The impact of trade, urbanization and biomass energy consumption on CO_2 emissions: results from a panel of emerging and frontier countries

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1. Introduction

It is widely agreed that energy plays a vital role in both the production and consumption of goods and services within an economy, actively contributing to countries' growth and development. Fossil fuels remained the most adopted energy sources, reaching 80% of total energy use in 2015. The expansion of energy-consuming activities in the developed and emerging countries, however, is leading to several concerns. First of all, the overexploitation of natural resources and the shortage in fossil energy supply. According to the Peak Oil Theory, there is a growing consensus that in a near future the maximum rate of extraction of petroleum will be reached, after which it is expected to decline forever. Therefore, it is necessary to reduce all the forms of fossil fuels (Li, 2007). Other important issues concern the deterioration and loss of wildlife habitat. Actually, it is well known that environmental degradation and climate change are mainly due to rapidly increasing emissions of greenhouse gases such as carbon dioxide (CO_2) and methane. Emerging economies are particularly involved, since they exhibit faster expansion paces than those of advanced ones with a remarkable increase of urbanization too, whose level is now larger than 60% from 37.2% in 1960 (World Bank Development Indicators). Some authors claim urbanization reduces energy demand by utilizing the public infrastructure (e.g. utilities and public conveyance) efficiently, thus reducing energy consumption and carbon emission (Chen et al., 2008). On the contrary, other researchers indicated that urbanization boosts energy demand, with harmful emissions and environmental degradation. Evidence shows that although they cover less than 2 per cent of the earth's surface, urban areas account for 71 to 76 per cent of the world's carbon dioxide from global final energy use and a significant portion of total greenhouse gas emissions. Congestion, vehicular and industrial emissions in urban areas also inflate the high environmental costs of urban crowding. This is especially true for developing countries where a substantial urban growth is expected (Nagendra et al., 2018).[1] Building infrastructure for fast-growing cities in developing countries is estimated to release 226 gigatonnes of carbon dioxide by 2050, that is more than four times the amount used to build existing developed-world infrastructure (Bai et al., 2018). The link between urbanization and environmental degradation may also work in the opposite direction. Since 90 percent of the world's urban areas are located on coastlines, cities are highly vulnerable to the devastating impacts of climate change, such as rising sea levels and powerful coastal storms.

Growing concern over the sustainability and environmental impact of conventional fuels is arousing interest towards renewable energy sources. The use of clean energy sources is needed to achieve the changes required to address the impacts of global warming. Biomasses may be a suitable form of energy sources and they can be easily adopted in developing nations too. Yet, they still represent only a small portion of the world total, that has been fairly stable around the 10% in the last fifty years. Biomasses can be burned to produce heat and electricity, changed to gas-like fuels such as methane, hydrogen, and carbon monoxide or changed to a liquid fuel. Differently from solar, wind, geothermal, tide and wave, they are not a completely clean, especially when they entail burning. In this case, however, plants and trees that are part of the cogeneration process, are able to compensate the carbon dioxide emissions during the burning by absorbing CO_2 and producing oxygen during their growth. Compared to conventional fossil fuels, it is widely acknowledged biomasses have milder environmental and health effects and do not need thousands or millions of years for reproduction as, for instance, oil (Van Loo and Koppejan, 2012). However, some scholars point out process emissions and displacement effects, suggesting biomasses and biofuel are associated with a net increase

1 According to World bank, their world share of CO_2 emissions rose from 19% in 1960 to 62% in 2014, although much of this steep rise was recorded between the end of the '80s and the beginning of the '90s.

rather than a net decrease in CO_2 emissions (Hill et. al., 2009; Scovronick et al., 2016; DeCicco et al., 2016).

This paper aims at filling this gap providing new fresh evidence about the relationship between biomass consumption and CO_2 emissions in emerging countries, taking into account also the impact of economic growth, urbanization, trade openness and total energy consumption. Actually, we provide a better understanding about the causal relationship between the abovementioned variables which can help in the design and implementation of environmental and energy policies. To accomplish such a task, we analyze a balanced sample of 21 emerging and frontier economies over the period 1974-2014. First, we discuss the presence of common factors and cross-sectional dependency. Then, we address the integrating properties of the variable under investigation and find that the ARDL model is the best approach to address long-run causality. Hence, we determine the cointegrated relationship which shows, as expected, the positive link between environmental degradation, per capita GDP, trade openness, and total energy consumption. On the contrary, biomass energy use and urbanization are negatively associated with CO_2 emissions. Causality analysis reveals that only trade openness and urbanization are exogenous variables, while the others are endogenously determined. Hence, in emerging and frontier countries, urbanization appears to reduce both energy and economic growth as well as pollution, while trade openness plays an opposite role.

