

Short Communication

Dynamic Linkages between Green Energy, Knowledge Spillover, and Carbon Emissions: Global Evidence

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Abstract

Covering 3168 annual observations of 132 countries for 1995-2018, the study investigated the role of knowledge spillover (KNOW), renewable energy (RE) demand, and food production (FP) in mitigation of CO₂ emissions to achieve global environmental sustainability (ES) agenda. The study used Arellano-Bond (A-R) differenced GMM estimator to handle endogeneity and serial correlation issues for robust inferences. The results confirmed the hump-shaped relationship between KNOW and CO₂ emissions to support 'Knowledge Kuznets curve (KKC)' across countries. The results further reveal that FDI inflows and trade openness (TOP) both increases CO₂ emissions that substantiate the 'pollution haven hypothesis (PHH)'. The positive relationship between FP and CO₂ emissions exhibits 'food footprints (FFP)' across countries. The negative relationship between RE demand and CO₂ emissions imply that increased use of RE helps to reduce emissions, which is a positive sign to precede towards cleaner production technologies for achieving global ES agenda.

Keywords: carbon emissions, knowledge spillover, renewable energy demand, food production, GMM estimator

Introduction

The nexus between CO₂ emissions and economic growth (EG) is largely discussed under the literature

of environmental Kuznets curve (EKC) [1-2]. The study extended the EKC modeling by including KS, RE demand, FP, FDI inflows, and TOP to testing the four different plausible hypotheses, including, KKC, PHH, FFP, and energy associated emissions (EAE). The KKC is the bond between CO₂ emissions and KS, which is expected to have a positive relationship at an initial level while it becomes negative at the

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later stages, thus it would exhibit a hump-shaped associated between the two variables [3-4]. The PHH shows the affirmative link between FDI (and TOP) and CO₂ emissions, which validate the existence of dirty polluting industries that affect the country's EG [5]. The FFP correspond the affirmative association between FP and CO₂ emissions that are an account of unsustainable use of production technologies, which led to an increase in health damages across countries [6-8], and finally, EAE is considered the affirmative connection between energy demand (ED) and CO₂ emissions that could be reduced by the increasing use of RE demand across countries [9-11]. Thus, based on significant discussion, the study intended the following two research questions, i.e., i) does KS would be helpful to decrease CO₂ emissions under economic resource policies, and ii) to what extent RE demand reduces CO₂ emissions to support food challenges issues. Both the research questions are important to precede towards cleaner production agenda. The main objective of the study is to analyze the role of KS, FDI inflows, and TOP in mitigation of CO₂ emissions. Further, the impact of RE demand and FP on CO₂ emissions is evaluated, which linked it with the casual and anticipated liaison between the stated factors. The stated objectives would be achieved by using panel econometric techniques to get robust inferences.

Material and Methods

Table 1 shows the list of the variables. The variable CO₂ emissions served as a 'response' variable while the remaining variables act as explanatory variables of the study. The data is taken from World Bank [12] database covering 3168 annual observations of 132 countries for 1995-2018. The study is inspired by the latest work of Shahbaz et al. [13], Nizam et al. [14], Anser et al. [15], Dogan et al. [16], Sarkodie & Ozturk [17], etc. The study is unique as it added KS as a main explanatory variable that would provide more insights into KKC in the bond between emissions and income factors across countries. The study used the following equation for inferences, i.e.,

$$\ln(CO_2)_{it} = \beta_0 + \beta_1 \ln(CO_2)_{it-1} + \beta_2 \ln(KNOW)_{it} + \beta_3 \ln(SQKNOW)_{it} + \beta_4 \ln(FDI)_{it} + \beta_5 \ln(TOP)_{it} + \beta_6 \ln(FPINDEX)_{it} + \beta_7 \ln(REC)_{it} + \lambda_{it} + \varepsilon_{it} \quad (1)$$

...where, λ shows list of instrumental variables, 'i' and 't' shows 132 countries and time period is 1995-2018, and ε shows error term.

