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20

CO_2 Emissions, Energy Consumption, Deforestation and Agricultural Income in LDCs

Lessons for Post-2015 Development Agenda

Fahmida Khatun
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Preface

The *Southern Voice on Post-MDG International Development Goals* works as an open platform, and is a network of 48 think tanks from Africa, Latin America and Asia that seeks to contribute to the global post-2015 dialogue. Motivated by the spirit of wide academic inquiry, the initiative is committed to provide quality data, empirical evidence and policy analyses, derived from research in the countries of global South. Through strategic engagements, *Southern Voice* aspires to address the existing 'knowledge asymmetry' and 'participation deficit' afflicting the global discourse on post-2015 agenda.

With these goals in mind, *Southern Voice* launched a call for papers among its members to inform the global debate based on promoting original research on new issues that have emerged from various reports, structured conversations concerning the post-2015 agenda as well as from the discussions around them and beyond. Eleven research grants were offered during this phase.

In response to the call, we received numerous proposals which were reviewed by *Southern Voice* members. The research papers were also peer reviewed, and the revised drafts were later validated by the reviewer.

The resulting collection of papers highlights some of the most pressing concerns for the countries of the global South. In doing so, they explore a variety of topics including social, governance, economic and environmental concerns. Each paper demonstrates the challenges of building an international agenda which responds to the specificities of each country, while also being internationally relevant. It is by acknowledging and analysing these challenges that the research from the global South supports the objective of a meaningful post-2015 agenda.

In connection with the ongoing debates on post-2015 international development goals, **CO_2 Emissions, Energy Consumption, Deforestation and Agricultural Income in LDCs: Lessons for Post-2015 Development Agenda** by *Dr Fahmida Khatun*, Research Director and *Mr Muhammad Al Amin*, Senior Research Associate, Centre for Policy Dialogue (CPD), Bangladesh, examines the dynamic causal relationship between CO_2 emissions, energy consumption, deforestation and agricultural production in the least developed countries (LDCs) for the period 1981-2010.

Contributions of *Ms Andrea Ordóñez*, Research Coordinator of the initiative and *Ms Mahenaw Ummul Wara* (Research Associate, Centre for Policy Dialogue (CPD) and Focal Point at the *Southern Voice* Secretariat) in managing and organising the smooth implementation of the research programme are gratefully acknowledged.

I would also like to thank *Ms Mireya Villacis,* Project Coordinator, Centro Ecuatoriano de Derecho Ambiental (CEDA) for peer reviewing, and *Mr Oliver Turner* for copy editing the paper. I would like to take this opportunity to recognise the support of Think Tank Initiative (TTI) towards *Southern Voice*, particularly that of *Dr Peter Taylor*, Programme Leader, TTI.

I hope the engaged readership will find the paper stimulating.

Dhaka, Bangladesh
February 2015

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Abstract

This paper examines the dynamic causal relationship between carbon dioxide (CO_2) emissions, energy consumption, deforestation and agricultural production in LDCs for the period 1981-2010. The study applies co-integration and vector error correction modeling to examine the relationship. A long-run relationship is found to exist among the variables. That is, in the long-run energy consumption and deforestation are likely to affect CO_2 emissions positively. This implies that over time, higher energy consumption and deforestation in LDCs give rise to more CO_2 emissions, which is likely to lead to more environmental pollution. In the short-run, increases in deforestation and agricultural production causes higher CO_2 emissions, but increases in energy consumption does not. The study suggests that the post-2015 development agenda should include sustainable agriculture as one of the goals, which would be low carbon by nature, and can be achieved by balanced and efficient use of fertilisers and pesticides.

Contents

Acronyms

ADF	Augmented Dickey Fuller
ARDL	Autoregressive Distributed Lag
ASEAN	Association of Southeast Asian Nations
CO_2	Carbon Dioxide
ECM	Error Correction Model
GDP	Gross Domestic Product
GHG	Green House Gas
GNI	Gross National Income
LDC	Least Developed Country
PP	Phillips-Perron
SDG	Sustainable Development Goal
USD	United States Dollar
VAR	Vector Auto-Regression
WDI	World Development Indicator

CO_2 Emissions, Energy Consumption, Deforestation and Agricultural Income in LDCs
Lessons for Post-2015 Development Agenda[*]

Fahmida Khatun

Muhammad Al Amin

1. Introduction

The world is getting warmer at an increasing pace, with each of the last three decades being warmer than the preceding decade since 1850 (IPCC, 2013). Greenhouse gas (GHG) emissions are considered one of the most important causes of global warming. Among the GHGs, carbon dioxide (CO_2) is the most prevalent in the atmosphere. Most of the CO_2 emissions come from the consumption of fossil fuels such as coal, oil and gas. Driving the acceleration of economic growth across the world requires intensive use of fossil fuels, which eventually leads to huge CO_2 emissions in the atmosphere. Economic activities such as manufacturing, agriculture and transportation necessitate the intensive use of coal, oil and gas which consequently generates significant amounts of CO_2 each year. CO_2 emissions and economic growth are thereby intrinsically linked.

