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The water-energy-food resources and environment: Evidence from selected SAARC countries

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Abstract. The objective of the study is to examine the relationship between water resources, energy demand, food production, and environmental pollutants in selected SAARC nations, namely, Bangladesh, India, Pakistan, and Sri Lanka, during the period of 1990-2016. The results show that water, energy, and food (WEF) resources substantially affected air quality in the form of high mass carbon emissions, fossil fuel energy demand, methane discharges, nitrous oxide emissions, and greenhouse gas emissions in these countries. Food production and food deficit largely increase CO_2 emissions due to unsustainable production and malnutrition, while land use under cereal production increases CH_4 and N_2O emissions. Electricity production escalates CO_2 emissions and fossil emissions across countries. The results support the carbon EKC hypothesis, while monotonic increasing function exists in case of fossil fuel energy. The study emphasizes the need to ensure environmental sustainability agenda by adopting cleaner production technologies in WEF resources.

Keywords: CO_2 emission; energy and environment; energy efficiency; energy management; Sustainability and life cycle assessments

1. Introduction

The subject of dynamic relationship amid energy use and income variables has been analyzed by several scholars (Keong 2005, Ayres *et al.* 2007, Oh *et al.* 2010, etc). Several studies have inspected the underlying association between energy consumption and numerous socio-economic and environmental factors, such as financial development (Boutabba 2014, Salahuddin *et al.* 2015, Abidin *et al.* 2015), biodiversity loss (Brook and Bradshaw 2015, Zaman 2017, etc) , tourism (Ozturk 2016, Katircioglu *et al.* 2014, etc), health (Zou *et al.* 2016), among others. Energy is an important factor for economic development of a country and it is considered as a most vivacious instrument of socio economic progress. Energy is vital component for economic operations; however, its supply remains short in most of the developing countries, which is considered as the main hurdle against economic development across countries (Masih, 2018, Gyamfi *et al.* 2018, etc).

SAARC region constitutes one fifth of the global population and accumulates world's largest

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resources. SAARC countries are highly affected by number of factors, including, high population growth rate, natural resource degradation, prevalence of poverty, and food insecurity. The IPCC (2014) report documents that SAARC Region has encountered a portion of the overwhelming effects of flooding, food deficiencies, and stagnating economic development because of propelling environmental change. The drought and changing cycle of occasional rainfall cause economic destruction via the source of natural and man-made resources, include flooding that wreak SAARC's countries productivity, while the shifting patterns of monsoon rains influenced the water accessibility across countries. The linkages between water, food and energy (WEF) insecurity particularly in SAARC region stress upon the urgent need of inter-sectoral solutions, like regulatory system for the organization of demand for water, energy production, and food production. In this study, a panel of selected sample of SAARC states has been considered due to the lack of available data. The data is borrowed from World Bank (2017). Table 1 shows the average growth rates of WEF and environmental resources in the selected SAARC countries between 1990 and 2016. We used a data of two time period i.e., 1990 and 2016 and calculated the average growth rates of economic and environmental factors, where the data are in the form of an index for food production (2004-2006 = 100), depth of famine taken in kcal preson^{-1} d^{-1}, land under cereal production in ha, production of electricity from conventional resources like coal, oil and gas is taken as a percentage of aggregate energy consumption, energy demand per kg oil equivalent is assessed by per unit increase in constant 2011 USD GDP, purchasing power parity (PPP), improved water resources as percentage of total population accessible, emissions of methane and nitrous oxide gases as kt of carbon equivalent, carbon dioxide emission per capita is in t capita^{-1}, energy from fossil, greenhouse gases (GHG) emission taken as kt of CO_2 equivalent, per capita GDP is counted in PPP (base year =2011, USD), industry production/GDP, and population concentration km^{-2} of land area.

Table 1 shows that growth rate of CO_2 emissions is progress substantially in Sri Lanka, followed by Bangladesh, India, and Pakistan. The fossil emissions in Sri Lanka is about more than 100%, which indicates the country's high dependency level on fossil fuel consumption. Methane emissions are quite high in Pakistan whereas Bangladesh and Sri Lanka shows negative growth rate. The negative value for CH_4 emission for Bangladesh and Sri Lanka is due to high and low intensity emission figure between the two time periods, i.e., 1990 and 2016. The average growth rate of nitrous oxide emissions are higher in Pakistan, followed by Bangladesh, India, and Sri Lanka. Pakistan and India is the major polluter among the SAARC countries, where the growth rate exceeds more than 100% during the two time periods. Pakistan is devoted substantial land for cereal production, followed by Sri Lanka and Bangladesh, while there is adverse growing rate found for Indian economy between the two time periods. The food production index is high in Bangladesh, trailed by India, Sri Lanka, and Pakistan. The growth rate of food deficit shows a negative tendency between the two-time periods in the selected panel of SAARC countries, which is good sign of recovery to meet the necessities goods across countries. The production of electricity from the conventional sources like grease oil, firewood coal and natural gas is higher in Sri Lanka while Pakistan exploits just 19.61% of its conventional resources to produce electricity. The energy efficiency measured in terms of energy per unit use of energy is substantial higher in Bangladesh, followed by India, Sri Lanka, and Pakistan. The per capita GDP steadily improve in Sri Lanka followed by Pakistan, India and Bangladesh. Sri Lanka shows greater value added in industrialization process, followed by Bangladesh, India, and Pakistan, which due to the globalization competitiveness across Asian countries. Bangladesh shows a large population density between two time periods while Pakistan shows the least density country in the region. The

