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The Effect of Hydroelectricity Consumption on Environmental Degradation– The Case of South America region

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Abstract. This article analyses the impact of hydroelectricity consumption on environmental degradation (CO_2 emissions) in seven South American countries, in a period from 1966 to 2015. The Unrestricted Error Correction Model (UECM) form of the Auto-regressive Distributive Lag (ARDL) was utilized. The initial tests prove the presence of heteroskedasticity, cross-sectional independence, and first-order autocorrelation. The results show that the consumption of hydroelectricity causes a reduction of -0.0465 in environmental degradation in the short-run, and increase 0.0593 in the long-run. This empirical evidence could encourage the creation of new policies, which introduce new energy technologies that release zero carbon in the energy matrix.

Keywords. *Energy economics; Economic growth; Environmental degradation; Renewable energy; South America.*

1. Introduction. The increase of fossil fuel dependency and environmental degradation (CO_2 emissions) has led many countries to adopt hydroelectricity sources in their energy matrices. Moreover, this kind of source is clean if compared with fossil fuels, and reduces the use or need of more expensive alternatives (Clarke et al. 1996). For these reasons, hydropower is the most popular energy source in the world, contributing one-fifth to the world's power generation (Yuksel, 2010).

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The first hydroelectricity plant in the Latin America (L.A) region was installed around 1900. Brazil and Costa Rica were the pioneer countries in the region, although for most of the first decade hydroelectric developments were chiefly associated with mining enterprises in Bolivia, Chile, Mexico, and Peru (Rubio and Tafunell, 2014). Brazil was the pioneer country in L.A to use and generate with this kind of source. However, until the 1940s, Mexico accounted for a quarter and Chile for half of the generated and consumed hydroelectricity in L.A. In the 20th century, 90% of all hydroelectricity production and consumption in this region was concentrated in only three countries: Brazil, Chile, and Mexico. Today, L.A region has the largest share of hydroelectricity over total electricity generation in the world, with hydroelectricity representing 55% of the energy mix; a sizable proportion when compared with the world average of 17% (Rubio and Tafunell, 2014).

The aim of this investigation is to answer the following question: Does the consumption of hydroelectricity have an impact on environmental degradation? To answer this question, the effect of hydroelectricity consumption on environmental degradation will be analysed in seven countries from the South American region, in a period of 1966 to 2015. An unrestricted error correction model (UECM) form of the auto-regressive distributive lag (ARDL). In the literature, the impact of hydroelectricity consumption on environmental degradation has been widely researched. For instance, some studies have indicated that hydroelectricity consumption increases CO_2 emissions (e.g., Fearnside, 2016; Kemenes et al. 2011; Ribeiro and Silva, 2010; Galy-Lacaux et al. 1997). Other studies have found that the consumption of hydroelectricity is capable of reducing emissions (e.g., Varun et al. 2012; Cheng et al. 2012). The inconclusive nature of these studies on the impact of hydroelectricity consumption on CO_2 emissions is due to conflicting results. In fact, the hypothesis that hydroelectricity can increase CO_2 emissions is broadly counterintuitive, especially from a global perspective. This phenomenon has only been identified in tropical forest areas and mainly results from opportunity costs. This opportunity cost can be mitigated to some extent by planting an equivalent area in another place. Hydroelectric power plants throughout L.A are concentrated in tropical zones due to the concentration of rainfall and substantial water resources in this region that supply the dams. In addition, many hydroelectric power plants were built in the 1950s, 60s, and 70s with the aim of bringing economic development to specific regions, as in the case of Brazil, where the sheer size of the country hindered more egalitarian progress between its regions (Mendes, 2005, p.31). On the other hand, the construction of hydroelectric power plants was in many cases directly related to political cycles, i.e. many of these plants were built for an electoral purpose and consequently, many of these buildings did not have adequately dimensioned socio-environmental impacts, as in the case of the hydroelectric dam of Belo Monte (Brazil) (e.g., Araujo et al. 2014; Santos et al. 2012). In these hydroelectric plants, the environmental purpose was non-existent.

The study of this theme is important because it is fundamental to understand the real impact of hydroelectricity consumption on environmental degradation and because few academic studies seem to investigate this subject in the South America region. Additionally, the choice is justified by the region’s pioneering role in the development of this energy source.

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The paper is organized as follows. Section 2, presents the literature review. Section 3, presents the databases and model used. Section 4, the empirical results. Section 5, the discussion and, finally, Section 6 will present the conclusions.

2. Literature review. The effect of hydroelectricity consumption on environmental degradation has been explored in the ecological and economic literature. The use of different variables, countries, periods, and methodologies have shown several conclusions that do not lead to a consensus about this subject. Some studies have also indicated that hydroelectricity consumption is capable of increasing CO_2 emissions, while others show the opposite. Table 1, presents the summary of the literature review with several conclusions about this theme.