Least developed countries (LDCs) have been identified as the most vulnerable to the effects of climate change. Greater dependence on rain-fed agriculture and forestry as sources of income and employment make many LDCs vulnerable to climatic changes. Many LDCs are already subject to climatic stress. CO_2 emissions in LDCs are also increasing at an alarming pace. During the 1980s CO_2 emissions increased in LDCs by an average of 0.22 per cent; by 1.04 per cent in the 1990s and by 4.38 per cent during the 2000s (WDI, 2013). This acceleration in CO_2 emissions is making LDCs more vulnerable to the adverse effect of climate change. Rising levels of energy consumption are considered one of the main contributors to the continuously increasing CO_2 emissions. Between 1981 and 2010 per capita energy use in LDCs increased by 15.66 per cent. Besides rapid growth in energy consumption, LDCs are also experiencing rapid deforestation.

Deforestation is considered to be the second largest contributor towards rising global CO_2 emissions. According to the World Resources Institute (2014), forest loss contributes between 12 per cent and 17 per cent of annual global GHG emissions. Trees capture CO_2 by absorbing it into their cells through photosynthesis. However, when trees are destroyed they release their carbon back into the atmosphere. In a forest, the ground can hold 50 per cent of CO_2 and the loss of trees also generates degradation of the ground. Rapid reduction in trees therefore leads to huge CO_2 emissions in the atmosphere. Between 1990 and 2011 LDCs lost about 3.87 per cent of forest area. Thus deforestation is considered the other key reason behind higher CO_2 emissions in LDCs.

Agriculture represents one quarter of gross domestic product (GDP) in LDCs, and is another key source of CO_2 emissions (WDI, 2013). The UN's Food and Agriculture Organization (2014) estimates that over the past 50 years CO_2 emissions from agriculture have nearly doubled. Intensive use of chemical fertilisers and pesticides, and the mismanagement of agricultural residues generate and release high levels of CO_2 into the atmosphere of LDCs. Deposited manure and leftover pastures

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[*]The authors would like to acknowledge research assistance provided by *Ms Shahzeen Hafiz*, Programme Associate, Centre for Policy Dialouge (CPD).

also emit CO_2, further exacerbating the problem. Therefore, it is apparent that there are numerous factors which lead to rapid increases in CO_2 in the atmosphere of LDCs. However, the relationship among the variables has not yet been statistically investigated. Statistical evidence, which can definitively demonstrate the causes behind increasing CO_2 emissions, can assist LDCs in reducing their CO_2 emissions in a more knowledgeable way.

A new international development framework will be put forward after 2015, and the global community is now working on shaping the post-2015 Sustainable Development Goals (SDGs). The knowledge about how energy consumption, deforestation and agricultural income contribute to CO_2 emissions in LDCs can provide valuable inputs for global leaders in shaping the post-2015 SDGs in a more informed manner. Therefore, the objectives of this study are to:

(i) examine how CO_2 emissions, energy consumption, deforestation and agricultural production are related in the long-run;
(ii) estimate the long-term elasticity of energy consumption, deforestation and agricultural production with respect to CO_2 emissions;
(iii) investigate the causal relationship between CO_2 emissions and energy consumption, CO_2 emissions and deforestation, and CO_2 emissions and agricultural production.

The rest of the paper is organised as follows. Section 2 provides a brief review of the most relevant existing literature. Section 3 describes the model, data and estimation methodology. Section 4 presents the empirical results. Finally, Section 5 presents a few implications for shaping the post-2015 SDGs.

2. Review of Literature

A significant body of literature in ecological economics has investigated the relationship between economic activities and the emissions of pollutants. It finds that increases in per capita income, energy consumption, deforestation and trade liberalisation lead to higher levels of CO_2 emissions. The following is a short overview of the existing literature relevant to the present study.

Halicioglu (2009) examines the dynamic causal relationships between income, energy consumption, CO_2 emissions and foreign trade in Turkey by using time series data for the period 1960-2005. He applies the bounds testing and the co-integration procedure to find an interrelationship between the variables. The bounds test results indicate that two forms of long-run relationships exist between the variables. In the first, income, CO_2 emissions and foreign trade determine energy consumption. In the second, income is determined by energy consumption, CO_2 emissions and foreign trade. The author concludes that in Turkey, income is the most significant variable in explaining CO_2 emissions, while energy consumption and foreign trade are the next most significant.

Mozumder and Marathe (2006) examine the causal relationship between per capita GDP (PCGDP) and per capita electricity consumption (PCEC) in Bangladesh using techniques of co-integration and vector error correction model. They find evidence of uni-directional causality running from PCGDP to PCEC. However, the inverse is not true in the case of Bangladesh, i.e. PCEC does not cause per capita GDP. They also investigate the co-integrating relationship between the variables by employing the Johansen co-integration test, and use the Granger causality framework which allows for the testing of the existence and the direction of causality between the variables. The results indicate that PCGDP Granger causes PCEC at a 5 per cent level of significance. However, the reverse causality, i.e. PCEC Granger causes PCGDP, was not found to be significant even at a 10 per cent significance level.