The rest of the paper is organized as follows. Section 2 reviews the relevant literature, Section 3 describes the theoretical and the empirical methodology. Section 4 describes the findings while Section 5 concludes and provides policy implications.

2. Literature review

A growing number of theoretical and empirical studies have been analyzing the link between urbanization level, energy use, carbon emissions, economic growth, renewable and non-renewable energy production or consumption. Empirical evidences from these studies, however, are mixed and remain ambiguous. The variation in results may be attributed to different issues such as variable selection, model specification, country and time periods under investigation as well as the econometric approach.

Many scholars applied the STIRPAT method to investigate the effects of driving forces (population, affluence in terms of per capita consumption or production, and technology) on pollutant emissions, but no consensus has emerged from these studies. Some of them find that there is a positive association between the urbanization rate and CO_2 emissions, for example Cole and Neumayer (2004), Poumanyvong and Kaneko (2010) for high-income countries, Zhang and Lin (2012) for China, Shafiei and Salim (2014) for OECD countries. In contrast, Fan et al. (2006) show a negative relationship for developed countries over the period 1975 to 2000. The same result is obtained by Martínez-Zarzoso et al. (2007) who analyze the determinants of CO_2 emissions during the period from 1975 to 2003 and reveal that, although the elasticity of emission-urbanization is positive in low-income countries, it is negative in middle upper and high income countries. Similar outcomes are reported in Lv and Xu (2019), who empirically analyze the impact of trade openness and urbanization on CO_2 emissions in 55 middle-income countries over the period 1992-2012. They confirm that urbanization has a negative and significant impact on CO_2 emissions both in the short and long run, implying that urbanization improves environmental quality. In a nutshell, contrasting results on the relationship between urbanization and emissions emerge even in countries with the same levels of development. However, developed and largely urbanized countries seem to be more capable to achieve low carbon intensity by adopting new energy technologies. Hence, the relationship between urbanization and emissions could be better explained by the environmental Kuznets curve in developed countries, implying that higher levels of urbanization contribute to reductions in environmental degradation. This finding confirms the ecological modernization theory, which argues that if the environment and the economy are properly managed through structural changes or modernization, emissions can be curbed. Therefore, as urbanization is a key indicator of modernization (Ehrhardt-Martinez et al., 2002; York et al., 2003a, 2003b), it is expected that at higher levels of urbanization, the environmental impact decreases. Ehrhardt-Martinez (1998), in particular, explains that the urbanization process in its initial stages depends more on resource extraction and then advanced urbanization is accompanied by capital deepening with urban infrastructure as well as larger use of less polluting fuels. In contrast, Zhu et al. (2012) performed a semiparametric panel model to examine the urbanization-carbon emission nexus for a panel of 20 emerging countries and their findings could not confirm the Kuznets hypothesis.