Equation (1) shows the different determinants of CO₂ emissions in a panel of selected countries. It is expected that $\beta_2 > 0$, $\beta_3 < 0$ to verify the KKC hypothesis, whereas $\beta_4 > 0$, $\beta_5 > 0$ is expected to substantiate the PHH. The coefficient value of $\beta_6 > 0$ is expected to validate the FFP across countries. Finally, it is likely

that the impact of REC on CO₂ emissions will be negative ($\beta_7 < 0$) that implies the need of more use of RE demand in cleaner production to lessen CO₂ emissions accordingly. Equation (1) is empirically estimated by Arellano-Bond differenced GMM estimator that handled possible endogeneity and autocorrelation issue. Further instrumental reliability checked by Sargen -Hansen J-statistics and instrumental rank accordingly.

Results and Discussion

Table 1 show that CO₂ emissions have a mean value of 0.645 metric tons per capita with a maximum value of 3.211 and standard deviation of 1.502. Additionally, KNOW has a mean value of 6.436 number counts of scientific & technical journals with a maximum value of 12.995 counts. The mean value of FPINDEX, FDI inflows, TOP, and REC is about 4.634, 0.942% of GDP, 4.279% of GDP, and 2.809% of energy consumption, respectively.

The GMM estimates show that FDI inflows and TOP both substantially increases CO₂ emissions to substantiate PHH. The stringent environmental regulations [18], carbon pricing [19], environmental governance [20], environmental certifications [21], resource management [22], and waste handling [23] are the few policy options to limit CO₂ emissions, while financial and trade liberalization policies should be in tandem with green financing options and eco-friendly goods to sustained long-term sustainable development across countries [24]. The results further reveal that FPINDEX increases CO₂ emissions with an elasticity estimate of 0.152% while increases 1% increase in FPINDEX, which confirmed the existence of FFP across countries. The need for progression in green production technologies [25], shifted non-renewable fuels with renewable fuels [26], food regulation and monitoring programmes [27], hygienic food production [28], low carbon oil-burning stoves [29], etc., are the few sustainable action policies to mitigate CO₂ emissions. The hump-shaped relationship found between KNOW and CO₂ emissions, as KNOW first increases CO₂ emissions while its second-degree coefficient substantially decreases CO₂ emissions to verify KKC hypothesis. The environmental KNOW is imperative for achieving countries towards long-term sustainable development. The campaigns for cleaning environment [30], waste disposal and recycling initiatives [31], eco-friendly production [32], sustainable consumption and production [33], extend environmental awareness at the grass root level [34], respond to the international call for ES [35], and all other modes of techniques through which environmental degradation should be reduced and compliance as per the international standard for environmental resource conservation are the vital factors to achieve a clean and green agenda.

Table 1. Estimation Matrix.

Descriptive Statistics					
Variables	Average	Highest value	Dispersion from mean value	Skewness	Kurtosis
CO ₂ emissions (metric tons per capita)	0.645	3.211	1.502	-0.658	2.599
KNOW (Scientific and technical journal articles)	6.436	12.995	2.852	0.010	2.256
FPINDEX (Food production index) (2004-2006 = 100)	4.634	5.596	0.214	0.101	3.845
FDI Inflows (% of GDP)	0.942	6.113	1.238	-0.859	6.565
TOP (% of GDP)	4.279	6.080	0.661	-3.475	35.435
REC (% of total final energy consumption)	2.809	4.588	1.545	-1.527	6.709
A-R Estimates: Dependent variable: ln(CO ₂)					
Variables	Coefficient	Standard Error	t-statistics	Prob.value	Statistical Tests
ln(CO ₂) _{t-1}	0.563	0.003	171.268	0.000	
ln(FDI) _t	0.005	0.0005	8.859	0.000	J-statistic: 128.433
ln(FPINDEX) _t	0.152	0.005	27.420	0.000	Prob.J-statistic: 0.422
ln(REC) _t	-0.166	0.002	-66.782	0.000	Instrumental rank: 133
ln(KNOW) _t	0.117	0.005	23.089	0.000	Arellano-Bond Serial Correlation Test
ln(SQKNOW) _t	-0.005	0.0004	-12.277	0.000	AR(1)-rho: -14.220
ln(TOP) _t	0.059	0.002	22.511	0.000	AR(2)-rho: -0.674
VAR Granger Causality					
TOP↔CO ₂	CO ₂ →FDI	KNOW↔FDI	TOP↔FDI	CO ₂ →FPINDEX	FDI→FPINDEX
KNOW↔FPINDEX	CO ₂ →REC	KNOW↔REC	TOP↔REC	CO ₂ →KNOW	TOP↔KNOW
IRF Estimates					
2019-2028	FDI↑CO ₂ ↑	FPINDEX↑CO ₂ ↑	REC↑CO ₂ ↓	KNOW↑CO ₂ ↓	TOP↑CO ₂ ↑
VDA Estimates					
2019-2028	FDI influenced 44.9% to carbon emissions	REC influenced 25% to carbon emissions	TOP influenced 15.4% to carbon emissions	FPINDEX influenced 4% to carbon emissions	KNOW influenced 0.9% to carbon emissions