Ang (2007) examines the dynamic causal relationships between energy consumption, pollutant emissions and output in France for the period 1960 to 2000. The author applies co-integration and vector error-correction modelling techniques to investigate the relationship. The study finds the existence of a strong long-term relationship between the variables. The causality test results indicate that economic growth exerts a causal influence on pollution and energy use in the long-term. The study also finds that in the short-term, there is uni-directional causality running from energy use to output growth.

Soytas and Sari (2007) examine the causal relationship between energy use, environmental pollution and income in the Turkish economy. They also apply the TY procedure to test for Granger causality. The study finds that CO_2 emissions cause energy consumption, but energy consumption does not affect CO_2 emissions. The study also finds a long-term causal relationship between CO_2 emissions, energy consumption and economic growth in Turkey, controlling for labour and gross fixed capital formation.

Ang (2008) investigates the dynamic causal relationship between energy consumption, output and CO_2 emissions in Malaysia for the period 1971-1999. The study applies the procedure of co-integration and the tri-variate vector error correction model for examining the relationship. The study finds that pollution and energy use are positively related to output in the long-term. The study also finds a strong causal relationship running from economic growth to energy consumption both in the long and the short-terms.

Zhang and Cheng (2009) investigate the existence and direction of Granger causality between energy consumption, CO_2 emissions and economic growth in China for the period of 1960 to 2007. The study finds evidence of long-run uni-directional Granger causality running from energy consumption to CO_2 emissions. The study also finds a uni-directional Granger causality running from GDP to energy consumption for the same period. Moreover, the study indicates that neither energy consumption nor CO_2 emissions lead to economic growth. Therefore, the study suggests that in the long-term, the government of China can pursue a CO_2 emissions reduction policy and a conservative energy policy without impeding economic growth.

Jalil and Mahmud (2009) examine the long-term relationship between foreign trade, income, energy consumption and CO_2 emissions in China for the period 1975 to 2005. They also investigate whether or not the environmental Kuznets curve (EKC) relationship exists between per capita real GDP and CO_2 emissions in the long-run in China. In order to conduct the analysis, they employ the autoregressive distributed lag (ARDL) bound test method. The study finds a quadratic relationship between CO_2 emissions and income for the sample period which supports the EKC relationship. The Granger causality test results suggest that one way causality runs through economic growth to CO_2 emissions. The study also finds that in the long-run, CO_2 emissions are mainly determined by energy consumption and income. However, the study finds that foreign trade does not relate to CO_2 emissions in China.

Lean and Smyth (2010) examine the causal relationship between economic growth, electricity consumption and CO_2 emissions, using a panel vector error correction model for five ASEAN (Association of Southeast Asian Nations) countries for the period 1980 to 2006. The study finds evidence of the environmental Kuznets curve for these countries. The study also finds a positive association between electricity consumption and emissions and a non-linear relationship between real output and emissions. However, the long-term estimates do not indicate the direction of causality between the variables. The authors also examine for Granger causality among the variables. The Granger causality tests suggest that in the long-term, there is uni-directional causality running from emissions to economic growth and electricity consumption. However, in the short-term, the Granger causality runs from emissions to electricity consumption only.

Ghosh (2010) investigates the causality and co-integration between economic growth and CO_2 emissions for India by using the ARDL bounds testing approach and the Johansen-Juselius maximum likelihood procedure for the period 1971-2006. The study results indicate a uni-directional short-term causality running from energy supply to CO_2 emissions and economic growth to energy supply. However, the study fails to establish any long-term causality or any long-term equilibrium relationship between economic growth and CO_2 emissions.

Sharma (2010) investigates the determinants of CO_2 emissions in a global panel consisting of 69 countries during the period 1985-2005. The study makes the panel data more homogenous by constructing a number of sub-panels such as the high-income country panel, the middle-income country panel, and the low-income country panel. The study finds that increases in per capita GDP, trade openness, per capita electric power consumption, and energy consumption (using per capita total primary energy consumption as a proxy variable) lead to increased levels of CO_2 emissions. It also finds that urbanisation leads to lower levels of CO_2 emissions in the high-income, middle-income and low-income panels. In the context of the global panel, only per capita total primary energy consumption and GDP per capita are found to be statistically significant determinants of CO_2 emissions. However, per capita electric power consumption, urbanisation and trade openness have a negative impact on CO_2 emissions.

Yousefi-Sahzabi *et al.* (2010) investigate the relationship between Iran's economic growth and CO_2 emissions for the period 1994 to 2007 using a national panel data set. They construct the Pearson product-moment correlation coefficients (PMCC) matrix to test the relationships between GDP and CO_2 emissions. The study finds enough evidence of correlation between economic development and CO_2 emissions in Iran. The study also conducts a sector-wise analysis for Iran. They find that there is a strong positive correlation between economic growth and CO_2 emissions across all sectors (excluding agriculture). However, in most sectors it is observed that absolute emission rapidly increases with economic growth, while CO_2 emission intensity (the emission per unit of GDP) does not necessarily show increasing trends.