Table 1 Water-energy-food, environment, and growth specific factors in selected SAARC countries

SAARC Countries	CO_2 (metric tons)	FF (kt of CO_2 equivalent)	ME (000’ metric tons of CO_2 equivalent)	NE (000’ metric tons of CO_2 equivalent)	GHG (kt of CO_2 equivalent)	LUCP (ha)	DFD (kcal capita^{-1} d^{-1})
Bangladesh	199.345	62.043	-2.873	51.376	44.670	8.370	-53.036
Pakistan	32.841	13.325	45.383	56.361	114.275	17.664	-3.910
India	123.610	36.640	3.552	34.001	116.444	-3.469	-33.939
Sri Lanka	243.649	108.465	-11.101	11.677	65.688	9.6450	-15.789
SAARC Countries	FPI (2004-2006 = 100)	EP (% of total energy consumption)	EU (per kg oil equivalent)	GDPPC (PPP, US$)	IVD (% of GDP)	PD (per km2 of land area)	WS (% of total population access)
Bangladesh	110.578	11.418	85.276	859.853	722.257	51.906	27.606
Pakistan	55.342	19.611	21.845	1729.502	474.918	5.909	75.568
India	97.43	11.324	81.324	1449.113	616.712	33.475	50.591
Sri Lanka	65.230	38202.54	59.655	2730.896	1010.312	39.970	22.766

Note: CO_2 shows carbon dioxide emissions, FF shows fossil fuel energy use, ME shows methane emissions, NE shows nitrous oxide emissions, GHG shows greenhouse gas emissions, LUCP shows land used under cereal production, DFD shows depth of food deficit, FDI shows food production index, EP shows electricity production, EU shows energy efficiency, GDPPC shows per capita GDP, IVD shows industry value-added, PD shows population density, and WS shows improved water sources

improved water sources are reported to be consistent in the selected sample of SAARC countries. The current economic situation of these countries in the light of the given statistics presented the crucial facts about water-energy-food production in the SAARC countries companied by the extent of air quality indicators and selected growth factors that leads us to the conclusion about the sustainable ecological transformation process across countries.

The following are the vital factors that need to be addressed for sustainable development agenda, i.e.,

i) Air quality indicators should be improved in terms of reduction in the major air pollutants, including, CO_2 emissions, fossil fuel energy consumption, CH_4 emissions, N_2O emissions, and GHG emissions.

ii) To efficiently utilize energy for economic gains, this ultimately translated into increase sectoral value added.

iii) To reduce water borne diseases and improved water sources for household consumption.

iv) The issue of food security across the region underprivileged the dwellers of the country with increasing the prevalence of poverty and malnourishment, and

v) The extent of population is the major factor of exhausting the natural resources and it put a straining on the atmosphere that substantially exaggerated the environmental sustainability agenda among SAARC nations.

This study scrutinized the association amongst WEF and air quality indicators in the light of the EKC hypothesis by considering an annual time series data ranging from 1990-2016 for a panel of selected SAARC nations. The structure of our study is designed in a manner, i.e., introduction is followed by the segment of a brief literature review, than presented statistical inferences, results and discussions, followed by policy recommendation at the last.

2. Literature review

The literature reviewed energy, water, and food production with respect to sustainability measures in a worldwide monetary calamity to build up an interactive environmental model for adopting 'go-to-green' policies. The main stream of this study relates to the modified U-shaped EKC structure, which is spread out by various air contaminants that react distinctively with the economic development in the panel of SAARC countries. The EKC is a theorized as a hypothetical relationship between different pointers of ecological degradation and per capita income, which is worked under the stylist fashion of Kuznets (1955) seminal work on emission-inequality. The EKC is given name after Grossman and Krueger's (Grossman and Krueger 1991) who conjectured income imbalances that initially raises environmental pollutants and afterward it comes up with improved air quality indicators with advances in the income continuously. There are various studies that affirmed the EKC connection between various air toxins and income per capita in various cross sections, time series, and longitudinal overviews, i.e., Aperjis and Ozturk (2015) studied the existence of EKC theory in the panel of 14 Asian nations. They conclude the significant confirmation of income-emissions co-relationship by applying GMM methodology across the group of countries. Bilgili *et al.* (2016) used the panel data of 17 Organisation for OECD nations by employing panel Dynamic OLS (DOLS) estimation to confirm the presence of EKC in a panel of countries. They documented that renewable energy shows a negative impact on CO_2 emissions. The findings of Wang *et al.* (2016) added to the writings on the economic development- pollution nexus by finding a supportive evidence of an inverted parabolic curve between economic prosperity and SO_2 concentration in Chinese economy.

