell, King, Webber, Duncan, & Hardberger, 2011). Energy demand is the key factor that increases pollution emissions. Climate change and socioeconomic changes increase energy demand and threaten energy security. Severe climate change impacts exacerbate water stress which resultantly affects agriculture and energy output. Forecast of 50 percent increase in world population growth by 2050 suggests, increase in energy, water, and food needs (Moadel et al., 2022).

The current study is an attempt to comment on the water-energy-environment nexus and its effects on the environmental sustainability for the case of developing economies. Water-energy-environment nexus is closely associated with the sustainable development goals (SDGs), mainly 6, 7 and 13 (water and sanitation, affordable energy and climate action). There is a two-way dependence between energy sector and the water availability. Hydropower share in global electricity production is 17 percent and is contingent on water availability (Kalair et al., 2019). Energy production techniques are contingent on accessibility of water, and clean water production consumes energy. Energy production from fossil fuels consumes water, hence, water use for domestic and industrial processes results in water pollution. Moreover, energy is required for the abatement of water pollution in order to recycle clean water back into the natural environment (Lim et al., 2012).

Water scarcity is not only related to the quantity of available water but also to the quality of water for utilization in future. Climate change has caused imbalance in water availability. Worldwide, water scarcity affects 4 billion people for at least one month in a year, greater than the estimate of two to three billion in literature (Du Plessis & du Plessis, 2019). 1.1 billion people face difficulty in accessing clean water. It is projected that two-thirds of the global population can face water scarcity by 2025. Developing countries are most endangered from this threat as they face water scarcity, poor water quality and flooding.

Contaminated water possesses serious health risks such as diarrhea, cholera, dysentery, typhoid, and polio. 80 percent of the diseases in developing countries emerge due to poor water and sanitation (Du Plessis & du Plessis, 2019). 2.6 billion individuals do not have access to sanitization, and 1.8 million children die from diarrhea every year. Obstacles to improvements in water quality in developing nations include poor and bad governance, lack of education, poverty, and climate change (Organization, 2019).

The income growth in the global economy is associated with growth in per capita energy use. 90 percent of fossil fuel resources are currently consumed by 10 percent of global population. Energy systems nowadays depend on fossil fuel resources which are diminishing more rapidly, hence, earth is expecting a future deprived of fossil fuels (Bilgen, 2014). Developing countries consume approximately 60 percent of the global energy resources and their growth rate in 2018 was 2.7 percent. Although developing countries will use 65 percent of the world energy in 2040, international energy consumption is predicted to grow up to 50 percent by 2035 (IEA., 2017).

Developing countries on the other hand are also facing severe energy crisis. 992 million of global population does not have access to electricity and majority of this population resides in Sub-Saharan Africa and Asia (Energy, 2018). Albeit India is one of the major global energy user it also has the largest electricity shortfall of 168 million people living without electricity access (Energy, 2018). Ethiopia is fastest growing economy in Africa but only 23 percent of its population was linked to the national grid in 2012. In the same year, 87 percent of urban population and only 5 percent rural population had electricity access (Mondal, Bryan, Ringler, & Rosegrant, 2017).

Energy-related policies are being formulated to achieve sustainable development and achieve cleaner environment as 90 percent of the global CO_2 emissions are caused by the energy sector (Energy, 2018).Hence, energy efficiency is a significant tool to tackle many energy-related challenges including climate change (Shahiduzzaman & Layton, 2017). Since 2000, the improved energy efficiency policies have resulted in reduction of GHGs emissions by 12 percent and fossil fuels imports by 20 percent (Gielen et al., 2019). Global CO_2 emissions stayed fixed during 2014-2016 as enhanced energy efficiency and the increased use of low carbon technologies (Energy, 2018). It is predicted that despite increase in population and three times increase in global economy by 2050, energy efficiency will ensure 35 percent savings in CO_2 emissions (Energy, 2018).

Geographically, most of the developing countries are situated in high temperature zones. The rising temperature increases the probability of temperature related injuries and deaths (Ketzenberger, 2013). Within developing countries, the masses belonging to the lowest income strata are the most vulnerable to climate change (Hallegatte & Rozenberg, 2017). In 2100, GDP per capita would be lower by 9 percent in developing countries than it would have been without the temperature rise (Goncalves & Smith, 2017). CO_2 emissions in developed countries are declining while the CO_2 emissions from developing countries are increasing at a higher pace (Ogle et al., 2018).