Table 1. Summary of literature review

Author(s)	Period	Methodology	Country	Conclusion(s)
Zaman and Moemen (2017)	1980-2013	Ordinary Least Square (OLS), panel fixed effect, and panel random effect	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Jamaica, Mexico, Panama, Paraguay, Peru, Uruguay, and Venezuela	Renewable electricity production increases the CO_2 emissions in the long-run in the Latin American countries. (Note: The authors do not specify the composition of the renewable energy production. However, as the source of this variable is the World Bank Data, this variable includes renewable energy produced by geothermal, solar photovoltaic, solar thermal, tide, wind, industrial waste, municipal waste, primary solid biofuels, biogases, biogasoline, biodiesels, other liquid biofuels, non-specified primary biofuels, and waste. Some caution should be taken regarding these results. Some

				of these sources are relatively recent and the database begins in 1980, which causes large numbers of zeros in the sample).
Fearnside (2016)	n.a.	n.a.	Brazil	The hydroelectric dams emit a substantial amount of greenhouse gases (GHG). These emissions are released from above-water decay of the trees that die due to flooding.
Zwaan et al. (2016)	2000-2050	Multi-model comparison (e.g. EPPA, GCAM, Phoenix, POLES, TIAM-ECN, and TIAM-WORLD)	Latin America region	Hydropower technology has the capacity to reduce CO_2 emissions in the long-run.
Fearnside (2015)	2013-2022	n.a.	Brazil	Increased the CO_2, Methane (CH_4), GHG, and Nitrous Oxide (N_2O) are released from above-water decay of trees that die due to flooding, and by bubbling or diffusion through the reservoir surface or from the water being released through the spillways and turbines.
Rubio and Tafunell (2014)	1900-2000	Fixed and random effects models	Latin American countries: Argentina,	Hydropower plants reduce the consumption of fossil fuels and consequently decrease CO_2

			Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, Guatemala, Honduras, Haiti, Mexico, Nicaragua, Panama, Peru, Paraguay, Dominican Republic, El Salvador, Uruguay, and Venezuela.	emissions.
Amponsah et al. (2014)	n.a.	The EIO-LCA methodology	UK	GHG emissions from hydropower are small.
Varun et al. (2012)	2004-2005	The EIO-LCA methodology	India	As the capacity of the hydropower project increases, the relative GHG emissions decrease.
Cheng et al. (2012)	2012-2020	n.a.	China	Hydropower plants are the key to emission reduction by China in 2020.
Kemenes et al. (2011)	2004-2006	Limnological methodology	Brazil	Emissions from hydropower dams increase due to degassing at the turbine outflow. The total annual GHG emissions

				from dams are equivalent to approximately 50% of the CO_2 emissions derived from the burning of fossil fuels.
Varun et al. (2010)	2004-2005	The EIO-LCA methodology	India	GHG emissions from hydropower generation emit less CO_2 than conventional electricity generation systems, like oil, coal, and gas.
Ribeiro and Silva (2010)	1984-2007	The EIO-LCA methodology	Brazil and Paraguay	CO_2 and CH_4 emissions increase due to the steel life-cycle, cement life-cycle and the operation of civil construction machines.
Gunkel (2009)	n.a.	n.a.	French Guiana	Hydropower plants have high emission rates of the GHG, CO_2, and CH_4. The emissions of those gases are related to water being released through the spillways and turbines, ebullition, degassing in turbines, and the initial river stretch.
Zhang et al. (2007)	1992 and 2003	The EIO-LCA methodology	China	Hydropower, particularly large hydropower, is indicated as an efficient electrical source with relatively low GHG emissions.
Galy-Lacaux et al. (1997)	1994-1997	Diffusive fluxes, Bubbling fluxes, Dissolved gas profiles and	French Guiana	The increase of CH_4 and CO_2 emissions in hydropower plants is induced by forest submersion.

		CO_2 and CH_4 gas chromatography analyses		

Notes: The abbreviations are as follows: not available (n.a.); Ordinary Least Square (OLS); Economic input–output-life cycle assessment (EIO-LCA); Carbon Dioxide Emissions (CO_2); Greenhouse Gas (GHG); Methane (CH_4); Nitrous Oxide (N_2O).