Walker *et al.* (2014) gathered food leftover in drains together with developing algae growth in waste water treatment plants that usefully raise the measure of carbon origin gases discharge from sustainable renewable energy. An option for adaptation of climatic changes in the region of South Asia, there is an immense need of effective exploitation of land, water and energy and to make efforts for the minimization of trade off between them and maximizing synergies accordingly. This will increase the extent of food security, water and energy security by increasing the resource utilization efficiency. Olsson (2013) stressed on the immense requirement for integration in energy-water-food that shared the load of climatic changes, food security and urbanization. Ang (2008) observed the relationship between output expansion, air pollutants and energy use in Malaysia. The study documented that in the long term, air pollution and energy demand is highly correlated as there is strong evidence of one-way causality running from GDP growth to energy in the long run. Geels (2013) found that second order coefficient for finance and governance is negative in green niche innovations in take-off stage of growth. Gain *et al.* (2015) provides an overview of the WEF relationship in Bangladesh. The results show that WEF nexus isn't yet perceived in the strategy archives in a country. The policies for green development are desirable for integration in the WEF nexus. There are few other studies that directly linked WEF resources with sustainability agenda, including, Bargendahi *et al.* (2018), where sustainability principle agenda is discussed under the premises of supply chain management practices and it further aligned with WEF nexus for sound policy implications. Das and Cabezas (2018) confirmed WEF footprints in sugar-ethanol and leather industry perspective and proposed long-term sustainable policies for environmental reforms across countries. Kibler *et al.* (2018) discussed the feasibility of food waste management by WEF nexus and conclude with sustainable production techniques to accrue benefits to the society. Avellán *et al.* (2018) concluded that WEF resources and ecosystem protection highly inducive for irrigation and drainage system that helpful to safeguard the global environment. Zhang *et al.* (2018) emphasized the need of hydropower development, which could served as a good source of provision of global energy system that ultimately would be helpful for sustainable energy future. Zhao *et al.* (2018) concluded that agriculture intensification and energy efficiency could be attained by mechanized farming and water saving irrigation system that is pivotal for agriculture associated emissions reduction across countries. Lee *et al.* (2018) argued that to attained sustainable development, carbon free policies are imperative for long-term sustained growth. Awan *et al.* (2018) discussed the social sustainability agenda in supply chain management process that is interlinked with corporate governance mechanism and confirmed the viability of environmental sustainability across countries. Yamagata *et al.* (2018) opined that land devoted for bioenergy crop production should be taken with care in order to reduce negative externality on water, food and ecosystem services for human sustainability. The earlier research demands justifiable policies that must intact with the food-water-energy resources, quality of air indicators, economic factors and financial calamity. The current time economic problems cause damage to the world environment sideways with economic health that must need some supportable production to fight with food crisis, hydro pollution along with energy problems with the help of justifiable food technologies, better-quality water resources and alternatives of energy sources with fiscal push and other economic inducements. An effective strategy is required to stabilize the twin calamities of economic prosperity and clean environment for a vigorous and well-off future.

3. Material and methods

This study employed panel fixed effect estimator to assess water, food and energy relationship across selected SAARC countries, covering a period from 1990 to 2016. This study borrowed the research mechanism Zaman *et al.* (2017) and extended it the SAARC countries. In this study, environment pollution *(ep)* is taken as an endogenous variable while the exogenous variables are water *(wt)*, energy *(en)* and food source *(fd)*. The study explains the association among the said variables in the light of parabolic function. The generalized equation for this assessment is given as below in which υ_i shows the fixed effect with respect to country, φ_t highlights the time variant shocks, the subscript '*i*' indicates the arrangement of country in selected group of countries, i.e., (*I*= 1,….., 4), *t* is the time in which this study is conducted while ε_i is the random error term of the model.

$$ep_{it} = c + \alpha_{i1}en_{it} + \beta_{i2}wt_{it} + \gamma_{i3}fd_{it} + v_i + \varphi_t + \varepsilon_i \tag{1}$$

Eq. (1) is decomposed further in to various set of growth related factors *(grf)* that clarifies the process of environmental sustainability with reference to the environmental Kuznets curve hypothesis. This equation is given as

$$ep_{it} = c + \alpha_{i1}en_{it} + \beta_{i2}wt_{it} + \gamma_{i3}fd_{it} + \eta_{i4}grf_{it+} + \theta_{i5}grf^2{}_{it} + v_i + \varphi_t + \varepsilon_i \tag{2}$$