The causal relationship between renewable energy consumption and output has been synthesized into four hypotheses within the literature. First, the growth hypothesis asserts unidirectional causality from energy consumption to economic growth. In such a case, a reduction in renewable energy consumption may have a negative impact on economic growth. Second, the conservation hypothesis establishes the opposite unidirectional causality link that runs from economic growth to renewable energy consumption. Hence, a growing economy might lead to an increase in renewables use and a decrease in renewable energy consumption without jeopardizing growth. Third, the neutrality hypothesis is characterized by the absence of any causality between energy consumption and economic growth. The former does not play a pivotal role in economic growth and vice versa as growth is driven by other factors. Fourth, the feedback hypothesis emphasizes an interdependent causality between energy consumption and economic growth. Therefore, conservation measures aimed at improving the efficiency in renewable energy consumption will positively impact economic growth but causation runs also in the opposite direction, so changes on economic growth will impact biomass energy consumption too. We can extend such a theory assuming that all relevant variables, such as trade and emissions, are interconnected. The studies analyzing such relationships for emerging economies provide diverging results, finding support for the different hypotheses. Amongst them, few works focus on biomasses as renewable sources. Solarin et al. (2018) explore their impact on CO_2 emissions for 80 developed and developing countries, finding that both biomass and fossil fuel consumption increases environmental degradation, but the magnitude of the former is lower than that of the latter. Moreover, trade openness seems to decrease CO_2 emissions in developed nations and increase them in developing countries, in line with the pollution haven hypothesis. Works in support of the growth hypothesis are those of Payne (2011) for the USA and Bilgili and Ozturk (2015) for the G7 countries. Bildirici (2013) addresses separately some emerging and developing countries. His results sustain the conservation hypothesis (GDP to biomass energy consumption) in Colombia, the growth hypothesis in Bolivia, Brazil, and Chile, and a bi-directional relationship in Guatemala. However, the feedback hypothesis is verified for all countries in the long-run. This author supports the short, long, and strong causality feedback hypothesis in formerly socialist countries (Belarus, Estonia, Georgia, Latvia, Lithuania and Moldova), while in European transition economies (Albania, Bulgaria, Poland and Romania) there is no unidirectional causality from biomass energy consumption to GDP in the short-run only. Analyzing other European countries Bildirici and Ozaksoy (2013) find a unidirectional causality from GDP to biomass energy consumption in Austria and Turkey, the opposite in Hungary and Poland, and bidirectional causality in Spain, Sweden, and France.

At the world level, Piroli et al. (2015) find that biofuels significantly reduce global CO_2 emissions in the medium and long-run whereas, in the short-run, the sign of the relation may reverse. Investigating the causality direction between biomass energy, CO_2 emissions and economic development in USA, Bilgili et al. (2017) find that an increase in biomass energy consumption per capita Granger causes a reduction in CO_2 emissions per capita and augments GDP per capita.

Our work contributes to the existing literature in at least four directions. First, we adopt the Squalli and Wilson (2011) Composite Trade Index (CTS) to measure countries' trade openness. Differently from traditional indices (trade openness ratio, export propensity, and import penetration), CTS captures the benefits associated with trading relatively intensively with the rest of the world, correctly classifying larger economies as open. Second, we account for urbanization level. Interpreting it as an indicator of modernization, it occurs when economies develop shifting production from agriculture to manufacturing. Third, we shed light on the long-run association amongst the abovementioned variables through Granger-causality tests (Engle and Granger, 1987). Fourth, we employ a robust econometric approach to tackle CSD and we derive long-run heterogeneous panel elasticities via the CCEMG estimator in line with Topcu and Payne (2018) and Shahbaz et al. (2018).

3. Methodology

In this study we analyze the short and long-run linkages between CO_2 emissions, energy consumption, GDP, combustible renewables and waste, urbanization and trade. The latter is measured by the Composite Trade Share (CTS) developed by Squalli and Wilson (2011), which weights trade openness with the proportion of a country's trade level relative to the average world trade. This index takes into account country's share of trade and correctly classifies integrated but large economies as open ones. Emissions, real GDP, energy consumption, and combustible renewables and waste are in per capita units. Urban population, measured as the percentage of total population, refers to people living in urban areas as defined by national statistical offices. All the variables are transformed in logs so that estimated coefficients can be interpreted as elasticities.

The first step in our empirical analysis consists in checking whether there exists interdependencies among the variables under investigations and unobserved common factors. We test the presence of cross-sectional dependence (CSD) by making use of the Pesaran (2015) test for weak cross sectional dependence (CD-test). The second step is to check stationarity. The existence of CSD in our panel suggests to employ "second-generation" panel unit-root tests such as the cross-section augmented Im-Pesaran-Shin (CIPS) test with common and unit specific lags. Finally, we apply also the test proposed by Herwartz and Siedenburg (2008) to address time variant variance.

