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SHORT RESEARCH AND DISCUSSION ARTICLE

Relationship between energy demand, financial development, and carbon emissions in a panel of 101 countries: "go the extra mile" for sustainable development

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Abstract
The objective of the study is to examine the impact of energy demand on carbon emissions in mediation of financial development and economic growth in a panel of 101 countries by using the time series data from 1995 to 2018. The study employed dynamic GMM estimator in order to reduce possible endogeneity in the given model. Further, the study used Granger causality and innovation accounting matrix (IAM) to find the causal relationships and variance error shocks between the variables. The results show that energy demand and FDI inflows increase carbon emissions, while financial development decreases carbon emissions across countries. Moreover, the results confirmed the inverted U-shaped relationship between income and emissions with a turning point of US$43,500. Among 101 countries, only 13 countries hold environmental Kuznets curve (EKC) hypothesis as their per capita income surpassed the stated turning point, while the remaining countries exhibit "race to the bottom" hypothesis. The feedback relationship is established between (i) income and carbon emissions, (ii) money supply and carbon emissions, and (iii) FDI inflows and energy demand across countries, whereas one-way linkages found in (i) carbon emissions to money supply, (ii) energy demand to money supply, (iii) money supply to FDI inflows and income, and (iv) energy demand to income across countries. The IAM analysis shows that energy demand, FDI inflows, and money supply will likely to increase carbon emissions, while money supply will decrease carbon emissions over a time horizon.

Keywords Carbon emissions · Energy demand · Financial development · Economic growth · FDI inflows · GMM estimator

Introduction

The balance between energy demand and carbon emissions is highly desirable in order to reduce negative environmental externalities in the form of exacerbation of GHG emissions and climate change that affect countries' sustainable development projects (Sarkodie and Strezov 2019, Anser et al. 2020, etc.). The need of global renewable energy demand is increasing due to its greening effects on environment (Dietzenbacher et al. 2020, Chu and Hawkes 2020, Naz et al. 2019, etc.). Financial development is another important factor that would be helpful to reduce carbon emissions through financing in the eco-friendly production and technologies (Saud et al. 2020, Anton and Nucu 2020, Chen et al. 2019, etc.). Table 1 shows the current literature on energy and carbon emissions across countries.

Earlier literature widely discussed the different scenarios of EKC hypothesis, especially, Taguchi (2013) and Rasli et al. (2018) that are considered the main proponents, which presented the divergent views of EKC, including "new toxics pollutants," "race to the bottom hypothesis," "conventional EKC hypothesis," and "revised EKC hypothesis." The "conventional EKC hypothesis" stated that income is the main predictor that influenced the level of emissions, as higher income level would surpassed after some times to be helpful to reduce emissions intensity; however, it required more policy-oriented mechanism to limit emissions. Carbon pricing is the

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Table 1 Current literature on energy-finance-environment nexus

Authors	Country	Time period	Results
Akram et al. (2020)	66 countries	1990–2014	EEF↑CO2↓
			RE↑CO2↓
			NE↑CO2↓
Shaheen et al. (2020)	Pakistan	1972–2014	EC↑CO2↑
			EG↑CO2↑
Mukhtarov et al. (2020)	Kazakhstan	1993–2014	FD↑EC↑
			EG↑EC↑
			EP↑EC↓
Saud et al. (2020)	49 countries	1990–2014	FD↑EF↑
			GLOB↑EF↓
Ehigiamusoe et al. (2020)	64 countries	1990–2014	EC↑CO2↑
Mahi et al. (2020)	ASEAN-5 countries	1980–2017	EC↑CO2↑
Shahbaz et al. (2020)	UAE	1975–2014	FD↑CO2↑
			EG↑CO2↑
			EC↑CO2↓
			GLOB↑CO2↓
Saint Akadiri et al. (2020)	Turkey	1970–2014	EC↑CO2↑
			EG↑CO2↑
Awodumi and Adewuyi (2020)	Selected African countries	1980–2015	NREC↑CO2↑
Rahman et al. (2020)	Lithuania	1989–2018	EG → CO2
			TOP→CO2
Wasti and Zaidi (2020)	Kuwait	1971–2017	EC↑EG↑
			EC↑CO2↑
			CO2↔EC
Magazzino et al. (2020)	South Africa	1965–2017	EG↔CO2
			EG↔CC
Khattak et al. (2020)	BRICS	1980–2016	INOV↔CO2
			INOV↔EG
Przychodzen and Przychodzen (2020)	27 countries	1990–2014	EG↑RE↑
			RE↑CO2↓