Alam *et al.* (2012) investigate the likely existence of dynamic causality between electricity consumption, CO_2 emissions, energy consumption and economic growth in Bangladesh. The study used the Johansen bi-variate co-integration model to check for co-integrating relationships. An analysis of an ARDL model was carried out to check for robustness. Next, the vector error correction modeling framework tests were carried out to test for Granger short-term, long-term and strong causality. The results indicate that a bi-directional long-run causality exists between electricity consumption and economic growth, while uni-directional causality exists from energy consumption to economic growth both in the short and the long-terms. However, no causal relationship exists in the short-term. The strong causality results indicate bi-directional causality in both cases. The study also finds that a feedback causality exists in the long-term from energy consumption to CO_2 emission while uni-directional causality runs in the short-term. Moreover, CO_2 Granger causes economic growth both in the short and in the long-terms.

Hossain (2012) examines the dynamic causal relationship between energy consumption, CO_2 emissions, foreign trade, economic growth and urbanisation in Japan for the period 1960-2009. The study finds short-term uni-directional causality from trade openness to energy consumption, from CO_2 emissions to economic growth, from economic growth to trade openness and from energy consumption and trade openness to CO_2 emissions. The study also finds that CO_2 emissions, energy consumption, economic growth, foreign trade and urbanisation are co-integrated. This implies that despite of having deviations in the short-term, the explanatory variables merge with CO_2 emissions in the long-term to achieve steady-state equilibrium. It is found that both in the long-term and in the short-term, energy consumption has a significant positive impact on CO_2 emissions, which implies that due to the expansion of industrial output for economic development, more and more energy is being consumed in Japan. The study also finds that given there is uni-directional causality from CO_2 emissions to economic growth in Japan, any policy in respect of reduction of CO_2 emissions will be harmful for further economic development.

Even though a significant number of studies have been carried out to explore how energy consumption and economic activities affect CO_2 emissions, there has been no study in the context of LDCs as a whole. This study addresses this particular gap in the existing literature. Moreover, this study examines how deforestation is related to CO_2 emissions both in the short and long-terms, which is also a unique initiative in the literature of ecological economics.

3. Model, Data and Econometric Methodology

3.1 Model

In order to find the long-term relationship between CO_2 emissions, energy consumption, deforestation and agricultural income, utilising Hossain (2012), the following logarithmic functional form is estimated:

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln ENC_t + \beta_2 \ln DFRST_t + \beta_3 \ln PCAGY_t + \varepsilon_t \quad (1)$$

where CO_{2t} is the per capita CO_2 emission in LDCs in year t; ENC_t is the per capita energy consumption in LDCs in year t; $DFRST_t$ is net forest depletion as percentage of gross national income(GNI)[1] in LDCs in year t; $PCAGY_t$ is the per capita agricultural income in LDCs in year t; *β's* are the parameters to be estimated; ln is natural logarithm; and ε_t is an error term. Following Ang (2007 and 2008), Jalil and Mahmud (2009), Soytas and Sari (2009), Alam *et al.* (2012), and Hossain (2012), we use CO_2 emissions as the proxy for the level of environmental degradation.

Generally, it is expected that higher levels of energy consumption lead to higher levels of economic activity and generate more CO_2 emissions, therefore we expect $\beta_1 > 0$. Since deforestation is considered to be one of the leading contributors of CO_2 worldwide, we assume $\beta_2 > 0$. Agricultural activities, such as the use of chemical fertilisers in farming and agricultural residues, emit CO_2. Therefore, we also assume, if per capita agricultural income increases, CO_2 emissions are also likely to increase.

3.2 Data

The present study covers the period 1981 to 2010 and uses annual aggregated time series data for 48 LDCs[2] as defined by the United Nations. A detailed description of the variables used in this study and the summary statistics is provided in Table 1 and Table 2. Data used in this study are collated from the World Development Indicator (WDI) released by the World Bank in 2013. WDI measures per capita CO_2 emissions in metric tonnes, per capita energy consumption in kilograms of oil equivalent, and net forest depletion as percentage of GNI. For per capita real value added in agriculture, the total value addition in agriculture (in constant 2005 USD) is divided by the total population in LDCs. Population data has also been obtained from the WDI. Finally, for the ease of modelling, data are defined as follows: CO_2 is per capita CO_2 emissions, ENC is per capita energy consumption, DFRST is net forest depletion as percentage of GNI and PCAGY is per capita real value added in agriculture. Time series plots of the variables are presented in Figure 1, which will provide a snapshot on the features of the data used in this study.