Hydroelectricity production can emit GHG in various ways throughout its lifespan, from construction to operation. Firstly, some emissions come from the dam through the cement, steel, and fuels, which are used during the construction process of these infrastructures. These emissions are greater than those from fossil fuels or from another RES (Fearnside, 2016).
Another major source of emissions consists of the released carbon that comes from the decayed trees that die due to the flooding of the reservoirs (Abril et al. 2013). The trees are generally left standing in the reservoir where they project above the water and rot in the presence of oxygen, releasing their carbon as CO_2 (Fearnside, 2016). The water in the reservoir also emits CO_2, through bubbling or diffusion through the reservoir surface, or from the water being released through the turbines and spillways (Fearnside, 2016).
The consumption of hydroelectricity can reduce CO_2 emissions if the consumption of this source reduces the use of fossil fuels by substantially improving efficiency in a mixed power system (Cheng et al. 2012).
These studies on the impact of hydroelectricity consumption on CO_2 emissions are inconclusive due to conflicting results.

3. Data and Model. This section is divided into two parts. The first one shows the variables and the database used. The second part shows the model's specifications.

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3.1 Data. This article studies seven countries from the South America region, namely: Argentina, Brazil, Chile, Colombia, Ecuador, Peru, and Venezuela in a period between 1966-2015. The choice of these countries and time series are due to the availability of existing data. To analyze the effect of hydroelectricity consumption on CO_2 emissions, the following variables were used (see Table 2). However, the consumption of hydroelectricity is only a rough proxy of hydroelectric capacity, since we only know the consumption, and dams may be built but little used to generate electricity. Consequently, the effect (of the period) of the construction is not "captured". The variables more directly related to construction, such as cement and steel used would be more accurate. These variables are available only after 1995 (and end in 2013), which limit the usable time span. Fig. 1 and 2, show the evolution of the means values for the consumption of hydroelectricity and CO_2 emissions in the South American countries.

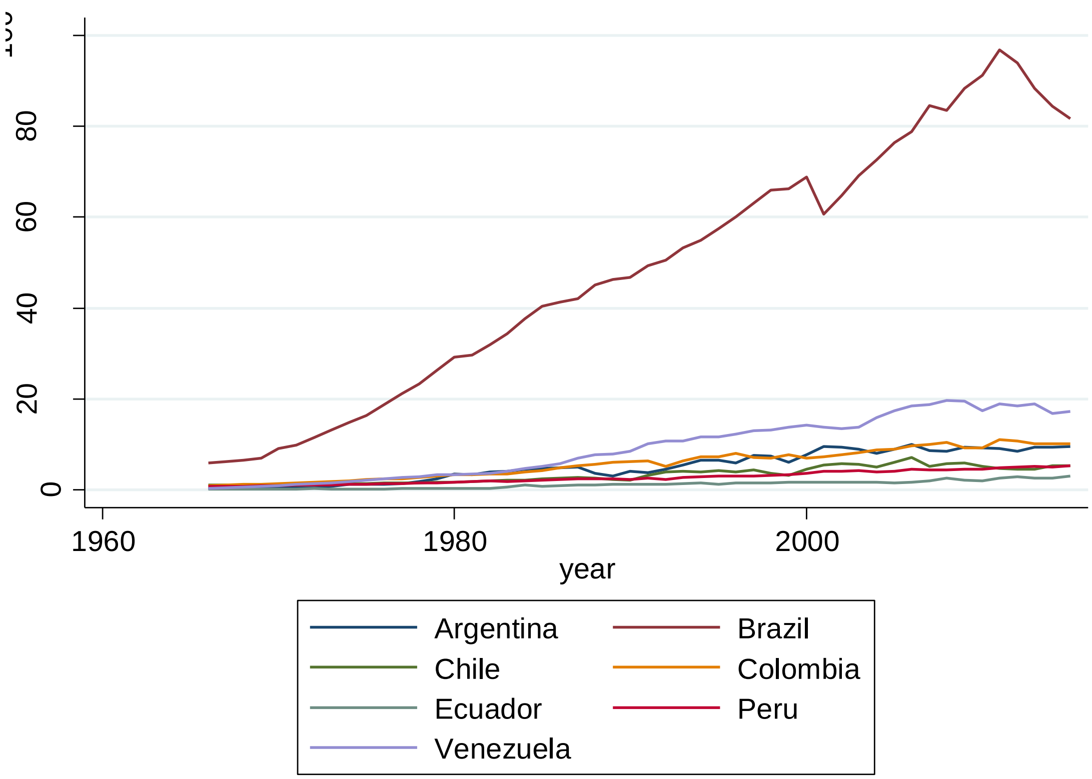

Fig.1. Consumption of hydroelectricity in Million tonnes oil equivalent, between 1966-2015.