EEF energy efficiency, *EC* energy consumption, *EP* energy prices, *EG* economic growth, *RE* renewable energy, *EF* ecological footprints, *CO2* carbon emissions, *INOV* innovation, *TOP* trade openness, *NREC* non-renewable energy consumption, *GLOB* globalization, *FD* financial development; ↑ shows increasing, ↓ shows decreasing, → shows one-way linkage, and ↔ shows two-way linkages

optimistic solution to achieve this target, and it benefited from generating extra revenues from carbon tax to spend on environmental conservation (Nassani et al. 2019). The parabola relationship could be found between income and emissions by adopting strict environmental regulations in the given hypothesis (Stern 2004). The second divergent view of EKC hypothesis is the emergence of "new toxic pollutants" phenomenon, as high-tech industrial production increases unregulated pollutants along with an increase in country's income that never could be stopped until and unless the countries could signed on some environmental treaties to be conserved the natural environmental through regulated production (Karsch 2019). The "race to the bottom hypothesis" presented another divergent view of EKC, which provoked that higher income of the country leads to increase pollution intensity at certain point interval, which becomes constantly increasing after doubling the income. Thus, an ease of environmental regulations shifts the pollution base from developed to developing countries that exacerbate the pollution level. Thus, the need of initiating the environmental certifications is highly desirable for limiting the pollution shifts from developed to developing countries (Dinda 2004). The "revised EKC hypothesis" shows that country's environmental reforms restrain income and pollution level due to growing public concern about environmental regulations, which although show a parabola relationship between the two variables; however, it is

lower than the "conventional EKC" (Yao et al. 2019). Table 2 shows the energy-finance embodied EKC hypothesis across countries.

The present study has some novel contribution in the existing literature to distinguish it with the other studies, i.e., broad money supply is used as a financial development indicator in the study that is important in order to analyzed the financial deepening of the financial sector, while the previous studies largely used "domestic credit to private sector" as a financial instrument in order to observe the financial depth of the capital market. Further, energy demand is included in between financial indicator and carbon emissions as a mediator to get insights about the financial deepening effect on energy sector to reduce carbon abatement costs. Both the FDI inflows

Table 2 Current literature on energy-finance embodied EKC hypothesis

Authors	Time period	Country	Results
Farhani and Balsalobre-Lorente (2020)	1965–2017	China, India, and the USA	EC_cΨCO2$_c$
			$EG_{I,US}$ΩCO2
Aziz et al. (2020)	1990–2018	Pakistan	REC↑EF↓
			EGΩEF
Dogan and Inglesi-Lotz (2020)	1980–2014	7 countries	EGΩCO2
			INDΨCO2
Danish et al. (2020)	1992–2016	BRICS countries	REC↑EF↓
			EGΩEF
Sarkodie and Ozturk (2020)	1971–2013	Kenya	EC↑CO2↑
			EGΩCO2
Raza et al. (2020)	1990–2015	16 countries	ECΩCO2
Ike et al. (2020)	1980–2010	15 countries	EC↑CO2↑
			EGΩCO2
			TOP↑CO2↑
			OP↑CO2↑
Chen and Taylor (2020)	Historic data	Singapore	HMΩCO2
Altıntaş and Kassouri (2020)	1990–2014	14 countries	EGΩEF
Ullah and Khan (2020)	1972–2014	Pakistan	CRΩCO2
			MCH↑CO2↑
Jin and Kim (2020)	1990–2016	34 countries	EGЙCO2
Badulescu et al. (2020)	1995–2013	28 countries	EGΩCO2
Destek and Sinha (2020)	1980–2014	24 countries	REC↑CO2↓
			EGЙCO2
Gulistan et al. (2020)	1995–2017	112 countries	EC↑CO2↑
			EGΩCO2
Gill et al. (2019)	1970–2016	Malaysia	FDΩCO2
			FD↑CO2↓
Phong (2019)	1971–2014	5 countries	FD↑CO2↑
			EC↑CO2↑
			EGΩCO2
Bass et al. (2019)	1990–2016	Russia	FD↑CO2↑
			EGΩCO2
Rahman et al. (2020)	1970–2016	Pakistan	FD↑CO2↓
			EGЙCO2
Saud et al. (2019)	1980–2016	18 countries	FD↑CO2↑
			EGΩCO2