[1]"GNI per capita (formerly GNP per capita) is the gross national income, converted to US dollars using the World Bank Atlas method, divided by the midyear population. GNI is the sum of value added by all resident producers plus any product taxes (less subsidies) not included in the valuation of output plus net receipts of primary income (compensation of employees and property income) from abroad (WDI, 2013).

[2]LDCs include Afghanistan, Angola, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Kiribati, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Samoa, Sao Tome and Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Sudan, Timor-Leste, Togo, Tuvalu, Uganda, United Republic of Tanzania, Vanuatu, Yemen, and Zambia (United Nations, 2013).

Table 1: Description of Variables

Variable	Description
CO_2	CO_2 emissions (metric tonnes per capita)
ENC	Energy use (kg of oil equivalent per capita)
DFRST	Net forest depletion (% of GNI)
PCAGY	Per capita real value added in agriculture (constant 2005 USD)

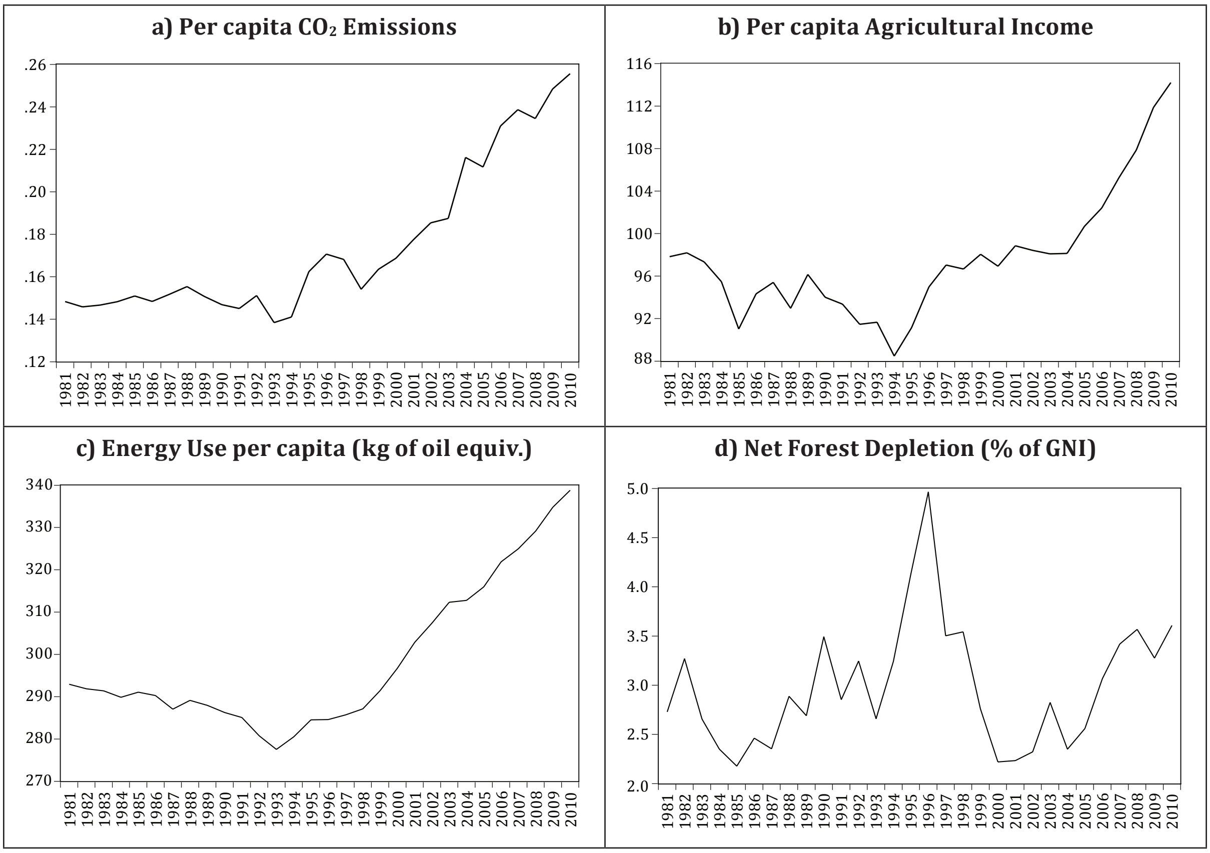
Source: Authors.

Table 2: Summary Statistics

Criteria	CO_2	ENC	DFRST	PCAGY
Mean	0.17	298	2.98	97.61
Median	0.16	291	2.84	96.99
Maximum (Year)	0.256 (2010)	338.8 (2010)	4.96 (1996)	114 (2010)
Minimum (Year)	0.138 (1993)	277.52 (1993)	2.18 (1985)	88 (1994)
Std.Dev.	0.04	17.34	0.63	5.88
Skewness	1.06	0.99	1.05	1.22
Kurtosis	2.69	2.72	4.35	4.37
Jarque-Bera	5.72*	4.98*	7.84***	9.80***
Sum	5.24	8953	89	
Observations	30	30	30	

Source: Authors.
Note: ***, ** and * indicate that Jarque-Bera statistics are significant at 1 per cent, 5 per cent and 10 per cent levels.