This study moreover adds up a financial dummy for the year 1997 *(D_{97})* to capture the extent of

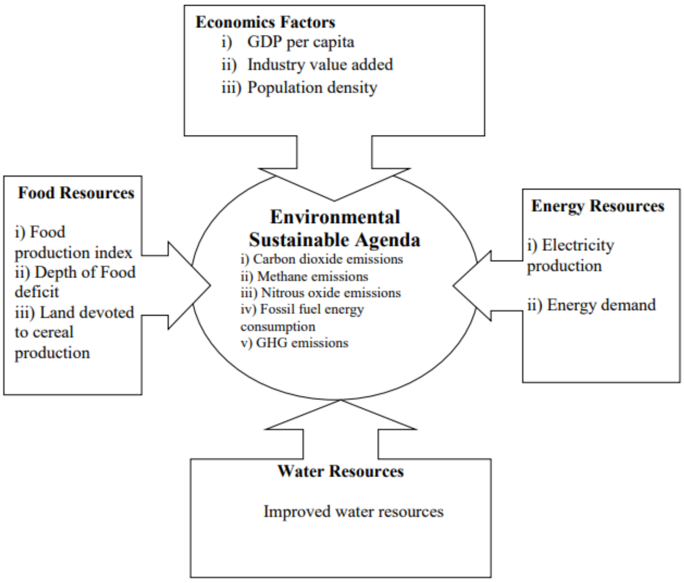

Fig. 1 Research framework (Source: Extracted from previous literatures)

financial disparity over the ecological sustainability across the sample countries. This addition also concludes the final empirical model for our study. The final equation is given as;

$$ep_{it} = c + \alpha_{i1}en_{it} + \beta_{i2}wt_{it} + \gamma_{i3}fd_{it} + \eta_{i4}grf_{it} + \theta_{i5}grf^2_{it} + \psi_{i6}D_{97} + vi + \varphi t + \varepsilon_i \quad (3)$$

In the empirical testing process, the first step involved is the unit root testing, which is estimated by panel fixed effect estimator. The unit root has a far-reaching significance in the analysis of univariate and multivariate econometric models. Without making the variable I(0) we are unable to conclude robust results. The methodology of unit root testing is lying with the fact that the single variable is regressed with its lagged value with a restriction implied that the variable under test is non-stationary or we can say it is or order I(1). This test is carried out with the help of Wald F-statistics.

Hausman test is used to discriminate between fixed effect (FE) and random effect (RE) model. This selection is assist based on a significant chi-square (χ^2) statistics. if χ^2 comes out to be a significant value, panel FE model is selected otherwise an appropriate model would be a panel RE model. There are so many recompenses of taking longitudinal data sets in research. For example, it provides an unbiased estimate of all parameters by controlling the stochastic elements that "*move across*" the data in the panel RE model and "*move over*" time in panel FEt model. Because of this property the chance of over-estimation unfairness in estimation reduces. The probabilities of correlation among the set of exogenous variables are relatively less in the panel modeling, i.e., a greater the variation anticipated in independent variables, more consistent would be the results. This difference in the panel regression technique provides the basis to document relative more robust and precise results of estimating econometric model. This study employed longitudinal time series data over the period of 1990-2016 for robust inferences. Research framework is shown in Fig. 1.

The expected relationship between quality of air indicators and per capita GDP is positive initially while it becomes negative at maturity stage, which is the justification of non-linear