The Granger causality estimates confirmed the feedback relationship between i) TOP and CO₂ emissions (and FDI, REC and KNOW), and ii) KNOW and FDI (and FPINDEX, REC, and TOP) while a causality is running from i) CO₂ to FDI, FPINDEX, REC, and KNOW), and ii) FDI to FPINDEX across countries. The causality analysis is confirmed the mutual integration of TOP and CO₂ emissions that moving in the same direction under the direction of FDI, REC, and KNOW, while KNOW moves together with the FDI inflows in the same direction with the conciliation of FPINDEX, REC, and TOP. The IRF estimates show that FDI inflows, FPINDEX, and TOP will increase CO₂ emissions while it will subsequently decline with REC and KNOW across countries. The VDA estimates

show that FDI inflows will be the largest contributor to influence CO₂ emissions, followed by REC, TOP, and FPINDEX, while the least contributor will be KNOW to influence CO₂ emissions over a time horizon.

Conclusions

The world economy affected by an enormous increase in CO₂ emissions because of the high usage of fossil fuel combustion, industrialization, non-renewable energy use and technology embodied emissions. The current study took initiative to explore the dynamic relationship between KNOW, REC, FPINDEX and CO₂ emissions in a panel of 132 countries by using a

time series data from 1995 to 2018. The results show that KNOW first increases and later decreases carbon emissions to support KKC hypothesis. Further, FDI inflows, TOP, and FPINDEX positively associated with the high CO₂ emissions that substantiate the PHH and FFP across countries. The study found the positive impact of REC on CO₂ mitigation that corresponds to the need to substitute non-renewable fuel to renewable fuel to achieve ES agenda across countries. The Granger causality results show the unidirectional causality running from i) CO₂ emissions to FDI inflows, FPINDEX, REC, and KNOW, and ii) FDI inflows to FPINDEX, while the bidirectional causality found between i) TOP and CO₂ emissions, ii) KNOW and FDI inflows, iii) TOP and FDI inflows, iv) KNOW and FPINDEX, v) KNOW and REC, vi) TOP and REC and vii) TOP and KNOW. The estimates of an IRF show that FDI inflows, FPINDEX and TOP will increase CO₂ emissions while KNOW and REC will decrease CO₂ emissions. The VDA analysis shows that FDI inflows will be the largest contributor to influence CO₂ emissions, followed by REC, TOP, FPINDEX, and TOP over a time horizon.

The study suggested the following policy formulation to achieve global ES agenda, i.e.,

- **Short-term Policy Implication:** The imposition of carbon taxes on dirty production is desirable to limit carbon emissions, followed by using ISO-certification, emissions trading pricing, hazardous material management, etc. Further, trade and financial liberalization policies should be sustainable to produce eco-friendly production through environmental certification programmes.

- **Medium-term Policy Implication:** Sustainable production and consumption is highly desirable to mitigate carbon emissions that can be achieved through the use of cleaner production technologies, technology spillover, knowledge diffusion, and waste management. The knowledge and technology spillover can be integrated by the cooperation of the developed countries, thus the mutual collaboration and cooperation of sustainable technology transfer from developed to developing countries could get mutual an exclusive global gain for environmental conservation.

- **Long-term Policy Implication:** The energy associated emissions are the major concern of the global economy and it's emphasized the need to limit the use of fossil fuel combustion and other non-renewable energy sources to achieve a sustainability agenda. Using renewable energy sources in existing energy portfolio would be helpful to reduce global average temperature, as mentioned in the mission statement of COP-21 agenda to reduce global temperature less than 1.5°C. The global economy should strive hard to combat climate change and mitigate GHG emissions through substituting fossil fuel to renewable energy sources, technology embodied emissions to cleaner production technologies, and dirty production to eco-friendly production through stringent environmental regulations and knowledge

spillovers. All these sources would desire to move forward for clean and green development across the globe.

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Conflict of Interest

The authors declare no conflict of interest.

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