Developing countries depend on climate-sensitive sectors like forestry, agriculture, and tourism; hence, increased temperature can result in fall in agricultural output, inadequate food for domestic consumption, and worsening of major exports. The changing climate has a variety of physical and health impacts, including extreme weather events like storms, floods, and heat waves (Ritchie & Roser, 2017).

Understanding water, energy, and environment nexus is, therefore, vital for sustainable development in developing countries. To the best of our knowledge, although some studies exist on water, energy, and environment nexus (Krajačić, Vujanović, Duić, Kılkış, & Rosen, 2018; Lofman, Petersen, & Bower, 2002; Moadel et al., 2022; Momblanch et al., 2019; Nair, George, Malano, Arora, & Nawarathna, 2014; Shahzad, Burhan, Ang, & Ng, 2017; Tidwell & Pebbles, 2015; Yazdandoost & Yazdani, 2019). Most of them are region-specific and country-specific (Lofman et al., 2002; Nair et al., 2014; Yazdandoost & Yazdani, 2019). This study adds to the prevailing literature in numerous aspects. Literature has discussed energy, water, and environment nexus through a qualitative approach and lacks empirical work for developing countries on this issue. Current study discusses sustainability in water, energy, and environment nexus in developing economies using a quantitative approach.

Research objectives of the study are to investigate the existence of water, energy, and environment nexus in developing economies, and to estimate dynamic relationship among water productivity, energy consumption, and climate change for developing economies. The remaining paper is structured such as section 2 covers literature review, whereas, section 3 elaborates on the methodology. Section 4 interprets results, while section 5 concludes with appropriate policy recommendations.

2. Review of Literature

The debate on water-energy-environment nexus has attracted economists as these are the main resources required for human development. Akbostancı, Türüt-Aşık, and Tunç (2009) examined the relationship between environment quality and income at national and provincial level in Turkey from 1968-2003 and found the existence of monotonically increasing relationship between CO_2 emissions and per capita income. Apergis, Payne, Menyah, and Wolde-Rufael (2010) explored the causal relationship among real output, energy consumption, and CO_2 emissions for commonwealth independent states from 1992-2004. Long-run panel VECM results found a positive association between energy consumption and CO_2 emissions. Short-run unidirectional causality exists from energy use to CO_2 emissions while in the long run, bidirectional causal relationship is found.

Alam (2010) investigated the link between industrialization, globalization, population, and urbanization and their impacts on CO_2 emissions in Pakistan. Results proposed that increasing industrialization, rapid urbanization, growing population and increasing economic growth significantly increases CO_2 emissions. The study concluded that to attain sustainability, it is necessary to increase global integration, reduce poverty, use efficient green technologies, and control growing population and urbanization.

Fodha and Zaghdoud (2010) employed cointegration analysis to quantify the relationship amid pollution emissions and economic growth in Tanzania from 1961-2004. Long run association exists between economic growth and pollution emissions. The study further found unidirectional relationship from income to pollution.

Molden et al. (2010) in their analysis for improving agricultural water productivity stated that water productivity is the net return for a unit of water consumed. Analysis suggested that improved water productivity is desired for producing more food, improving livelihood, income, services with a smaller amount of water and less social and environmental cost per unit of water consumed.

Different processes related to water like extraction, transfers and disposing off require energy and in the same way different sources of energy production require water. Siddiqi and Anadon (2011) found that water extraction and production is heavily dependent on energy. Plappally (2012) examined the literature and found that underground water pumping is more energy intensive as compared to surface water pumping. In the household sector, when the demand for pumped water is increased, the energy consumption also increased. Small wastewater treatment plants consume most energy in the digestion process.

Al-Karaghouli and Kazmerski (2013) studied the interrelationship between energy consumption and water production and showed that purification techniques increase water quality, significantly decrease problems of water shortage and develop better livelihood and economic status. Chen, Yang, and Chen (2013) divided CO_2 emissions into indices of energy structure, population, energy intensity, economic activity and structure of the economy from 1985-2011. Change in all factors increased CO_2 emissions except energy intensity. Energy intensity leads to reduction in energy related CO_2 emissions. Improvement in energy efficiency effectively reduces energy intensity. The results suggested policymakers to implement energy efficient technologies to effectively diminish CO_2 emissions.

Tidwell and Pebbles (2015) examined the energy, water and environment nexus in the Great Lakes Regions and explored how diverse energy production portfolios might disturb the water resources. Primarily, water and energy have a strong association as water is required for electricity generation in most parts of world, and, similarly, water treatment and transportation requires energy. Hamiche, Stambouli, and Flazi (2016) comprehensively analyzed this relationship and developed a classification system for the water-energy links. The study suggested that the earlier approaches in the literature are not appropriate and future research should examine it within a broader perspective.