Then, we address the long run relationship among the variables under investigation making use of the Autoregressive Distributed Lag model ARDL(P, Q), with the following factor error structure[2]:

[2] This technique is applicable when variables are integrated of different order, i.e. I(0) or (1).

$$c_{i,t} = \alpha_i + \sum_{j=1}^{P} \gamma_{i,j} c_{i,t-j} + \sum_{j=0}^{Q} \beta_{i,j}^{z} z_{i,t-j} + u_{i,t} \quad (1)$$

$$u_{i,t} = \zeta_i f_t + \varepsilon_{i,t} \quad (2)$$

$$z_{i,t} = a_i^z + \psi_i f_t + v_{i,t} \quad (3)$$

where α_i are the country-specific fixed effects to control for country factors that are stable over time, $c_{i,t}$ is the log of CO_2 emissions per capita of country *i* at time *t*, *z* is a vector of regressors incorporating the (logs of the) trade openness index variable (*o*), GDP per capita (*g*), energy consumption per capita (*n*), urbanization (*b*) and combustible renewables and waste consumption per capita (*r*). The error term $u_{i,t}$ contains unobservables which include *m* common factors f_t. Vectors ζ_i and ψ_i are factor loadings. Both ε and *v* are assumed to be uncorrelated idiosyncratic error terms. This model can be usefully rewritten into the well-known Error Correction Model (ECM):

$$\Delta c_{i,t} = \delta_i + \varphi_i (c_{i,t-1} - \theta_i^o o_{i,t} - \theta_i^g g_{i,t} - \theta_i^n n_{i,t} - \theta_i^b b_{i,t} - \theta_i^r r_{i,t}) + \\ + \sum_{j=1}^{P-1} \lambda_{i,j} \Delta c_{i,t-j} + \sum_{j=0}^{Q-1} \mu_{i,j}^o \Delta o_{i,t-j} + \sum_{j=0}^{Q-1} \mu_{i,j}^g \Delta g_{i,t-j} + \sum_{j=0}^{Q-1} \mu_{i,j}^n \Delta n_{i,t-j} + \sum_{j=0}^{Q-1} \mu_{i,j}^b \Delta b_{i,t-j} + \sum_{j=0}^{Q-1} \mu_{i,j}^r \Delta r_{i,t-j} + u_{i,t} \quad (4)$$

where $\varphi_i = -(1 - \sum_{j=1}^{P} \gamma_{i,j})$ is the error-correcting speed of adjustment term and parameters of particular interest are the long-run elasticities $-\varphi_i \theta_i^j$, with *j* = *o*, *g*, *n*, *b, r*. The former is expected to be negative, but larger than -1 if the variables show a return to the long-run equilibrium. The vector $[1 \theta^o \theta^g \theta^n \theta^b \theta^r]$ expresses the cointegrating relationship between CO_2 emissions and all the explanatory variables under scrutiny, whereas $\lambda_{i,j}$ and $\mu_{i,j}$ define the short-run dynamics between the covariates.

Finally, we examine the direction of the causal relationship between the variables under investigation. At this aim, we apply the two-step procedure suggested by Canning and Pedroni (2008), that is a vector error correction model (VECM) version of Granger causality. Firstly, we estimate the long run relationship by using Fully Modified Ordinary Least Squares (FMOLS) to obtain the error correction term for each country, i.e. $\hat{e}_i = c_i - \hat{\theta}_i^o o_i - \hat{\theta}_i^g g_i - \hat{\theta}_i^n n_i - \hat{\theta}_i^b b_i - \hat{\theta}_i^r r_i$. Since all the variables in this ECM system are stationary, the superconsistency of the estimator of the cointegrating relationship assures the validity of the standard properties when replacing the error correction term with its estimate (Canning and Pedroni, 2008). In any case, in order to allow for the presence of common factors, we include some cross-section averages following Eberhardt and Teal (2013). In the second step we added the one period lagged error term obtained from the first step to the ECM system. Then, we can carry out the usual tests on the parameter estimates. Since the sample size is small with only 42 years of data across 21 countries, the reliability of individual tests is scarce. Hence, we rely on two panel tests suggested by Canning and Pedroni (2008): the Group Mean (GM) that simply averages countries' statistics; and a Fisher-Type (FT) test that is constructed from the p-values of the t-ratios in each ECM regression[3]. The null and alternative hypotheses for both the GM and FT tests are the same under the assumption that coefficients are homogenous and equal to zero across nations, while they are different from nil for some non-negligible portions of the countries under the alternative hypothesis.