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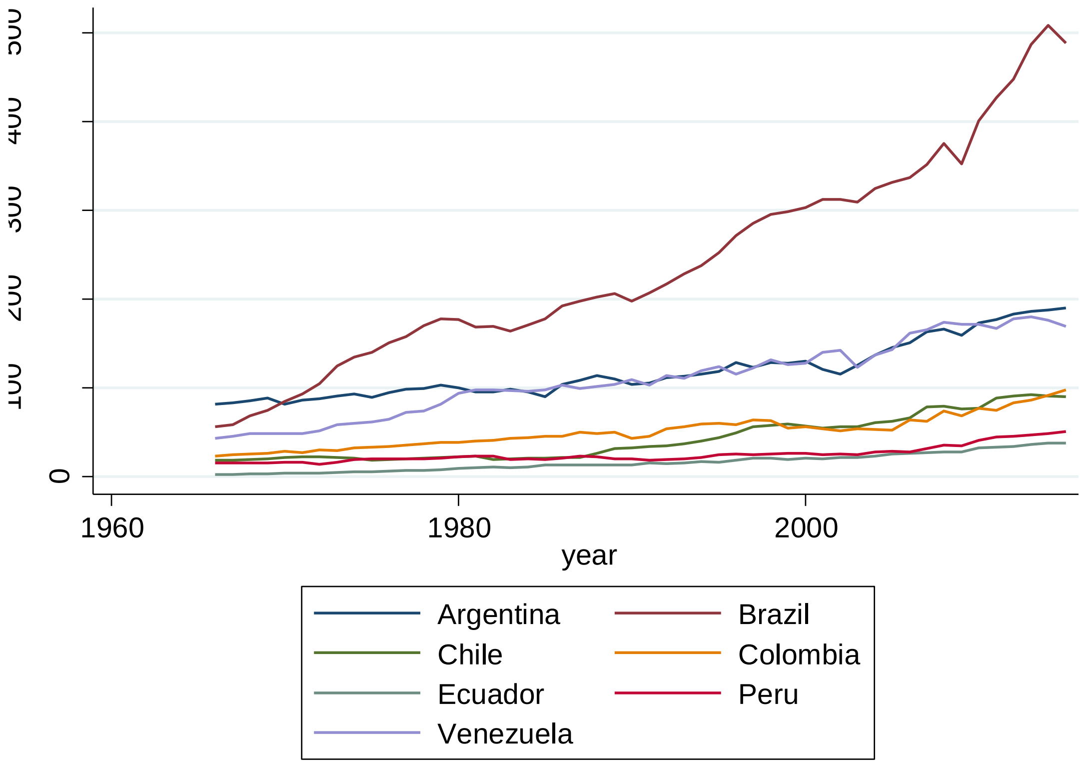

Fig. 2. Carbon dioxide emissions (CO_2) in million tonnes, between 1966-2015.

As can be seen in Fig. 1 and 2, the consumption of hydroelectricity and environmental degradation (CO_2 emissions) have more than doubled in the last four decades. After the presentation of the object of this study, the variables that will be used are presented in Table 2 below.

Table 2. Variables in the model

Variables		Description	Source
Carbon Dioxide Emissions (CO_2)	**LCO_2**	The million tonnes of CO_2 emissions from consumption of fossil fuels sources (e.g., oil, gas, and coal for combustion-related activities).	BP statistical review of world energy.
Hydroelectricity consumption	**LH**	Hydroelectricity consumption in Million tonnes oil equivalent.	BP statistical review of world energy.
Gross Domestic Product (GDP)	**LY**	GDP in constant local currency units (LCU).	The World Bank Data (WBD).
Oil consumption	**LO**	Oil consumption in million tonnes.	BP statistical review of world energy.

The variables were chosen considering the following criteria: (i) they have had hydroelectricity consumption over a long period; and (ii) they have data available for the entire period. The total population was used in order to transform all variables in the model into *per capita* values and to control for disparities in population growth among the South American countries. The option to use constant Local Currency Unit (LCU) in the variable LY, allowed the influence of exchange rates to be circumvented.

The best econometric practices recommend that, when is used the macro panel, it is necessary to test the presence of heterogeneity. Indeed, this heterogeneity could be arising when a long-time span is used in the model. Certainly, the long-time spans exacerbate the potential occurrence of a panel with the presence of cross-section dependence (CSD), and a parameter slope heterogeneity. In the South America region, the existence of CSD is expected due to some common characteristics shared by the countries. However, when the presence of CSD is not controlled in the model, it can produce both biased estimates and a severe identification problem that require appropriate estimators to handle them (Eberhardt and Presbitero, 2013).

The descriptive statistics of variables in logarithms (L) and first-differences (D), the CSD and the order of integration of the variables were examined to capture the features of both series and cross-sections. Table 3 reveals both the descriptive statistics of variables in logarithms and first-differences and the CSD of variables.