Khan et al. (2016) analyzed the triangular association amid water resources, energy consumption and air pollution in Pakistan from 1975-2012. Long run and short run association existed amongst CO_2 emissions, energy consumption and water resources. Water resources and energy consumption had positive relationship in both long run and the short run. Due to climatic factors, CO_2 emissions had negative impact on both air quality and GDP per unit of energy use.

Ozturk (2017) reviewed the water-energy-food-poverty nexus with respect to agriculture sustainability in sub-Sahara African countries. The study is limited to only African countries and do not discuss the overall case of developing economies. Ali, Anwar, and Nasreen (2017) observed causal link between renewable energy consumption, population, non-renewable energy consumption, GDP growth and CO_2 emissions in South Asia during 1980-2013. Johansson Cointegration approach was used to examine the long run association among these variables. The results indicated that economic growth, nonrenewable energy consumption and population density significantly increase CO_2 emissions. Renewable energy consumption had negative association with climate hazards in the long run. Moreover, the study confirmed the existence of EKC hypothesis in South Asian countries.

Momblanch et al. (2019) observed water, energy, environment and food nexus and explored that universal water administration approaches are vital to address the future environmental and socio-economic implications while achieving the relevant SDGs. Study used the system modeling method to determine the universal variation effects on the nexus and depicted that future socioeconomic instabilities will have robust effects on the environment.

Moadel et al. (2022) has developed a new framework established on bottom-up energy system model and associated GHG emissions aimed to forecast and show an obvious WEE nexus stance for agriculture, residential, and electric power industry in Iran under different scenarios. Results found the potential of 27.76 million barrels of oil equivalent of energy saving and 11.3 million metric tons of carbon dioxide equivalent of environmental pollutants abatement as per one scenario.

Siyal (2022) explored the research gaps on links in the water-energy-food nexus in Pakistan and found four key insights; damages in irrigation supply chain are substantial as water footprint literature underestimated blue water consumption and water management literature overestimated blue water losses, Freshwater competition causes water efficiency to increase, Inefficient water use is associated with wasteful energy use, and energy and carbon footprints of irrigation water demonstrate spatial and temporal inconsistencies.

3. Data and Methodology

This study uses panel data of 35 developing countries from 1995 to 2016 for assessment of energy-water-environment. The variables employed in this study consist of energy use, water productivity, ecological footprint, economic growth, gross capital formation, industry value added, labor force participation rate, natural resources depletion and net forest depletion, obtained from World development indicators (WDI, 2019).

3.1. Econometric Model

Cobb-Douglas production function framework is used to estimate the dynamic relationship among energy, water and environment variables for the panel of developing economies. Following the framework from Ozturk (2015), the functional relationship among variables is as follows;

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

Y depicts water, energy, and environment variables, respectively. A represents technology, W stands for economic growth, K refers to gross capital formation, H is per capita health expenditures, L represents labor force participation rate, and M stands for all the control variables namely; net forest depletion, improved water sources, natural resource depletion and industrial value added. *e* represents the error term.

To interpret the parameters in elasticity form, equation 1 is converted into natural logarithmic form in equation 2.

$$lnY_{it} = \beta_0 + \beta_1 lnW_{it} + \beta_2 lnK_{it} + \beta_3 lnH_{it} + \beta_4 lnL_{it} + \beta_5 lnM_{it} + \mu_{it} \quad (2)$$

ln shows natural log while the μ denotes the error term. To evaluate the dynamic relationship between water, energy and environment variables, three concurrent models are employed.

Model 1: Energy use

$$ln(ENRG_{i,t} - ENRG_{i,t-1}) = \beta_0 + \beta_1 ln(GDP_{it} - GDP_{i,t-1}) + \beta_2 \ln(GCF_{i,t} - GCF_{i,t-1}) + \beta_3 \ln(LFPR_{i,t} - LFPR_{i,t-1}) + \beta_4 ln(HEXPPC_{i,t} - HEXPPC_{i,t-1}) + \sum_{h=1}^{4} \delta W_{h,it-1} + n_i + \varepsilon_t + \mu_{it} \quad (3)$$

Energy use model estimates the effect of different independent and control variables on energy use. Where ENRG depicts energy use, GDP refers to gross domestic product per capita, HEXPPC reflects per capita health expenditures, LFPR denotes 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, and improved water resources. ε_t is the time specific effect and n_i shows country specific effect while μ_{it} is the usual error term.