4. Findings

The analysis focuses on emerging and frontier countries according to the MSCI market classification. Data about CO_2 emissions, measured in metric tons per capita (in short CO_2), energy consumption (EN), measured by energy use in kg of oil equivalent per capita, income (GDP), given by per capita GDP in constant 2010 US$, biomass use (BIO), measured by combustible renewables and waste use in kg of oil equivalent per capita, urbanization (URB), measured as the urban population over the total, and the trade index components (trade flows and GDP in current US$), are from the World Bank Development Indicators (retrieved on July 1st, 2019). We consider 21 countries, choosing those with the most complete (available) data for the variables of interest, obtaining a balanced panel. We make use of annual data from 1973 to 2014, thus relying on 42 observations per variable for all the countries under investigation. Table 1 shows summary statistics (before taking logs): the average GDP per capita is less than 5,000 constant US$, half of which has been traded in international markets, while pollution and energy use amount to 2,478 metric tons and 955 kg of oil equivalent per capita, respectively. Half of the sample is urbanized and, on average, 162 kg of oil equivalent combustible renewables and waste per capita are used. Countries' list with their summary statistics are presented in the Appendix.

Since cross-sectional units in panels may be affected by common shocks, generating inconsistent and biased estimators, the first step in our empirical analysis is to test for CSD. At this aim we employ the Pesaran (2015) test (CD-test), whose null hypothesis is the variable is weakly cross-sectional dependent. Under the null hypothesis the statistic is asymptotically N(0,1) distributed. Results are shown in Table 2 where variables are expressed in logs. The CD-test

3 This lambda–Pearson statistic is equal to $-2\sum_{i=1}^{N} lnp_{\varphi_i}$ where φ_i is the probability associated to the t-test of the error correction term in each country. This statistic is distributed as a χ^2 with 2N degrees of freedom under the null of no long-run causation for the panel.

strongly rejects the null hypothesis of weak CSD at the 1% significance level both when variables are in level and in first differences.

Our second step is to check for stationarity. Given the presence of CSD we adopt second generation panel unit root tests. We first perform the standard cross-sectional augmented Ims-Pesaran-Shin (CIPS) test (Pesaran, 2007). Here the statistic is constructed from the results of panel-member-specific (A)DF regressions also including cross-section averages of the dependent and independent variables (with the lagged differences to account for serial correlation). Outcomes with and without adding a trend, are summarized in Table 3.

Table 1 – Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CO_2	882	2.478	2.257	0.192	9.871
GDP	882	4808.9	4884.4	253.7	30055
EN	882	955.1	659.0	206.7	2967.5
BIO	882	162.18	96.5	17.10	592.1
URB	882	0.517	0.216	0.118	0.916
CTS	882	0.597	1.093	0.022	8.523

Table 2 – Cross sectional dependence

	Levels		Differences	
	CD-test	p-value	CD-test	p-value
CO_2	27.326	0.00	13.883	0.00
BIO	93.702	0.00	3.435	0.00
GDP	93.816	0.00	34.751	0.00
EN	93.843	0.00	17.491	0.00
CTS	61.440	0.00	23.559	0.00
URB	92.779	0.00	58.810	0.00

Table 3 – Pesaran (2007) Panel Unit Root test (CIPS) with common lags

		Levels				Differences			
		Without trend		With trend		Without trend		With trend	
Variable	lags	Zt-bar	p-value	Zt-bar	p-value	Zt-bar	p-value	Zt-bar	p-value
CO_2	0	0.335	0.63	1.753	0.96	-18.792	0.00	-18.394	0.00
	1	0.492	0.69	2.602	1.00	-10.605	0.00	-9.793	0.00
	2	0.453	0.68	2.566	1.00	-5.503	0.00	-4.392	0.00
	3	-0.272	0.39	1.593	0.94	-4.414	0.00	-3.724	0.00
BIO	0	2.042	0.98	2.939	1.00	-15.447	0.00	-14.696	0.00
	1	1.583	0.94	2.550	1.00	-10.653	0.00	-9.694	0.00
	2	3.036	1.00	4.644	1.00	-5.074	0.00	-3.664	0.00
	3	3.573	1.00	5.413	1.00	-1.876	0.03	-0.118	0.45
GDP	0	1.780	0.96	1.465	0.93	-14.575	0.00	-13.490	0.00
	1	-0.382	0.35	-0.612	0.27	-9.485	0.00	-8.401	0.00
	2	-0.303	0.38	-0.817	0.21	-7.012	0.00	-5.456	0.00
	3	0.200	0.58	0.287	0.61	-5.813	0.00	-4.862	0.00
EN	0	1.512	0.94	4.795	1.00	-17.090	0.00	-17.288	0.00
	1	1.983	0.98	5.265	1.00	-9.017	0.00	-8.335	0.00
	2	1.900	0.97	4.940	1.00	-4.254	0.00	-3.342	0.00
	3	1.852	0.97	4.369	1.00	-2.745	0.00	-2.410	0.01
CTS	0	-0.076	0.47	2.800	1.00	-17.405	0.00	-16.304	0.00
	1	-0.188	0.43	2.851	1.00	-11.316	0.00	-9.937	0.00
	2	0.855	0.80	3.968	1.00	-6.833	0.00	-5.341	0.00
	3	0.381	0.65	4.158	1.00	-3.842	0.00	-2.536	0.01
URB	0	1.058	0.86	0.210	0.58	0.909	0.82	3.288	1.00
	1	-4.002	0.00	-7.120	0.00	-2.225	0.01	0.231	0.59
	2	-0.470	0.32	-4.512	0.00	-2.956	0.00	0.026	0.51
	3	-0.863	0.19	-3.278	0.00	-2.722	0.00	-0.158	0.44