Figure 1: Time Series Plots of the Variables



Source: Authors.

3.3 Econometric Methodology

The dynamic causal relationship between CO_2 emissions, energy consumption, deforestation and agricultural income in LDCs are tested by using standard time series techniques. The testing procedure involves three steps: (i) explore whether each variable contains a unit root; (ii) examine whether there is a long-term co-integrating relationship between the variables; and finally, (iii) estimate a vector error correction model.

Time series data may produce spurious results if the variables under consideration are linked to common factors. Therefore, to identify the correct model, the presence of stochastic term in the variables needs to be examined. A series is said to be non-stationary if the mean and variance of the variable are not constant over time, i.e. it follows a time trend. Two non-stationary variables may seem to be related, simply because of the common nature of their time trends when in fact they are not. This motivates us to perform the Augmented Dickey Fuller (1979) (ADF) and the Phillips-Perron (1988) (PP) unit root test to check for data stationarity.

When time series data are characterised by non-stationarity, co-integration is a particularly appropriate statistical technique (Engle and Granger, 1987). Consequently, Johansen's method is used which is capable of determining the number of co-integrating vectors for any given number of non-stationary series of the same order. However, before applying the Johansen approach, it is important to determine the lag length or order of the Vector Auto-Regression (VAR). This is a key element in the specification of the VAR and forms the basis for co-integrating ranks. In order to identify the number of co-integrating ranks, i.e. the number of co-integrating equations, trace tests and maximum eigenvalue tests are applied.

The hypothesis that is tested is that there are 'r' co-integrating vectors against the alternative of 'r or more' (trace statistic) or 'r+1' (maximum eigenvalue statistic) co-integrating vectors.

If the Johansen test indicates a co-integrating relationship between the variables, estimation of an Error Correction Model (ECM) can be performed. The ECM has an advantage of combining both the short-term properties of economic relationships in the first difference form, as well as the long-term information in the level form. It should be noted that an ECM enables estimation of the speed of adjustment back to the long-term condition among the variables. If variables are found to be co-integrated, then there must exist an associated error correction mechanism (Engle and Granger, 1987). Therefore, for the four variable cases, assuming that there is only one co-integrated relationship, the VECMs can be expressed as follows:

$$\begin{aligned} \Delta lnCO_{2_t} = \alpha_1 + \alpha_{11} ECT_{t-1} & \\ + \sum_{j=1}^{p-1} \phi_{1j} \Delta lnCO_{2_{t-j}} & \\ + \sum_{j=1}^{p-1} \theta_{1j} \Delta lnENC_{t-j} & \\ + \sum_{j=1}^{p-1} \psi_{1j} \Delta lnDFRST_{t-j} + \sum_{j=1}^{p-1} \delta_{1j} \Delta lnPCAGY_{t-j} + \varepsilon_{1t} & \qquad (2) \end{aligned}$$

$$\Delta lnENC_t = \alpha_2 + \alpha_{21}ECT_{t-1} + \sum_{j=1}^{p-1} \phi_{2j}\Delta lnCO_{2_{t-j}} + \sum_{j=1}^{p-1} \theta_{2j}\Delta lnENC_{t-j} + \sum_{j=1}^{p-1} \psi_{2j}\Delta lnDFRST_{t-j} + \sum_{j=1}^{p-1} \delta_{2j}\Delta lnPCAGY_{t-j} + \varepsilon_{2t} \quad (3)$$

$$\Delta lnDFRST_t = \alpha_3 + \alpha_{31}ECT_{t-1} + \sum_{j=1}^{p-1} \phi_{3j}\Delta lnCO_{2_{t-j}} + \sum_{j=1}^{p-1} \theta_{3j}\Delta lnENC_{t-j} + \sum_{j=1}^{p-1} \psi_{3j}\Delta lnDFRST_{t-j} + \sum_{j=1}^{p-1} \delta_{3j}\Delta lnPCAGY_{t-j} + \varepsilon_{3t} \quad (4)$$

$$\Delta lnPCAGY_t = \alpha_4 + \alpha_{41}ECT_{t-1} + \sum_{j=1}^{p-1} \phi_{4j}\Delta lnCO_{2_{t-j}} + \sum_{j=1}^{p-1} \theta_{4j}\Delta lnENC_{t-j} + \sum_{j=1}^{p-1} \psi_{4j}\Delta lnDFRST_{t-j} + \sum_{j=1}^{p-1} \delta_{4j}\Delta lnPCAGY_{t-j} + \varepsilon_{4t} \quad (5)$$

Where, $ECT_{t-1} = CO_{2_{t-1}} + \left(\frac{\beta_{21}}{\beta_{11}}\right)ENC_{t-1} + \left(\frac{\beta_{31}}{\beta_{11}}\right)DFRST_{t-1} + \left(\frac{\beta_{41}}{\beta_{11}}\right)PCAGY_{t-1}$ is the normalised co-integrated equation. The ECT measures the long-term equilibrium relationship while the coefficients on lagged difference terms indicate the short-term dynamics.