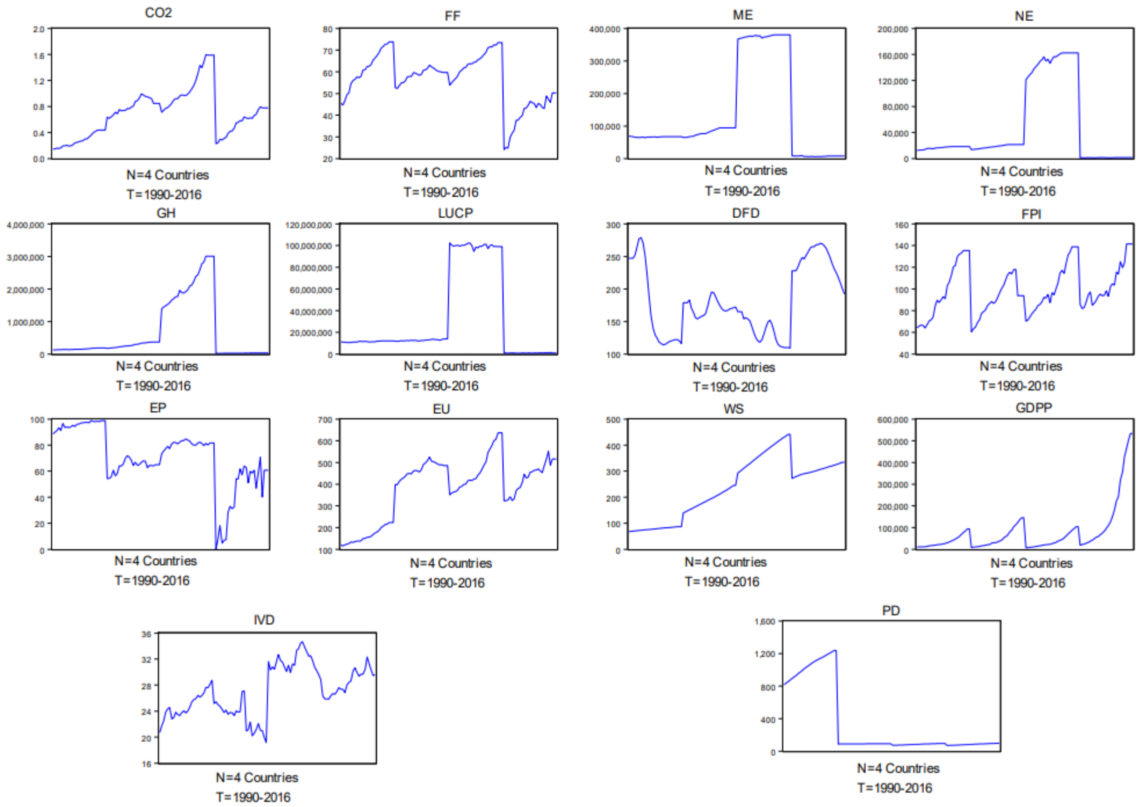

Fig. 2 Graphical plots of level data. Source: World Bank (2017)

parabolic curve. Similarly, there is a direct relationship expected between food resources and air pollutants, as unsustainable mode of productions largely tends to escalate air pollutants that severe threat to the environment. The energy source is likely to raise the air pollution due to high dependency of fossil emissions in energy portfolio mix across SAARC countries. Air contaminants may appear in water source because of seepage of big pipes of industrial waste in water. The industrial production and demographic progression are probable to worsen the atmosphere with the channel of heavy smoke exhaustion.

The study formulated the following hypothesize, i.e.,

H1: There is likelihood that food production largely increases high mass environmental emissions due to unsustainable food production techniques across countries.

H2: There is expected that energy resources substantially increases air pollutants to support energy led emissions.

H3: There is a probability that improve water resources support air quality indicators across countries.

H4: There is likelihood that per capita income first increases emissions while it decline at later stages to verified EKC hypothesis across countries, and

H5: There is likelihood that industrialization and population density degrade environment.

Fig. 2 shows the level data trend of stated variables.

The worldwide monetary imbalances deeply sluggish the pace of economic prosperity as well as worsen the environment, however, develop nations quickly goes out of the instable conditions by renovating both of their monetary as well as environmental assets by sustainable growth reforms. On the contrary, developing countries has a vice versa case in this regard due to which they merely fail to balance their ecological and financial resources. Specifically, with reference to SAARC member countries, the worldwide financial crisis strikes out South Asia in a time when it hardly came out of the critical trade shocks from the worldwide food and oil price shocks. Moving ahead the selected SAARC nations can do various steps to lessen the impact of the monetary crisis and make the way forward for the sustainable growth in the region. The step may involve an effective policy macroeconomic policy to create an additional fiscal space to prop up the economic stability, careful look over the expenditure priorities, increase domestic productivity, and finally greater attention toward the implementation plan that lessen the amount of air pollutants to provide a human friendly and clean environment.

4. Results and discussion

Table 2 shows the outcomes of different panel unit root tests and found that there are number of candidate variables are differenced stationary, i.e., CO_2 emissions, CH_4 emissions, GHG emissions, depth of famine, food production index, energy effectiveness, per capita income, and industrial production at least among one of the used panel unit root.

Table 3 demonstrates the results of panel FE model that encircles five distinctive air quality indicators and their prospective predecessors. The air quality indicators, i.e., CO_2 emissions, CH_4 emissions, N_2O emissions and consumption of fossil fuel energy are explained by the food resources, energy resources, selected growth factors along with the introduction of dummy that is used for the environmental reforms in the region for the year 1997. The results reveal under the environment induced Kuznets curve framework which shows a positive link between CO_2 emissions and intensity of food deficit, i.e., 1% decreases in the productivity of food cause a decline of 0.111% points in pollution cause by the emission of CO_2 gases in the panel countries. Similarly, the index of food production shows a positive linkage with the CO_2 emission; however, we have not found any association between CO_2 emissions and land under cereal production during the years 1990-2016. The results further provoke the existence of energy induce carbon emissions across countries. The impact of improved water sources on CO_2 discharges is indirect, which implies that improved water sources substantially reduces CO_2 emissions that helpful to determine the need of cleaning water by industrial wastes across countries. Our outcomes strongly confirm the practicability of parabolic carbon EKC. The results are in line with the results of Shahbaz *et al.* (2013), Zaman *et al.* (2017b), Zaman and Moemen (2017), etc. These studies motivated the need of eco-friendly sustainability agenda that fall under the premises of different socio-economic and environmental factor to verify the EKC hypothesis across countries. The study does not find an evidence of industrial value added and financial crisis with the environmental pollution over the study period. Finally, the population density found another major predictor that largely increases CO_2 gases discharges in a panel of selected SAARC countries, which need serious attention to control massive population by healthcare agenda.