All the variables are I(1) but urbanization that appears to be I(0) in the specification without a trend exception made for the first lag. When we add a trend results are puzzling. However, this CIPS test assumes the very same number of lags in all the countries' whereas heterogeneity may produce deceiving results. Therefore, we set individual dynamics specifications as suggested by Burdisso and Sangiacomo (2016). They propose two criteria for individual lag selection: a Wald test of composite linear hypothesis about the parameters of the model and a Portmanteau test for white noise. In particular, the number of lags to include in each individual regression is obtained with an iterative process from 0 to a fixed maximum number, based on the test's significance level set to select dynamics – reject H0 (at 5% or below) in the Wald test or do not reject (at 95% or above) H0 in the Portmanteau – or the maximum number of lags, whichever comes first. Results for this CIPS test are presented in Table 4.

Results confirm variable under scrutiny but urbanization are I(1). The only exception, again, regards the urbanization that appears to be I(0).

Table 4 – Panel Unit Root Test (CIPS) with individual lags

		Without trend		With trend	
		Level	Differences	Level	Differences
CO_2	Wald	-1.745	-5.625***	-2.057	-5.872***
	Portmanteau	-1.713	-5.625***	-1.935	-5.872***
BIO	Wald	-1.426	-4.789***	-1.733	-4.951***
	Portmanteau	-1.497	-4.939***	-1.937	-5.162***
GDP	Wald	-1.568	-4.842***	-2.313	-5.014***
	Portmanteau	-1.511	-4.760***	-2.141	-4.930***
EN	Wald	-1.533	-5.275***	-1.419	-5.660***
	Portmanteau	-1.433	-5.275***	-1.371	-5.660***
CTS	Wald	-1.813	-5.340***	-1.839	-5.419***
	Portmanteau	-1.854	-5.256***	-1.806	-5.387***
URB	Wald	-2.350***	-2.020	-3.505***	-2.106
	Portmanteau	-2.194**	-1.667	-3.414***	-1.795

Critical values without trend at 10%, 5%, and 1% are -2.040, -2.110 and -2.230, respectively.
Critical values with trend at 10%, 5%, and 1% are -2.540, -2.610 and -2.730, respectively.

Table 5 – Herwartz and Siedenburg tests

	Levels		First Difference	
	HB-test	p-value	HB-test	p-value
CO_2	2.468	0.99	-4.516	0.00
BIO	0.726	0.77	-3.330	0.00
GDP	2.125	0.98	-3.790	0.00
EN	3.941	1.00	-3.563	0.00
CTS	0.795	0.79	-2.813	0.00
URB	-1.244	0.11	-2.218	0.01

To get a better understanding we also perform the test proposed by Herwartz and Siedenburg (2008) which allows for time variant variance and is also robust to both heteroschedasticity and CSD (Herwartz et al., 2018). Outcomes in Table 5 confirm that all time-series are non-stationary at levels, and stationary at their first order differentials, so they are I(1).

Hence, we can safely use the ARDL model using the CCEMG estimator. Results are reported in Table 6.