Model 2: Water Productivity

$$ln(WPRO_{i,t} - WPRO_{i,t-1}) = \beta_0 + \beta_1 ln(GDP_{it} - GDP_{i,t-1}) + \beta_2 ln(GCF_{i,t} - GCF_{i,t-1}) + \beta_3 ln(LFPR_{i,t} - LFPR_{i,t-1}) + \beta_4 ln(HEXPPC_{i,t} - HEXPPC_{i,t-1}) + \sum_{h=1}^{4} \delta W_{h,it-1} + n_i + \varepsilon_t + \mu_{it} \quad (4)$$

Model 2 estimates the effect of change in different variables on water productivity in developing economies.

Model 3: Ecological Footprint

$$ln(EF_{i,t} - EF_{i,t-1}) = \beta_0 + \beta_1 ln(GDP_{it} - GDP_{i,t-1}) + \beta_2 ln(GCF_{i,t} - GCF_{i,t-1}) + \beta_3 ln(LFPR_{i,t} - LFPR_{i,t-1}) + \beta_4 ln(HEXPPC_{i,t} - HEXPPC_{i,t-1}) + \sum_{h=1}^{4} \delta W_{h,it-1} + n_i + \varepsilon_t + \mu_{it} \quad (5)$$

Model 3 has been used to measure environmental quality and sustainability. It represents the global impact of human activities. Ecological Footprint is a key measure that allows us to assess the resource use and pollutant absorption by human populace using productive land area. Ecological footprint can be measured either for consumption or production. EF based on consumption is shown as deficit (Ecological footprint exceed Biological capacity) while Ecological Footprint based on production is known as overshoot (Ecological resource depletion).

Generalized methods of moments (GMM) is an appropriate technique for model estimation when panel endogeneity exists (as it uses instrumental variables and reduces small sample bias). The rule of thumb for GMM application is, T < N (T denotes time period in years and N denotes number of countries). Arellano-Bond model for dynamic panel estimation is used when all regressors are transformed by the differencing method along with generalized method of moments known as difference GMM.

The Difference in Hansen test (DHT) tests the exogeneity of instruments. The The test validity is dependent on the acceptance of null hypothesis (H_0). Over-identifying restrictions (OIR) test (Sargan test) postulates, validity of over-identifying restrictions through the null hypothesis, hence, the acceptance of H_0 indicates that the model instruments are uncorrelated with the error term.

Autocorrelation of models is assessed through the Arellano-Bond test (equation 6 and 7), where, null hypothesis is of no autocorrelation. As the AR (1) is applied on difference residuals, therefore, test ought to be significant and should reject H_0.

$$\Delta\mu_{i,t} = \mu_{i,t} - \mu_{i,(t-1)} \quad (6)$$

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

4. Results and Discussion

Table 1 presents the results from difference GMM for three specified models. For every model two estimates of difference GMM are obtained. Results in columns 2 and 3 of model 1 show significant parameters for the effect of health expenditures, GDP, improved water resources, Gross capital formation, industry value added, labor force participation, NRD and NFD, on energy consumption. Health expenditures, improved water sources, NRD and NFD have positive impact on energy use along with the positive impact of GDP, GCF, industry value added, and labor force participation on energy demand in developing countries.

Table 1
Difference GMM Results

Variables	lnENRG		WPRO		LnEF	
	GMM I	GMMII	GMMI	GMMII	GMM I	GMM II
$(\ln ENRG)_{t-1}$	0.162	0.790	-	-	-	-
	(4.93)	(15.45)				
$(LnEF)_{t-1}$	-	-	-	-	0.231	0.231
					(14.51)	(17.20)
$(WPRO)_{t-1}$	-	-	0.673	0.845	-	-
			(10.49)	(35.55)		
LHEXPPC	0.331	0.224	0.706	0.361	0.124	0.394
	(3.13)	(8.23)	(3.17)	(3.22)	(2.07)	(4.75)
LnGDP	0.924	0.399	4.384	0.575	2.150	0.280
	(2.59)	(2.73)	(4.17)	(2.07)	(13.58)	(1.73)
$LnGDP^2$	0.002	-0.008	-0.971	-0.015	-0.036	-0.007
	(-3.42)	(-3.96)	(-4.82)	(-2.63)	(-8.76)	(-1.98)
IWS	0.008	0.007	0.003	0.003	0.005	0.004
	(5.29)	(3.92)	(2.04)	(5.44)	(5.44)	(5.18)
LnGCF	0.030	0.009	0.007	0.015	-0.008	0.009
	(4.00)	(2.14)	(2.30)	(4.12)	(2.94)	(4.24)
LnIND	0.104	0.095	0.201	0.106	0.070	0.827
	(4.85)	(3.97)	(6.00)	(3.72)	(2.63)	(4.16)
LFPR	0.006	0.002	0.036	0.015	-0.017	0.010
	(10.87)	(3.72)	(5.90)	(4.60)	(13.20)	(11.48)
NRD	-0.004	0.004	-0.000	0.002	-0.007	0.000
	(8.32)	(9.07)	(3.04)	(4.30)	(16.39)	(0.38)
NFD	-0.000	0.003	-0.002	0.002	-0.003	0.003
	(9.07)	(3.20)	(2.73)	(4.14)	(13.86)	(8.54)
AR(1)	0.023	0.001	0.002	0.046	0.045	0.007
AR(2)	0.662	0.830	0.618	0.277	0.320	0.618
Sargan OI	0.524	0.511	0.401	0.691	0.691	0.595
Hansen OI	0.729	0.729	0.814	0.795	0.795	0.814
Observation	710	710	710	710	710	710
Countries	36	36	36	36	36	36
Instruments	40	72	46	61	60	90