4. Empirical Results

Both the ADF and PP tests indicate that all of our variables are non-stationary at their levels but stationary at their first difference, irrespective of using the random walk model with drift or random walk model with slope (Table 3). Hence it can be concluded that all series are *I* (1) at the 1 per cent level of significance.

Before undertaking the co-integration test, the relevant order of lengths of the VAR model should be specified. Given the sample size, a maximum lag length of three is considered. However, based on the log likelihood ratio (LR), final prediction error (FPE), Akaike information criterion (AIC) and HQ test, an optimal lag length of two is found. This lag structure for the rest of the estimations is followed in this study (Table 4).

Table 3: Unit Root Test

Variable	Phillips-Perron		Phillips-Perron		I(d)
	Intercept	Trend and Intercept	Intercept	Trend and Intercept	
CO_2	0.664268	-1.519475	1.337769	-1.246172	I(1)
ΔCO_2	-5.479409***	-5.8994***	-5.52239***	-12.26926***	
ENC	0.774427	-0.848385	1.650792	-0.533538	I(1)
ΔENC	-2.530724	-3.783686**	-2.383999	-3.783686**	
DFRST	-2.324915	-2.394247	-2.474022	-2.532756	I(1)
ΔDFRST	-6.190929***	-6.133407***	-6.179343***	-6.122296***	
PCAGY	0.8557	-0.843285	0.900821	-0.624628	I(1)
ΔPCAGY	-4.739478***	-5.935609***	-4.757812***	-5.975266***	

Source: Authors.
Note: The lag length for ADF test is decided based on Schwarz information criteria (SIC) and the maximum bandwidth for PP test is decided based on Newey and West (1994).*, ** and *** indicate 10 per cent, 5 per cent and 1 per cent level of significance, respectively.

Table 4: VAR Lag Order Selection Criteria

Lag	LR	FPE	AIC	SIC	HQ
0	n.a	2E-10	-11.21	-11.02	-11.15
1	131.60	1E-12	-16.01	-15.05*	-15.72
2	27.75*	1.02e-12*	-16.36*	-14.64	-15.85*
3	13.51	2E-12	-16.14	-13.65	-15.40

Source: Authors.
Note: * indicates lag order selected by the criterion.

As we understand that our variables are stationary at first difference, we proceed to carry out the Johansen co-integration test to determine whether any combinations of variables are co-integrated. Both the trace tests and maximum eigenvalue tests indicate that there is one co-integrating equation among the selected variables at the 1 per cent level of significance (Table 5). It implies that our variables are co-integrated and that in the long-term, CO_2 emissions, energy consumption, deforestation and agricultural income move together.

Table 5: Johansen Co-Integration Test

Null Hypothesis: No co-integration						
No. of Cointegrated Equation(s)	**Trace Statistic**	**Critical Value at 95 per cent**	**Probability****	**Max-Eigen**	**Critical Value at 95 per cent**	**Probability****
r=0***	57.1948	47.8561	0.0052	28.0789	27.5843	0.0432
r≤1	29.1159	29.7971	0.0598	15.2310	21.1316	0.2730
r≤2	13.8849	15.4947	0.0862	13.6183	14.2646	0.0631
r≤3	0.2667	3.8415	0.6056	0.2667	3.8415	0.6056

Source: Authors.
Note: *** denotes rejection of the null hypothesis at the 1 per cent level; ** MacKinnon-Haug-Michelis (1999) values.

Then for estimating the long-run co-integrated equation the following can be written:

$$\ln CO_2 = 20.69 + 6.10 \ln ENC_{t-1} + 0.26 \ln DFRST_{t-1} - 3.51 \ln PCAGY_{t-1}$$

$$R^2 = 0.67 \qquad F = 3.84^{***}$$

$$\alpha_{11} = -0.97961^{***}$$

All coefficients in the long-term co-integrated equation have the expected signs except for agricultural income. It is found that energy consumption and deforestation are positively related to CO_2 emissions. However, CO_2 emissions are negatively related with agricultural income. Since a double logarithmic functional form is used, the β coefficients are interpreted as long-term elasticities. Energy consumption and deforestation have positive elasticity coefficients of 6.10 and 0.26. It means a 1 per cent increase in energy consumption and deforestation leads to 6.10 per cent and 0.26 per cent CO_2 emissions in LDCs. However, agricultural income elasticity is negative and 3.51 which implies that in the long-term if agricultural income increases by 1 per cent, it is likely to reduce CO_2 emissions by 3.51 per cent. The findings of the study that increased energy consumption affects CO_2 emissions is consistent with the existing literature. For example, Saboori and Solaymani (2010) found that energy consumption leads to CO_2 emissions in the long-term in Iran. Zhang and Cheng (2009) found that energy consumption and CO_2 emissions are related in the long-term in China. Kim and Baek (2011) found that energy consumption causes environmental degradation in developed and developing countries, while Menyah and Wolde-Rufael (2010) found a relationship between energy consumption and CO_2 emissions in South Africa.