The results of Table 3 show the relationship of food-energy-water resources and growth factors with fossil fuel energy. These results highlight that depth of food deficit increases fossil fuel energy demand with the magnitude value of 0.145%. Similarly, the production of electricity from the conventional sources has shown a positive association with the fossil emissions across selected

Table 2 Results of panel unit root test

At level	CO_2	FF	ME	NE	GHG	LUCP	DFD	FPI	EP	EU	GDPPC	IVD	PD	WS
Levin, Lin & Chu t*	0.008	-3.090*	-1.431	-3.260*	-0.616	-1.288	0.290	0.949	-3.281*	1.488	4.989	3.210	-5.566*	-2.441*
Psarian and Shin W-stat	1.960	-1.061	-0.985	-3.001*	2.239	-1.287	-0.540	3.513	-2.149*	2.836	4.656	4.841	-1.581	0.497
ADF - Fisher Chi-square	2.735	10.330	9.962	22.542*	1.477	16.198**	11.766	2.452	17.822**	3.817	11.202	0.137	22.450*	6.632
PP - Fisher Chi-square	2.728	20.504	13.825	47.776*	1.400	16.162**	4.0672	2.474	18.856**	3.746	0.0003	0.038	27.757*	7.873
At first difference	D(CO_2)	D(FF)	D(ME)	D(NE)	D(GHG)	D(LUCP)	D(DFD)	D(FPI)	D(EP)	D(EU)	D(GDPPC)	D(IVD)	D(PD)	D(WS)
Levin, Lin & Chu t*	-5.547*	-8.001*	-7.411*	-2.935*	-8.735*	-11.423*	-1.356	-9.070*	-12.699*	-6.333*	-2.255**	0.372	8.803	-12.762*
Psarian and Shin W-stat	-6.006*	-7.420*	-7.577*	-5.679*	-8.448*	-10.318*	-2.920	-8.365*	-11.999*	-5.889*	-2.631*	-1.016	5.276	-3.001*
ADF - Fisher Chi-square	46.262*	58.449*	60.495*	47.920*	66.864*	82.839*	25.220*	66.512*	90.531*	48.468*	20.8309**	17.457	0.910	10.137
PP - Fisher Chi-square	46.484*	58.383*	72.369*	53.057*	70.953*	97.906*	10.363	68.525*	92.764*	62.044*	10.758	33.6667*	1.157	4.626

Table 3 Results of panel fixed effect model

Variables	LCO_2	LFF	LME	LNE	LGH
Constant	-8.751*	0.505	6.568*	-0.321	5.918*
LLUCP	-0.093	-0.091	0.368*	0.136**	0.0007
LDFD	0.111***	0.145*	-0.019	0.053	0.065**
LFPI	0.230**	0.074	0.390*	0.294*	0.101***
LEP	0.035**	0.040*	-0.024*	0.008	0.004
LEU	0.740*	0.188**	-0.351*	-0.221*	0.333*
LWS	-0.995**	-0.499***	0.679**	0.964*	0.631*
LGDPP	0.999**	0.482***	-0.317	0.314	0.324
LGDPP^2	-0.033**	-0.014	0.014***	-0.014***	-0.010
LIVD	-0.132**	-0.145*	-0.004	-0.136*	0.071**
LPD	1.043**	1.047*	-0.537**	0.771*	-0.734*
D_{1997}	-0.029	0.007	-0.028***	-0.024***	-0.006
AR(1)	0.528*	-----	-----	-----	-----
Statistical Tests					
R^2	0.997	0.979	0.9993	0.9997	0.9997
R^2 (adjusted)	0.996	0.976	0.9991	0.9996	0.9996

Table 3 Continued

Variables	LCO_2	LFF	LME	LNE	LGH
Statistical Tests					
F- Statistics	1964.909*	312.084*	14524.88*	22190.28*	23681.85*

Note: *, **, and *** represent significance at 1, 5, and 10%respectively.