Table 3. Descriptive statistics and CSD-test

	Descriptive statistics					CSD-test			
	Obs.	**Mean**	**Std. Dev**	**Min.**	**Max.**	**CD test**		**Corr.**	**Abs(Corr)**
LCO_2	343	-13.1042	0.6215	-14.7372	-11.9940	15.93	***	0.492	0.495
LH	343	-15.7066	0.8314	-18.2140	-14.1753	30.21	***	0.932	0.932
LY	343	10.5064	3.1210	7.2290	16.2150	17.64	***	0.544	0.621
LO	343	-14.5344	0.5269	-15.8726	-13.4813	2.24	**	0.069	0.439
$DLCO_2$	350	0.0151	0.0617	-0.1850	0.19841	4.07	***	0.127	0.150
DLH	350	0.0396	0.1275	-0.6460	0.6730	3.13	***	0.098	0.169
DLY	350	0.0155	0.0453	-0.1780	0.1504	9.24	***	0.288	0.302
DLO	350	0.0112	0.0665	-0.2390	0.2397	2.94	***	0.092	0.137

Notes: ***, **, * denote statistically significant at 1% and 5% level, respectively. Pesaran (2004) CD test has N(0,1) distribution, under the H_0: cross-sectional independence. The Stata command *xtcd* was used to compute the results for CSD.

The CSD-test (Pesaran, 2004) suggested the existence of CSD among the variables, both in logarithms and first differences. The presence of CSD shows the interdependence between the cross-sections, i.e. the countries of model share common shocks.

To check the matrices of correlation and multicollinearity between the variables of the model, the variance inflation (VIF), and correlation test were applied. Therefore, the VIF-test provides an indication of the impact of multi-Collinearity on the accuracy of estimated regression coefficients (O'Brien, 2007). Table 4 revels the outcomes of matrices of correlation and VIF statistics.

Table 4. Matrices of correlations and VIF statistics

	LCO_2		LH		LY		LO
LCO_2	1.0000						
LH	0.4758	***	1.0000				
LY	-0.0569		0.0671		1.0000		
LO	0.9319	***	0.4078	***	-0.2676	***	1.0000
VIF			1.25		1.12		1.34
Mean VIF				1.24			
	$DLCO_2$		**DLH**		**DLY**		**DLO**
$DLCO_2$	1.0000						
DLH	-0.1497	***	1.0000				
DLY	0.5075	***	0.0430		1.0000		
DLO	0.8434	***	-0.0719		0.4719	***	1.0000
VIF			1.01		1.30		1.30
Mean VIF				1.20			

Notes: *** denotes statically significant at 1% level.

The correlation coefficients signal the absence of collinearity among variables in the model. Despite this evidence, with the purpose of solve any remaining doubt about the presence of collinearity in the model, the VIF test for multicollinearity was calculated; the mean VIF of 1.25 to the long-run and 1.20 to the short-run. The low values for the individual Mean VIFs reveal that collinearity is, in fact, not a problem on the model. On the other hand, the variable LO and DLO have a high correlation with LCO_2 and $DLCO_2$. The probable reason for the high correlation among the variables is that the consumption of fossil sources contributes to increasing of CO_2 emissions.

To analyze the integration order of the variables, the unit root test of first-generation that are the LLC (Levin, Lin, and Chu, 2002), the ADF-Fisher (Maddala and Wu, 1999), and the ADF-Choi (Choi, 2001), and Second-generation (Pesaran, 2007) were calculated. Furthermore, the null

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hypothesis of both tests indicates the existence of unit root. Table 5 shows the outcomes of unit root test of the first-and-second generation.

Table 5. Unit roots tests

	1st Generation test						2nd Generation unit root test			
	LLC		ADF-FISHER		ADF-CHOI		CIPS (Zt-bar)			
	Individual Intercept and Trend						Without trend		With trend	
LCO_2	-1.3719	*	13.7007		0.4043		-1.094		0.004	
LH	-2.9801	***	13.5457		-0.0323		-3.921	***	-3.546	***
LY	-1.3503	*	16.3517		-0.7299		-1.056		-1.522	*
LO	-1.1528		16.8084		-0.0842		-0.577		-0.255	
$DLCO_2$	-8.2792	***	96.9332	***	-7.8567	***	-8.663	***	-8.430	***
DLH	-12.5485	***	138.144	***	-10.1646	***	-10.439	***	-10.019	***
DLY	-4.8892	***	59.7318	***	-5.6221	***	-6.392	***	-5.730	***
DLO	-8.0741	***	85.3659	***	-7.0079	***	-7.402	***	-7.179	***

Notes:***,** ,* denote significant at 1%, 5%, and 10% level, respectively: the null hypotheses are as follow LLC: Unit root (common unit root process); this unit root test controls for individuals effects, individual linear trends, has a lag length 1, and Newey-West automatic bandwidth selection and Bartlett kernel; ADF-FISHER and ADF-Choi: Unit root (individual unit root process); this unit root test controls for individual effects, individual linear trends have a lag length 1; first generation tests follow the option “individual intercept and trend” which was decided after a visual inspection; The EViews 9.5 was used. The CIPS test (Pesaran, 2007) has H_0: series are I(1); the Stata command *multipurt* was used to compute CIPS test.