EC_c Chinese energy consumption, *REC* renewable energy consumption, *EF* ecological footprints, *IND* industry value added, *EC* energy consumption, *$EG_{I,US}$* India-USA economic growth, *EG* economic growth, *REC* renewable energy, *$CO2_c$* Chinese carbon emissions, *CO2* carbon emissions, *TOP* trade openness, *FD* financial development, *HM* heavy metal, *MCH* machinery, *OP* oil prices; ↑ shows increasing, ↓ shows decreasing, Ψ shows U-shaped, Ω shows inverted U-shaped, and Й shows no EKC hold

Table 3 List of variables and descriptive statistics

Descriptive statistics

Variables	Mean	Maximum	Standard deviation	Skewness	Kurtosis
Carbon emissions (CO2) (metric tons per capita)	5.393	70.042	7.865	3.371	18.948
Broad money Supply (BMS) (% of GDP)	57.456	258.831	40.693	1.857	7.556
Energy use (ENU) (kg of oil equivalent)	160.064	861.365	106.443	2.486	11.240
FDI inflows (FDI) (% of GDP)	3.644	55.075	5.193	2.878	32.063
GDP per capita (GDPpc) (constant 2010 US$)	11,758.18	92,077.57	17,269.07	2.217	7.573

Source: World Bank (2019)

and economic growth simultaneous be used in the given nexus to substantiate "pollution haven" hypothesis and EKC hypothesis, respectively, under the capital market gains. Thus, these motivations bring to make this study more pragmatic and policy oriented. The main questions that also evolved in the key prescribed variables that used in this study are as follows:

- To what extent financial market capitalize green energy projects to limit carbon emissions?
- Does FDI inflows would be helpful to reduce carbon emissions through cleaner production technologies?
- Whether continued economic growth improves environmental quality under green financing projects?

These questions would be highly needed to explore the given nexus for sustainable development across countries. The objectives of the study are as follows:

i) To examine the impact of financial development, energy demand, and economic growth on carbon emissions across countries
ii) To evaluate the EKC hypothesis and "pollution haven" hypothesis under financial development indicator
iii) To analyze the causal relationship and variance error shocks among the variables

These objectives have been set to analyze the dynamic linkages among the studied variables at level and over a time horizon, which would give more insights into the future-oriented action plans towards reaching environmental sustainable goals at global scale.

Material, methods, results, and discussion

Table 3 shows the list of variables and their descriptive statistics for ready reference. The carbon emissions served as a "criterion" variable, while money supply, FDI inflows, energy demand, and GDP per capita served as predictors of the response variable. The maximum carbon emissions value is about 70.042 metric tons during the period of 1990–2018. The average growth in the money supply, on average, is far higher than the FDI inflows during the stipulated time period, which are about 57.45% relative to GDP in money supply and 3.64% in FDI inflows across countries. The maximum value of per capita income and energy demand reached US$92077.57 and 160.06 kg of oil equivalent, respectively.

The data of the candidate variables of 101 countries for a period of 1995–2018 are taken from World Bank (2019) data set. Table 4 shows the list of the sample countries for ready reference.

The study followed the Stern (2004) reduced form of equations where emissions are subject to be changed through increase in income at its second degree. The empirical equation of the study is further extended with the recent scholarly work of Yue et al. (2020), Nizam et al. (2020), and Khan et al. (2019) and illustrated in a schematic manner, i.e.:

$$CO2_{i,t} = \alpha_0 + \alpha_1 BMS_{i,t} + \alpha_2 ENU_{i,t} + \alpha_3 FDI_{i,t} + \alpha_4 GDPpc_{i,t} + \alpha_5 SQGDPpc_{i,t} + \varepsilon_{i,t}$$
$$\therefore \frac{\partial BMS}{\partial CO2} < 0, \frac{\partial ENU}{\partial CO2} > 0, \frac{\partial FDI}{\partial CO2} > 0, \frac{\partial GDPpc}{\partial CO2} > 0, \frac{\partial GDPpc}{\partial CO2} <, 0\ EKC = \frac{\alpha_4}{-2\alpha_5} \quad (1)$$

where CO2 shows carbon emissions, BMS shows broad money supply, ENU shows energy use, FDI shows FDI inflows, GDPpc shows per capita GDP, SQGDPpc shows square of GDPpc, and shows error term.