countries. These outcomes are contrary to the verdicts of Zaman *et al.* (2017) documented a negative relationship between the variables across Arica. The results further provided the no carbon footprints of improved water resources, as it remarkably reduces the fossil emissions. Thus, we can infer that the improvement in the water resources will decrease the dependency on the fossil emissions, which is associated with the upturned fossil induced EKC, i.e., monotonic increasing relationship with the per capita GDP. This can be proved with fact that fossil emissions increases with the income in the early phases of economic development, while its turned to be insignificant at the far along stages of economic development. There exists an inverse association between industrial value added and fossil emissions, while there is a direct relationship between population density and fossil emissions. Although a positive sign of coefficient is linked in relation with the financial calamity and fossil emissions, however, it is insignificant that might not imprison its shock on the fossil fuel during the study period. According to Demirbas (2007), the growing demand of energy consumption can be met with the alternatives ways of producing energy of innovating the industrial machinery to consume renewable energy instead of fossil fuel energy. According to him, biodiesel is the best option to replace the common energy sources that has efficient and less costly as it can be produced by vegetables oils, palm oils, and soya bean oils, etc. There is a positive link documented between population density and energy by Brownstone and Golob (2009), according to them the population indirectly affects the energy demand by the people having cars of various engine types and then move from one place to another place for routine activities. Poumanyvong (2018) described a direct association between urban population and energy use in developed countries, while the more visible impact is recorded among the high- and middle-income group.

The third model is associated with the methane emissions that are influenced by WEF resources and growth specific factors. The results show that methane emissions are influenced by larger food index and cereal cultivation, however, energy sources substantially reduce methane emissions in a given time period. The positive relationship between improved water sources and methane emissions turned out into the later stages of economic growth, where square of GDP per capita income is largely influenced methane emissions across countries. Nitrous oxide is another air pollutant in our study, which shows a positive relationship with land under cereal production and food production, i.e., larger cereal land devoted for production cause higher nitrous oxide emissions that would throw an adverse effect on the environment. Population density per square kilometer of land has substantially given rise to the emission of nitrous oxide; though, energy efficacy puts a significant influence on decrease of nitrous oxide emission. In count, this study does not support the existence of parabolic function between income and methane emissions.

Finally, GHG emissions are largely increased by depth of famine and food index. We can infer that1% increase in food deficit and food production, it increases GHG emissions about 0.065and 0.101% respectively. We have found no mark of energy production from conventional sources linked with GHG emissions, while GDP per unit of energy largely increases GHG emissions across countries. There is a visible trade off between water sources and GHG emissions as discussed by Raymond *et al.* (2003) and also Blasing (2015) that carbon dioxide transfers from the water sources to the atmosphere is called carbon dioxide evasion which is a worldly carbon cycle. The estimates predict the global evasion rate of 2.1 peta-grams carbon per year (pg C), while on the other hand, there is a positive association between industrialization and GHG emissions (2015), both the direct linkages confirmed the high resolution of GHG emissions that need to reduce by sustainable policy agenda across countries. Osborne *et al.* (2013) documented that changeability in the worldwide food provision, i.e., the threat of constancy of food production increases the risk of changes in the climatic graph that might give birth to the problems like malnutrition, hunger, poverty, etc. Thus, it is imperative to device environment friendly policies that aligned with water-energy-food resources for sustainable actions. Table 4 demonstrates the long-term estimates of elasticity by utilizing prior results of panel fixed effect model in the preceding table.

The results confirmed the food-carbon footprints while air quality indicators extensively increment alongside the expansion in power creation from regular sources, i.e., coal oil and gas,

Table 4 Results of long-run estimates

Variables	LCO_2	LFF	LME	LNE	LGH
LLUCP	-4.061	-0.959	2.592	1.316	0.023
LDFD	4.837	1.532	-0.138	0.514	2.051
LFPI	10.042	0.783	2.750	2.835	3.159
LEP	1.545	0.428	-0.174	0.081	0.137
LEU	32.186	1.979	-2.471	-2.125	10.417
LGDPP	43.441	5.079	-2.238	3.025	10.1491
LGDPP^2	-1.454	-0.155	0.099	-0.142	-0.337
LIVD	-5.761	-1.531	-0.035	-1.309	2.248
LPD	45.358	11.031	-3.786	7.419	-22.945

Note: DFD specifies the intensity of famine; FPI shows food production index; EP indicates energy production from coal, oil and gas; EU indicates energy use; Ws shows improved water resources; IVD shows industrial value added; PD specifies population density; D_{1997} indicates financial dummy -1997; GDP shows the gross domestic product and CO_2 indicates carbon dioxide gas emissions. “L” denotes the natural logarithm.