Since all variables are expressed in natural logarithms, the estimated long-run coefficients can be interpreted as long-run elasticities. Results in Table 6 show that GDP, energy use and trade openness all have a positive effect on environmental degradation, even if with a diverse magnitude and at different levels of statistical significance. An interesting aspect that emerges from Table 6 is the opposite impact on carbon dioxide emissions by the overall level of energy consumption, on the one hand, and the combustible renewables and wastes, on the other. More specifically, a larger energy use will degrade the environment with a more than proportional rise in CO_2 emissions. On the contrary, the use of biomass decreases pollution[4], but with a lower impact in absolute values. Hence, we can suppose that biomass and similar renewable energy consumption may curb the negative impact on environment generated by the overall energy use. If we observe the urbanization long-run estimate, we note that the impact on CO_2 emissions is negative and statistically significant at 5%. Higher levels of urbanization improve environmental quality. Advanced urbanization, in fact, is likely

[4] This outcome is similar to that of Dogan and Inglesi-Lotz (2017), who investigate the effects of real income and biomass energy consumption on carbon dioxide emissions. They find confirmation of the Environmental Kuznets Curve hypothesis and that biomass energy consumption decreases the level of CO_2 emissions.

to be accompanied by largely complete urban infrastructure as well as increased use of less polluting fuels.

Finally, we investigate the direction of causation. Results are shown in Table 7.

Table 6 – CCEMG estimates

$D.CO_2$	Coef.	Std. Err.	z	P>z
MEAN GROUP ESTIMATES:				
SHORT RUN ESTIMATES:				
D.BIO	-2.120	2.024	-1.05	0.30
D.GDP	0.103	0.081	1.27	0.20
D.EN	0.125	0.128	0.98	0.33
D.CTS	-0.016	0.013	-1.21	0.23
D.URB	3.763	2.758	1.36	0.17
_cons	-4.253	0.810	-5.25	0.00
LONG RUN ESTIMATES:				
ec	-0.731	0.068	-10.80	0.00
BIO	-0.624	0.346	-1.80	0.07
GDP	0.181	0.101	1.80	0.07
EN	1.227	0.197	6.22	0.00
CTS	0.117	0.059	1.98	0.05
URB	-0.642	0.274	-2.34	0.02
CD test	0.282		CD prob	0.78

Table 7 – Canning and Pedroni tests for direction of causation

	GM	*(p)*	*Fisher*	*(p)*	*Mean*	*Pr>z*
CO_2	0.124	0.90	116.987	0.00	-0.023	0.07
BIO	0.145	0.89	110.955	0.00	-0.016	0.58
GDP	0.349	0.73	90.672	0.00	-0.005	0.76
EN	0.907	0.36	85.076	0.00	-0.005	0.56
CTS	0.405	0.69	48.592	0.22	0.135	0.14
URB	-0.393	0.69	45.961	0.31	0.000	0.89

The Group Mean *t*-tests reveal no causality link in all the specifications, whereas the Fisher-based statistics point out causality runs from the other variables to CO_2 emissions, biomass and waste, GDP and energy use. Eberhardt and Teal (2013) underline the difference in the two tests. The GM is a two-sided test that can take positive or negative values under the alternative hypothesis. Therefore, it investigates if coefficients are on average zero, while the FT is a one-sided test that can only take positive values and checks if coefficients are pervasively zero. Summing up results in Table 7 we can conclude that only trade openness and urbanizations are exogenous variables, whereas CO_2 emissions, GDP per capita, energy consumption, and biomass use are jointly determined. Hence, an increase in urbanization triggers a reduction in economic growth, pollution as well as energy but biomass usage, whilst trade openness plays an opposite role in emerging and frontier markets.

5. Conclusions

This study investigates the effect that biomass and waste, trade openness, GDP, urbanization level, and energy consumption exert on CO_2 emissions in a balanced panel of 21 emerging and frontier countries over the period 1973-2014. These countries registered a GDP share in Purchasing Power Parity (PPP) that rose from 37% in 1980 to 59% in 2017 and now account for more than half of world GDP in PPP. At the same time, the gradual transition of the global population towards urban living has resulted in remarkable levels of urbanization. Their energy demand increased, mainly satisfied through fossil sources, but at the expenses of environmental degradation. Emerging countries' share on total CO_2 world emissions, in fact, more than tripled between 1960 and 2014. The growing concern over the sustainability and environmental impacts of conventional fuels, that are the main reasons for the global climate targets of the Paris Agreement, is making increasingly necessary for these countries to move towards a larger employment of renewables or at least less polluting energy sources. Modern biomass energy might be an interesting alternative because it is renewable, abundant and can be produced everywhere.