There are number of alternative panel statistical measures available in order to get sound inferences of the parameter of interests, not limited to the following, i.e., panel least squares regression, panel fixed effect versus random effect models, panel cointegration techniques, and panel instrumental variables techniques. The instrumental variable techniques have a distinct position among the rest of the methods, as it handles possible endogeneity issues among the regressors, for instance, two-stage least squares (2SLS) regression, 3SLS, and GMM estimator. These are the estimators used in different situations where the endogeneity issues become a major concern; hence, system and differenced GMM estimators are considered more reliable techniques where the number of cross-sections is larger than the variables of interest to get robust inferences. Thus, the study employed dynamic GMM

Table 4 List of sample countries

Sample countries (101)	"Albania, Algeria, Angola, Argentina, Armenia, Australia, Bahrain, Bangladesh, Azerbaijan, Belarus, Benin, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Cambodia, Cameroon, Canada, Chile, China, Colombia, Congo Dem Republic, Costa Rica, Cote d'Ivoire, Croatia, Czech Republic, Dominican Republic, Ecuador, Egypt, El Salvador, Eritrea, Ethiopia, Gabon, Georgia, Ghana, Guatemala, Haiti, Hungary, Iceland, India, Indonesia, Iran, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea, Kuwait, Kyrgyz Republic, Lebanon, Malaysia, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nepal, New Zealand, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Qatar, Romania, Russia, Saudi Arabia, Senegal, Singapore, South Africa, Sri Lanka, Sudan, Suriname, Sweden, Switzerland, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela RB, Vietnam, Zambia, Zimbabwe"

estimator proposed by Arellano-Bond differenced estimator that gives robust inferences by minimizing possible endogeneity from the given data set. The endogeneity is handled by incorporating the first lagged of the criterion variable and predictor variables. The Hansen J statistics and instrumental rank checked the instrumental validity in the given model. Equation (2) shows the Arellano-Bond illustration as follows:

$$CO2_{i,t} = \alpha_0 + \alpha 1 CO2_{i,t} + \alpha_2 BMS_{i,t} + \alpha_3 ENU_{i,t} + \alpha_4 FDI_{i,t} + \alpha_5 GDPpc_{i,t} + \alpha_6 SQGDPpc_{i,t} + z_{i,t} + \varepsilon_{i,t} \quad (2)$$

where z shows instrumental variables.

Table 5 shows the differenced GMM estimates of the given variables. The results show that the first lagged of the criterion variable has a positive sign that implies divergence in the carbon emissions data, which need sustainable policy instruments to mitigate carbon emissions across countries. The negative relationship is found between money supply and carbon emissions, which implies that financial development substantially decreases carbon emissions through initiating investment in the green financing projects (Hoque et al. 2019, Rani 2020, etc.), whereas the positive relationship found between energy demand and carbon emissions that provoked the viability of energy associated emissions, which could be reduced by shifting towards non-renewable to renewable energy fuels at global scale (Destek and Sinha 2020, Kabel and Bassim 2020, etc.). The emission intensity is increasing through financial liberalization policies, which substantiate "pollution haven" hypothesis in a panel of selected countries. The need of strict environmental regulations and use of cleaner production technologies would be the sustainable instruments for limiting dirty polluting industries at global scale (Dou and Han 2019, Shao et al. 2019, etc.).

The positive relationship exerts between GDPpc and carbon emissions at initial level, while it becomes negative relationship at its second degree coefficient value which tends to exhibit the inverted U-shaped relationship between them to support EKC hypothesis. The turning point of US$43,500 is required to achieve environmental sustainability agenda in the selected sample of the countries. On the basis of EKC turning point, only 13 countries are qualified to reduce carbon emissions through continued economic growth, which surpass the threshold level of US$43,500. Table 6 shows the qualified list of countries that could achieve EKC hypothesis through increasing their GDP per capita. The 13 countries listed in the given table show that the countries have an ability to achieve EKC hypothesis as their GDP per capita falls in the EKC threshold, while 88 countries have not yet achieved EKC hypothesis as their income level is far less than the threshold level. Thus, the "race to the bottom" hypothesis would be visible in the remaining countries.