The unit root test of first-generation was computed individual linear trends and a lag length (1). Moreover, this test follows the option “individual intercept and trend”, which was decided after a visual inspection. The null hypothesis rejection of this test means that the variables are stationary. The second-generation (CIPS-test) was calculated without trend and with the trend and a lag length (1). The null hypothesis rejection of this test is that the variables are I(1). The results of the first-generation test pointed that the variables in the first differences are of order I(1) and the second-generation unit root shows that the variables in the first differences and the variable LH are series of order I(1) and the logarithms are I(0). The possible stationarity in other variables in the long-run is due to several crises which impacted the region in the last three decades.

3.2 Model specification. The UECM form of ARDL was utilized with the purpose of investigate the effect of hydroelectricity consumption on environmental degradation. This model is able to decompose the total effect of a variable into its short- and long-run components (e.g., Fuinhas et al. 2017; Koengkan, 2017). Therefore, this model used in this empirical analysis follows the specification of Eq. (1):

$$\begin{aligned} DLCO2_{it} = {} & \alpha_{1i} + \delta_{1i} TREND_t + \sum_{j=1}^{k} \beta_{11ij} DLCO2_{it-j} + \sum_{j=0}^{k} \beta_{12ij} DLH_{it-j} + \\ & \sum_{j=0}^{k} \beta_{13ij} DLY_{it-j} + \sum_{j=0}^{k} \beta_{14ij} DLO_{it-j} + \gamma_{11i} LCO2_{it-1} + \\ & \gamma_{12i} LH_{it-1} + \gamma_{13i} LY_{it-1} + \gamma_{14i} LO_{it-1} + \varepsilon_{1it} \end{aligned} \quad (1)$$

where α_{1t} is the intercept of equation, δ_{1i} , $\beta_{1kij}, k = 1,.....,m,$ are the estimated parameters, and ε_{it} is the error term. The presence of individual effects must be tested against random effects (RE). For the RE model, the error term assumes the following form $\mu_{it} + \omega_{it}$, where, the μ_{it} denotes N-1 country-specific effects and ω_{it} are the independent and identically distributed errors. In conformity, Eq. (1) was converted in Eq. (2), by changing ε_{1i} for $\mu_i + \omega_{it}$, as follows:

$$\begin{aligned} DLCO2_{it} = {} & \alpha_{1i} + \delta_{1i} TREND_t + \sum_{j=1}^{k} \beta_{11ij} DLCO2_{it-j} + \sum_{j=0}^{k} \beta_{12ij} DLH_{it-j} + \\ & \sum_{j=0}^{k} \beta_{13ij} DLY_{it-j} + \sum_{j=0}^{k} \beta_{14ij} DLO_{it-j} + \gamma_{11i} LCO2_{it-1} + \\ & \gamma_{12i} LH_{it-1} + \gamma_{13i} LY_{it-1} + \gamma_{14i} LO_{it-1} + \mu_{it} + \omega_{it} \end{aligned} \quad (2)$$

To find the existence of RE or FE in the models, the Hausman test of the RE against the FE specification was performed. This test has the null hypothesis that the best model is RE. The

Hausman test results indicated that the FE is the best model to be used, where the statistical result is highly significant (χ^2_7 =33.14).

Indeed, to analyse the effect of variables over time, the FE model is more appropriate. This analyse allows a better estimate of the net effect of the explanatory variables in the model. Additionally, the test the heterogeneity in the parameters is highly recommended, in the presence of cross-sections and long-time spans in the macro panels. This testing could be classified in two types: (i) heterogeneity in the short-and long-run; and (ii) heterogeneity only in the short-run.

In the case of heterogeneity in the parameters, the Mean Group (MG) or Pooled Mean Group (PMG) estimators could be computed. The MG is an estimator that computes an average coefficient for all variables of equation (Pesaran et al. 1999). This test is most flexible and consistent in the average long-run, while, in the presence of slope homogeneity, the model is not efficient (Pesaran et al. 1999). The PMG create restriction among adjustment speed terms and cross-section in the long-run. This estimator is performed, when the UECM form of ARDL is computed, allowing corrections of serial correlation among residuals of regression. Moreover, the PMG is a better estimator in the presence of long-run homogeneity if compared with MG estimator. In fact, these estimators necessitate of many time observations (T), and cross-sections (N) (Blackburne III and Frank, 2007).