The error correction coefficient (α_{11}) is -0.976, and is correctly signed (negative) and significant at 1 per cent level. The error correction term indicates how the variables will adjust once they deviate from the equilibrium. The term should have negative sign and the magnitude should be less than unity. Results of the study imply that the variables adjust at the speed of 98 per cent every year, or it takes about 1.02 years to restore equilibrium when there is shock on the steady-state relationship.

ECM-based short-term causality tests are also performed in this study and reported in Table 6. It shows that no short-term causality exists between CO_2 emissions and energy consumption. However, in the short-term, both deforestation and agricultural income cause CO_2 emissions. This implies that, for a given growth in real agricultural income and deforestation, CO_2 emissions are likely to increase in LDCs in the short-term.

Table 6: Short-run Causality Test

Dependent Variable: CO_2			
Criteria	**Chi-Square Statistic**	**Probability**	**Decision**
Testing for the null hypothesis that coefficient of ENC_{t-1} and ENC_{t-2} is equal to 0	1.339	0.512	No SR causality
Testing for the null hypothesis that coefficient of $DFRST_{t-1}$ and $DFRST_{t-1}$ is equal to 0	5.655958	0.0591*	SR causality
Testing for the null hypothesis that coefficient of $PCAGY_{t-1}$ and $PCAGY_{t-1}$ is equal to 0	7.970717	0.0186**	SR causality

Source: Authors.
Note: *, ** and *** indicate 10 per cent, 5 per cent and 1 per cent level of significance, respectively.

Table 7: Diagnostic Test Results

Test	**Statistic**	**Probability**
Breusch-Godfrey serial correlation LM test	3.838	0.1467
Breusch-Pegan-Godfrey test of heteroskedasticity	12.378	0.4158
JB test for normality	1.533	0.4645

Source: Authors.

The model of this study is sound and robust. The F statistic is significant at the 1 per cent level and the R square value is 67 per cent, which indicates that the model is correctly specified and fits the data well. The residual diagnostic is also tested here. The Breusch-Godfrey serial correlation LM test indicates that there is no serial correlation in residuals in the model (Table 7). The Breusch-Pagan-Godfrey test for heteroskedasticity indicates that this model does not have any heteroskedasticity (Table 7). The test for normality indicates that the residuals are normally distributed (Table 7).

5. Lessons for Shaping Post-2015 Agenda

The findings of the study have a number of implications for both LDCs in terms of pursuing their development path, and for the global development communities in terms of setting development agendas. These are as follows:

(i) No relationship was found between higher CO_2 emissions and higher energy consumption in the short-term. This implies that, for the time being, higher energy use may not affect the environment of LDCs adversely. Therefore, LDCs could pursue a development path requiring a higher use of non-renewable fossil fuels, such as coal, gas and oil, in the short-term. This would help them achieve higher growth, eradicate poverty and improve the quality of lives of their populations. Since the post-2015 agenda aims to be inclusive and not leave anyone behind, access to energy for all is a pre-requisite. Thus the findings on the relationship between energy consumption and carbon emission have significance for LDCs.

(ii) The study finds that in the long-term higher energy consumption leads to higher CO_2 emissions. Therefore, LDCs have to follow a development strategy which will help them reduce their energy consumption in the long-term so that development can be sustainable. They will also have to follow the strategy to use clean energy to control CO_2 emissions.

(iii) It is found that deforestation contributes to increased CO_2 emissions in LDCs in both the short and long-terms. Deforestation has been identified as the second largest contributor to global CO_2 emissions. As results of this study are consistent with the observed phenomenon, LDCs need to take the initiative for preservation and restoration of forests. Conversion of forestland to agricultural and industrial uses needs to be limited. Moreover, reclamation of land for jungles, woodlands, and sustainable forestry industry should be given priority. The specific focus of the post-2015 development agenda should be to set a target to maintain a specific level of forest cover in each country. To achieve this, a baseline standard for forest covers should be established, which can be achieved by each country within a specific timeline.

(iv) The study finds that in the short-term, increases in agricultural income (production) leads to higher CO_2 emissions in LDCs. The intensive use of chemical fertilisers and pesticides in farming leads to CO_2 emissions in the atmosphere. Therefore, LDCs need to engage in agricultural activities from which CO_2 emissions are low. They should pursue a balanced and efficient use of chemical fertilisers and pesticides. Furthermore, agricultural residues such as straw and animal slurry also cause CO_2 emissions. LDCs could focus on environmentally friendly use of these residues. For example, animal slurry can widely be used for soil nutrient recycling. Therefore, in the post-2015 SDGs attention should be placed on developing a goal for the practice of sustainable agriculture. This should be achieved by, for example, the balanced and efficient use of chemical fertilisers and pesticides and by the proper management of agricultural wastes and residues.

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