Table 5 Differenced GMM estimates

Dependent variable: $\ln(CO2)_t$				
Variables	Coefficient	Standard error	Prob. value	Statistical tests
$(CO2)_{t-1}$	0.609	2.82E-05	0.000	
$(BMS)_t$	− 0.021	1.18E-05	0.000	J statistic: 99.074
$(ENU)_t$	0.004	7.37E-06	0.000	Prob. J statistic: 0.405
$(FDI)_t$	0.016	3.07E-05	0.000	Instrumental rank: 103
$(GDPpc)^t$	0.0003	1.54E-07	0.000	AR(1)-t-statistics: −2.629*
$(SQGDPpc)_t$	− 3.45E-09	1.29E-12	0.000	AR(2)-rho: − 155.817
EKC turning point	-GDPpc/2(SQGDPPC) = $43,500			

* indicates 1% significance level

Table 6 EKC and "race to the bottom" hypotheses hold in the given sample of countries

Sample countries (101)	"Australia, Brunei Darussalam, Iceland, Japan, Kuwait, Norway, Qatar, Singapore, Sweden, Switzerland, United Arab Emirates, United Kingdom, and United States"
Eligible countries that may achieve EKC hypothesis (13)	13 countries hold EKC hypothesis
Countries that could not be achieved EKC hypothesis (88)	88 countries hold "race to the bottom" hypothesis

Source: Authors estimation

Table 7 shows the estimates of VAR Granger causality, IRF, and VDA for ready reference. The results confirmed the feedback relationship between GDPpc and carbon emissions and FDI inflows and energy demand while the unidirectional causality running from carbon emissions to money supply, energy demand to money supply, money supply to FDI inflows and GDP per capita, and energy demand to GDP per capita. The results supported carbon-led finance, energy-led finance, finance-led growth, and energy-led growth hypothesis across countries.

The IRF estimates show that energy demand, FDI inflows, and GDP per capita will likely to increase carbon emissions, whereas money supply will decrease carbon emissions for the next 10-year time period. The forecast variance error shocks show that income will exert a greater magnitude in terms of influencing carbon emissions, while money supply will exert a least influenced to carbon emissions over a time horizon.

Conclusion and policy implications

The environmental sustainability agenda is highly provoked in the academic and research literature, which need sustainable policy instruments to mitigate carbon emissions across countries. This study focused on energy demand and carbon emissions in the mediation of financial development and economic growth in a diversified panel of countries, and it is utilized in the long-term time series data from 1995 to 2018 to obtain robust inferences. The results confirmed the EKC hypothesis, energy associated emissions, and "pollution haven" hypothesis across countries. The bidirectional causality found between income and carbon emissions and energy and FDI inflows, while unidirectional relationship is running from carbon emissions to financial development, financial development to FDI inflows and income, and energy demand to income across countries. The variance error shocks show that country's income will exert a greater magnitude, while money supply will be least influence to carbon emissions for the next 10-year time period. The following policy implications are proposed to conserve global environment, i.e.:

i) Financial development may played a vital role to improve environmental quality through initiated green financing projects, for instance, investment in the renewable energy sources, alternative energy fuels, startups sustainable projects, and to get equipped with efficient machinery for eco-friendly production.
ii) Carbon pricing mechanism should be introduced in order to minimize the production of air pollutants, while at the same time the revenue generated from carbon tax would be spend for eco-friendly production, growing more plants, efficient waste recycling process, and carbon abatement cost. Thus, the advancement in the cleaner production process is key for achieving global environmental sustainability agenda.
iii) High need for environmental regulation to conserve natural environment is imperative for long-term sustainable development. The efforts should be made to limiting the use of chemicals that affect ozone layer and introduced emissions – cap trading programs for controlling emissions.

Table 7 VAR Granger causality and IAM estimates

VAR Granger causality					
GDPpc↔CO2	CO2 → BMS	ENU → BMS	FDI↔ENU	BMS → FDI	BMS → GDPpc
ENU → GDPpc					
Innovation accounting matrix: IRF estimates					
Forecast relationship (2019–2028)	BMS↑CO2↓	ENU↑CO2↑	FDI↑CO2↑	GDPpc↑CO2↑	
VDA estimates					
Forecast variance error shocks (2019–2028)	GDPpc will have a greater magnitude of 0.891% that influenced CO2 emissions		BMS will exert a least influenced on CO2 emissions for the next 10-year time period		

These policy implications are highly important for governing environmental laws to protect natural environment.

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