After the ARDL regression, it is necessary to apply the specification tests to check the characteristics of the model. To this end, a battery of diagnostic tests was calculated, namely: (i) Modified Wald test for identify the group-wise heteroskedasticity. The null hypothesis of this test is the existence of homoscedasticity in the model; (ii) Pesaran test of cross-section independence, in order to check the existence of correlation among cross-sections in the model. This test has as null hypothesis that the residuals of model are not correlated and that follows a normal distribution; (iii) Breusch and Pagan Lagrangian Multiplier test of independence, this test verify whether the variables across individuals are correlated in the model; and (iv) the Wooldridge test to check the presence of serial correlation.

The residuals of the model confirm the need to control for Venezuela in 1989, Colombia in 1996 and Argentina in 1997. For this reason, dummy variables were introduced with the goal to end these distortions and correct the shocks in the model. The ARDL model is robust to the inclusion of dummies where the dummies are statistically highly significant.

4. Empirical Results. To verify the presence of heterogeneity in the model the MG and PMG estimators were tested against the dynamic fixed effects (DFE). So, due to the presence of heteroskedasticity, contemporaneous correlation, first-order autocorrelation and cross-section dependence the Robust Driscoll and Kraay (1998) estimator was computed. This estimator in the presence of several phenomena in the sample error is able to generate a robust standard error.

The DFE, DFE robust standard errors, and DFE Driscoll and Kraay (DFE D.-K) estimators were computed in this investigation. So, the elasticities were computed by dividing the coefficient of the variables by the coefficient of variables LCO_2, both lagged once, and then multiplying by (-1). Moreover, the semi-elasticities were computed by adding the coefficients of variables in the first differences. Finally, with the purpose of verify the characteristics of the model a battery of specification tests quoted in the previous section were computed.

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The empirical results of MG, PMG estimators, Hausman test, semi-elasticities and elasticities of DFE, DFE (Robust), DFE (D-K) estimators, and the specification tests will be evidenced in Table 6 below.

Table 6. Estimation results

(Dependent Variable: $DLCO_2$)								
	Heterogeneous estimator				Fixed effects model			
	MG (a)		PMG (b)		Coefficient	DFE (c)	DFE (Robust) (d)	DFE (D.-K.) (e)
Constant	-3.5208	***	-0.4047	***	-1.0378	***	***	***
	Short-run (semi-elasticities)							
DLH	-0.0810	***	-0.0724	***	-0.0465	***		**
DLY	0.2373	***	0.2681	***	0.2308	***	**	***
DLO	0.7085	***	0.7212	***	0.6982	***	***	***
	Long-run (elasticities)							
LH(-1)	-0.0776	*	0.0431	***	0.0593	**	**	*
LY(-1)	0.3601	***	0.2051	***	0.3941	***	***	***
LO(-1)	0.6088	***	0.8373	***	0.5999	***	***	***
	Speed of adjustment							
ECM(-1)	-0.3163	***	-0.1675	***	-0.1374	***	***	***
	Hausman test				Specification tests			
	MG vs PMG		PMG vs DFE		Modified		Pesaran test	Wooldridge

		Wald test		test
χ^2_8 = n.a.	χ^2_8 = 0.02	χ^2_7 = 93.71***	N(0,1) = 2.115***	F(1,6) = 16.467***

Notes: ***, **, * denote statistically significant at 1%, 5%, and 10% level, respectively; Hausman results for H_0: Difference in coefficients not systematic; ECM denotes error correction mechanism; the long-run parameters are computed elasticities; the Stata commands *xtpmg*, and Hausman (with the sigmamore option) were used; in the fixed effects were used the *xtreg*, and *xtscc* Stata commands; for H_0 of Modified Wald test: sigma(i)^2 = sigma^2 for all I; results for H_0 of Pesaran test: residuals are not correlated; results for H_0 of Wooldridge test: no first-order autocorrelation. n.a. denotes not available.

The Hausman test indicates that the DFE is the better estimator. There is an indication that the panel is 'homogeneous'. The DFE (D.-K.) estimator points to the presence of long memory in the variables, and that the elasticities have highly significant signs. Indeed, the semi-elasticities of variable DLH exert a reduction of -0.0465 on variable $DLCO_2$ in the short-run and the elasticities of variable LH increase the variable LCO_2 by 0.0593 in the long-run. Furthermore, as expected, the variables LY and LO increase the variable LCO_2 in both the short- and long-run.
The ECM term is statistically significant at a 1% level and has a negative sign, indicating the presence of Granger causality in the model. Finally, the battery of specification tests, such as the Modified Wald test indicates the existence of heteroskedasticity in the model. The Pesaran test points to the presence of CSD. The Breusch-Pagan LM test cannot be carried out due to the correlation matrix of residuals being singular. The Wooldridge test evidence the presence of the first-order autocorrelation.