Table 5 Summary of hypothesis

Hypothesis	Statement	Decision
H1	Food production footprints to environment degradation	Accepted
H2	Energy footprints on environment	Accepted in case of CO_2, fossil fuel, and GHG emissions
H3	Water footprints on environment	Accepted in case of methane emissions, nitrous oxide emissions, and GHG emissions
H4	Environmental Kuznets curve	Accepted in case of CO_2 emissions
H5	Industry and population associated emissions	Accepted in case of GHG emissions and carbon-fossil-N_2O emissions respectively.

while they do extensively diminish the offer of GHG emanations over the nations. Energy efficiency supports to lower the air quality indicators but surprisingly it stimulates the emission of carbon dioxide gases. The reason behind is that energy efficiency shoots up along with rise in per capita income. As the improvement in the economic activity give rise to the emission of CO_2 as larger number of firms are entering in to the production circle. Water quality in the selected countries boosts the environment friendly atmosphere by reducing CO_2 emissions in the long-run. Water quality improves air quality indicators except GHG emissions. The EKC theory is affirmed with CO_2 discharges, fossil fuel, N_2O emissions, and GHG emissions, while it modelled the non-parabolic relationship with methane emissions in the long-run. Industrial value added documented an interesting outcome of reduction in the air pollutants except the greenhouse gases. These results validate the improved technology introduced in the industrial sectors of selected countries. Population density largely increases air pollutants over the long haul. Table 5 presented hypothesis summary for the ready reference.

The results confirmed 1st hypothesis, i.e., food production largely responsible to increase methane emissions, nitrous oxide emissions, carbon-fossil emissions and GHG emissions, while energy associated emissions (i.e., H2 hypothesis) is accepted in case of carbon-fossil-GHG emissions. The 3rd hypothesis is partially accepted, as water resources decreases carbon-fossil emissions, while it increases CH_4, N_2O, and GHG emissions. The results verified the 4th hypothesis related with EKC in case of CO_2 emissions, while it’s not substantiate with other air pollutants. Industrialization and population concentration (i.e., H5) both deteriorate environmental quality in the form of carbon-fossil-nitrous oxide emissions in a panel of countries.

5. Conclusions

The study examined the relationship between air quality indicators and WEF sources in non-linear modelling framework to determine the financial shocks in a panel of selected sample of SAARC nations, during the period of 1990-2016. The conclusion drawn from the application of panel fixed effect model is that the index of food production is strongly linked with GHG emissions while there is an increase in the emission of methane and nitrous oxide gases due to increase in land under cereal production across the selected SAARC countries. The carbon-fossil emissions considerably reduce along the improvement in the water sources while industrial value-added increases GHG emissions across countries. The outcome of this study authenticates the presence of environment based Kuznets curve that shows the link between carbon and fossil emissions with changes in per capita income. The investigation finishes up with some proposals for the better natural administration in SAARC nations that would be useful to give a reasonable course for their endeavours towards sustainability plan over the short and long run.

- *Short-Run Policy Implications*

Producing a maintainable food is the key issue towards the ecological supportability structure in South Asian nations, as the food's carbon impression is clear with the non-natural cultivating strategies that highly affect the earth's atmosphere. The policy suggestion is to maintain a strategic distance from nonorganic nourishment that is transmitted by various manufactured techniques for creature and product cultivating. Moreover, it is prudent to diminish food nourishment waste that exists in the production units while the process of manufacturing. The organic food cultivating strategies for development crops harvesting, reproducing for animal feeds, and lowering the amount of food-waste during the process of manufacturing are the useful strategy instruments that would have a practically lowers the effect on nature. There are certain short-term workout plans that will surely support in lowering the air pollution and enhance the food security, for example, to lower down the use of chemicals in agriculture, consumption of more vegetables instead of meat, to avoid food wastes, efficient energy resources should be use and to hold up "green supply chain management" practices and so on. The authorities should focus towards advancement in biofuel energy, as it is zero sensitive to the carbon discharge. Besides that, atmosphere friendly strategies would be useful to balance the ecological degradation.

- Long-Run Policy Implications

The worldwide monetary crisis extremely influenced global food challenges that harm the regular habitat of South Asian nations. The sound monetary policy is imperative to balanced financial crisis and helpful to reduce food security challenges across countries. In the long run the policy maker shall focus on utilizing green innovations and low-carbon venture. Moreover, working on the monetary integration interlinked with practical improvement objectives that are useful during the "transformative stage" of budgetary administration. The natural resource protection through financial boost crosswise over nations along with lower energy charges and better water sources is imperative that in turn boost up the worldwide food security.

UN Kyoto Protocol for relieving GHG outflows preserving natural possessions is the sustainable policy tool for formulating practical strategies over the globe. Even though the Kyoto Protocol isn't connected with the monetary related reconciliation of the economical markets, it is connected through resources market to lessen environmental pressure by less elastic and cost-minimizing mechanism, for example, adopting cleaner technologies, sustainable programmes, and public-private joint resource programmes are imperative for sustainable development. The selected sample of South Asian nations ought to need to consider these tools for moderating environmental change that support financial sector to send out carbon products and import supportable tools to produce healthy products. It eventually diminishes the danger of nourishment instability, water contamination, and energy related emissions in a region.

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