Therefore, it is interesting and useful from a policy perspective to address the long-run links between CO_2 emissions, renewable and non-renewable energy production or consumption, economic growth, urbanization, trade openness and energy consumption. We accomplished such a task by adopting an ARDL model which can shed light on long-run Granger causality between the variables under investigation. Our results show that there exists a cointegrated relationship between environmental degradation, per capita GDP, trade openness, and total energy consumption. CO_2 emissions are, as expected, positively associated with energy consumption, economic growth as well as trade openness. Therefore, the transition towards a green economy could be a desirable way to mitigate the environmental pressure resulting from the economic development. On the contrary, biomass energy use and urbanization are negatively associated with CO_2 emissions. Causality analysis reveals that only trade openness and urbanization are exogenous variables, while the others are endogenously determined. Hence, in emerging and frontier countries, urbanization appears to reduce both energy and economic growth as well as pollution, while trade openness plays an opposite role.

APPENDIX

Country	CO_2		GDP		EN		BIO		URB		CTS	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Argentina	3.866	0.404	8030.430	1276.438	1587.224	193.474	69.901	10.912	0.870	0.035	0.136	0.080
Brazil	1.680	0.331	8720.253	1439.614	1048.241	176.507	338.716	40.261	0.750	0.083	0.351	0.144
Chile	3.047	0.986	8077.519	3398.894	1295.793	472.639	256.341	100.967	0.843	0.033	0.289	0.146
China	3.133	1.964	1744.205	1691.292	1011.132	527.084	170.423	10.755	0.317	0.117	2.590	3.076
Colombia	1.570	0.135	4665.287	1102.974	663.293	43.437	127.048	39.941	0.686	0.056	0.124	0.046
Egypt, Arab Rep.	1.597	0.555	1707.611	541.250	574.797	200.746	18.483	0.558	0.433	0.004	0.243	0.083
Greece	6.891	1.470	21519.570	3949.361	2074.653	471.535	76.187	25.273	0.720	0.030	0.341	0.112
India	0.846	0.378	721.903	370.105	391.750	103.043	152.534	10.521	0.264	0.033	0.593	0.729
Indonesia	1.132	0.541	1994.134	776.492	591.242	196.057	220.696	14.519	0.349	0.112	0.641	0.208
Kenya	0.282	0.055	883.467	63.688	452.020	14.601	350.375	4.263	0.184	0.036	0.061	0.017
Malaysia	4.458	2.235	5786.391	2430.125	1659.957	779.069	93.600	21.749	0.547	0.119	2.552	1.600
Mexico	3.782	0.449	7805.231	1052.956	1408.650	187.680	89.478	11.358	0.718	0.051	1.102	0.775
Morocco	1.120	0.378	1907.052	588.207	361.733	108.159	44.180	8.607	0.492	0.069	0.178	0.057
Pakistan	0.657	0.215	778.781	195.441	410.812	73.960	175.335	2.794	0.317	0.035	0.095	0.020
Peru	1.280	0.293	3736.057	805.564	546.177	97.389	134.544	55.021	0.701	0.053	0.103	0.053
Philippines	0.801	0.125	1685.064	282.658	457.989	23.817	142.829	51.339	0.441	0.046	0.485	0.295
South Africa	8.518	0.842	6299.546	617.374	2455.282	230.695	258.642	27.145	0.544	0.054	0.557	0.136
Sri Lanka	0.411	0.202	1614.017	786.455	375.201	78.205	224.040	14.999	0.186	0.004	0.088	0.023
Thailand	2.281	1.374	2998.428	1458.086	986.137	518.365	250.428	45.898	0.323	0.071	1.381	1.032
Tunisia	1.813	0.466	2706.974	842.188	660.978	180.595	89.166	13.799	0.586	0.067	0.177	0.045
Turkey	2.868	0.892	7605.539	2378.523	1045.070	286.810	122.801	43.913	0.585	0.105	0.445	0.321

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