Note: Z-value in parentheses.

The issue of natural resource depletion arises when speed of resource usage is greater than the speed of replenishment. Rapid natural resource depletion tends to increase the energy consumption. The demand for energy increases in the early stages of development, hence, the energy utilization increases while later, this demand is fulfilled by energy mix. The results confirm the theory that GDP has a 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.

The phenomenon of pollution heaven results in countries with advance technologies and strict environmental policies shifting their dirty technologies to the developing countries with weak and negligent environmental laws causing their pollution stock to increase. Therefore, energy consumption and fossil fuel based energy technologies increase the environmental degradation.

Model 2 results in columns 4 and 5 (Table 1) present the impact of different factors on water productivity. Increase in energy use increases the water productivity as through energy, water consumption is efficient in each sector. Degradation of natural resources deteriorates the natural ecosystem. In initial stages of economic development, the water productivity reduces due to the process of industrialization. NRD, NFD and GCF negatively affect the water productivity because depletion of natural resources including forests affect groundwater, which lowers the agricultural output. Health expenditures, improved water sources, industry value added, and labor force participation have direct impact on water productivity in developing countries.

Model 3 results reflected in column 6 and 7 (table 1) analyze environmental degradation and existence of EKC in the developing countries. Increase in income results in increase of ecological footprint for some time, but after a certain point, the increase in income (GDP^2) has a negative impact on environmental pollution. These results confirm the existence of EKC in developing economies. These results also conform to Fodha and Zaghdoud (2010). All remaining variables have a positive impact on ecological footprint.

Arellano and Bond test for first order AR (1) and second order AR (2), Sargan and Hansen test of over identified restrictions are mainly used for the validity of results. The results depict that 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 of the models. The study cannot reject the null hypothesis in Sargan and Hansen test if $p > 0.05$. Sargan test for over identification is insignificant in energy, water and environment models. Hansen test of over-identification and test for instruments are also insignificant in all the models.

5. Conclusions and Policy Recommendations

Water, energy and environment nexus implies that changes in one sector affect the productivity of remaining two sectors. Results ascertain that water productivity and ecological footprint affect the energy use in developing economies. Per capita health expenditures have a significantly negative effect on energy use while changes in gross domestic product affect the energy consumption. Climate is also heavily affected by energy use due to mechanization and processing of energy and water, water productivity and improved water sources that are directly linked with the ecological footprint. Natural resources and forests resource depletion worsens the water productivity in developing economies.

It is evident that energy use and ecological footprint have strong positive effect on water productivity in developing economies. Changes in natural resource depletion, and net forest depletion affect the water sector negatively, whereas, water productivity is significantly affected by the improved water resources and gross capital formation. This study further concludes that EKC exists in selected panel of developing economies.

Integrated management is required to manage the water, energy and environmental resources in developing countries. The management of these resources is imperative to achieve sustainable development goals in developing economies. Water scarcity and clean environment are important global issues. Hence, current study helps the policymakers in devising policies to support the management of water and energy resources for better environment. Future research should address the WEE nexus for developed economies along with a comparative analysis to the developing economies.

Authors Contribution
Faisal Mehmood Mirza: introduction, literature search, data collection
Abre-Rehmat Qurat-ul-Ann: study design and concept, writing-original draft
Syed Badar-ul-Husnain Rizvi: data analysis, data interpretation
Wajeeha Arshad: proofreading, critical revision

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