5. Robustness of Results. The empirical results from the previous section suggest that hydroelectricity consumption (LY) reduces carbon dioxide emissions (LCO_2) in the short-run and increases emissions in the long run. To assess the robustness of the estimation results in DFE, DFE Robust, and DFE D.-K models, dummy variables to control for the shocks that occurred in Venezuela in 1989 (VEN1989), Colombia in 1996 (COL1996), and Argentina in 1997 (ARG1997) were introduced. Indeed, the results of semi-elasticities and the elasticities for the DFE, DFE Robust and DFE D.-K. estimators including the dummy variables are shown in Table 7 below.

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Table 7. Estimation results with dummy variables

(Dependent Variable: $DLCO_2$)				
	Fixed Effects			
	Coefficient	FE (f)	FE (Robust) (g)	FE (D.-K.) (h)
Constant	-1.0414	***	***	***
	Dummy variables			
VEN1989	0.0518	*	***	***
COL1996	-0.0614	**	***	***
ARG1997	-0.0521	*	***	***
	Short-run (semi-elasticities)			
DLH	-0.0431	***		**
DLY	0.2429	***	**	***
DLO	0.6969	***	***	***
	Long-run (elasticities)			
LH(-1)	0.0624	***	**	*
LY(-1)	0.3965	***	***	***
LO(-1)	0.5986	***	***	***
	Speed of adjustment			
ECM(-1)	-0.1379	***	***	***

Notes: ***, **, * denotes statistically significant at 1%, 5%, and 10% level, respectively; in the fixed effects were used the *xtreg*, and *xtscc* Stata commands.

The estimations of dummy variables are statistically significant at 1% and 5%. Furthermore, as it can be seen by comparing Tables 6 and 7, the estimation results of both models are basically the same, proving the robustness of the pursued approach, even in the presence of shocks.

6. Discussion. The initial tests prove the presence of heteroskedasticity, cross-sectional independence, and first-order autocorrelation. To control for the presence of shocks, country dummy variables were created. The South America region suffered several social and financial crises. In 1989, Venezuela suffered a political and social crisis after the rise of Carlos Andrés Pérez to the presidency of Venezuela, when people went onto the streets to express their repudiation of economic policy. Colombia in 1996 declared the end of FARC's (*Fuerzas Armadas Revolucionarias de Colombia*) control and also the removal of People's Army (EP) in more than 622 of the 1,071 municipalities; almost half of the country. In 1997, Argentina was also impacted by the Asian crisis that aggravated the structural problems which created severe political and social instability (Bandeira, 2002). All these shocks impacted CO_2.
Our analysis is focused on the results of the LH variable in the short- and long-run. The semi-elasticities of hydroelectricity consumption (LH) exert a reduction of -0.0465 on carbon dioxide emissions (LCO_2) in the short-run, and the elasticities of hydroelectricity consumption (LH) increase carbon dioxide emissions (LCO_2) by 0.0593 in the long-run. This result could be by reason of the consumption of hydroelectricity, which has the capacity to reduce the use of fossil fuels and improves energy efficiency in the short-run. The results found for the long-run (only statistically significant at 10%) could be the result of emissions from hydroelectric facilities occurring in the first few years after a reservoir is created, when the trees that die in the process of flooding release carbon dioxide emissions (CO_2) in the process of their decomposition, as well as during energy generation through turbines and spillways. Furthermore, although hydroelectricity consumption reduces CO_2 emissions in the short-run, the emissions from hydroelectricity in the long-run can be compared with the emissions from generating power from fossil fuel. In this context, it would be interesting to see what happens with other renewable energy sources. However, the investments and consumption of "new renewable energies" that include biomass, wind, solar, photovoltaic, waste, and wave, began in the 2000's in the South America region. This makes an analysis by disaggregated sources unfeasible, due to the number of zeros in the database. These findings can stimulate the creation of new policies, which may introduce new energy technologies that release zero carbon on the energy matrix.

7. Conclusions and policy implications. The impact of hydroelectricity consumption on CO_2 emissions was analysed in this article. The study focuses on seven South American countries in a period that from 1966 to 2015. During this process, the ARDL methodology was used. The initial tests prove the presence of heteroskedasticity, cross-sectional independence, and first-order autocorrelation. The empirical results complement the existing literature. Hydroelectricity consumption (LH) exerts a reduction of -0.0465 on carbon dioxide emissions (LCO_2) in the short-run and increases emissions by 0.0593 in the long-run. These results in the long-run could be due to hydroelectric emissions occurring in the first few years after a reservoir is created, where the trees that have died in the process of flooding, release CO_2 in their decomposition process, and from turbines and spillways during the process of energy generation. These emissions can be compared with those generated from fossil fuels. Therefore, it is fundamental to harness these findings to stimulate the creation of new policies capable of introducing energy technologies that release zero carbon in the energy matrix.

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