The relationship between CO_2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation in the Southern Common Market

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Abstract: The causalities between carbon dioxide emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation were examined for the panel of five countries (Argentina, Brazil, Paraguay, Uruguay, and Venezuela) from Southern Common Market, over thirty-five years (1980-2014), using a panel vector autoregression. The empirical analysis pointed to the existence of bi-directional causality between the consumption of fossil fuels, economic growth, consumption of renewable energy, and carbon dioxide emissions; and a uni-directional relationship between the consumption of renewable energy and urbanisation. The research also proves that the countries from Southern Common Market are dependent on fossil fuels consumption and that urbanisation process is highly linked with the consumption of this type of energy. Additionally, it was found that these countries have low renewable energy participation in their energy mix. Nevertheless, a substitutability effect between the consumption of renewable energy and the consumption of fossil fuels, as a possible response to periods of scarcity in reservoirs, was detected. Policymakers of Southern Common Market countries should speed up the deep reforms regarding renewable energy to mitigate environmental degradation.

Keywords: energy economics; environmental economics; economic growth; urbanisation; PVAR; Mercosur.

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1. Introduction

In the last three decades, the CO_2 emissions from the Southern Common Market (also known as Mercosur) countries have more than doubled. Indeed, there is a global consensus that fossil fuels consumption is one of the main responsible for both the increase in emissions and the anthropogenic climate change. In the Southern Common Market countries, the CO_2 emissions from the consumption of non-renewable sources have grown since the 1960s, reaching a value of 450 million metric tons in 2009 (e.g., Koengkan, 2018a; Koengkan et al., 2018c). The most polluting countries from this trade bloc are Brazil, Argentina, and Venezuela; while the least polluting countries are Paraguay and Uruguay (Boden et al., 2011).

Beyond fossil fuels consumption, these countries urbanisation process has also been shown to have a negative influence on the quality of their environment. The global level of urbanisation went from 39.1% in 1980 to 52.0% in 2011, mainly due to the gradual transition of rural population to urban areas. In Latin America, urbanisation grew from 25%, in the 1920s, to 48.9%, in the 1960s. During the period ranging from 1975 to 2007, the urbanisation rate grew 0.78%, and it is expected to grow 0.36% between 2007 and 2025. The rapid growth of urbanisation in Latin America is mainly linked with the introduction of new agricultural technologies, and with the industrialisation process, which led to a restructuring of the rural economies on most Latin American countries.

As the urbanisation process could be linked with both economic development and energy consumption, and consequently, with the increase in CO_2 emissions, it is natural that the relationship between CO_2 emissions, economic growth, energy consumption, and urbanisation has received a considerable degree of attention from various scholars (e.g., Wang et al., 2018; Sun et al., 2018; Faisal et al., 2018; Koengkan, 2017c; Behera and Dash, 2017; Sbia et al., 2017; Wang et al., 2016; Destek et al., 2016; Fakhri et al., 2015; Zhao and Wang, 2015; Kasman and Duman, 2015; Liddle, 2013; Solarin and Shahbaz, 2013; Liu, 2009).

Given the previous statements, the central question of this article is then: What is the direction of the causality between CO_2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation in the Southern Common Market countries? In this sense, this investigation aims to explore the link between CO_2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation in five Southern Common Market countries, over the period between 1980 and 2014. The panel vector autoregression (PVAR) model, created by Holtz-Eakin et al. (1988), will be used in order to achieve the results which will allow us to respond to the central question of this investigation.

This investigation is pioneering in relation to the existing literature for the following reasons: (i) the inclusion of GDP in constant local currency units (LCU); (ii) the use of PVAR lag-order selection test, eigenvalue stability condition, and forecast-error variance decomposition tests;(iii) the use of the Southern Common Market countries as our sample, given that this group is not addressed in the literature that approaches this same topic; and (iv) this investigation explains, more deeply, how these variables are related if compared with other studies which investigated these same relationships.

Moreover, this study proves to be relevant for the following reasons: (i) the empirical findings of this investigations will contribute to scarce the literature on this field of study; (ii) there is a need to comprehend how these variables interact with each other in the Southern Common Market countries; and (iii) this study will help policymakers on the development of appropriate economic and energy policies aimed to reduce the fossil fuels consumption and the environmental degradation of the Southern Common Market countries without neglecting their economic output.

The paper is organised as follows: **Section 2** presents the literature review; **Section 3** presents the data, model, and conceptual framework; **Section 4** presents the results and discussion; and finally, **Section 5** presents the conclusions, as well as, policy implications.

2. Literature review

In recent literature, the relationship between economic growth and energy consumption has received a high degree of attention. Evidence of this fact is the increasing number of studies in this field (see, e.g., the meta-analysis of Menegaki, 2014). One good example of the advances on the energy-growth nexus studies is the work of Menegaki (2018), who developed an extensive book focused on several questions surrounding this same nexus. This book presents several theoretical and practical explanations, provides helpful insight on the econometric techniques which has been used to investigate this issue, and deepens/clarifies the discussion of its empirical results.

Over time, the energy-growth literature evolved from the basic bi-variate models to the augmented models, with the inclusion of variables such as CO2 emissions in their estimations. Given the problems associated with environmental degradation, it was natural the transition for models which allowed to investigate the causal relationships between these variables (see, e.g. Mardani et al., 2019). Although, most authors have continued to omit the inclusion of some essential variables in their analysis (e.g. urbanisation). In the view of this investigation, urbanisation should not be neglected, mainly because of the increase in the economic activity influences in a great deal the urbanisation process which, consequently, can lead to an increase in both energy consumption and CO2 emissions. This lack of attention created a gap that needs to be filled, as well as a new area of study for energy and environmental economics.

In the literature that approaches this relationship, some authors have included the variable urbanisation (represented by the index of urbanisation) in a unified framework relationship (e.g. Wang et al., 2018; Sun et al., 2018; Faisal et al., 2018; Koengkan, 2017b; Behera and Dash, 2017; Sbia et al., 2017; Wang et al., 2016; Destek et al., 2016; Fakhri et al., 2015; Zhao and Wang, 2015; Kasman and Duman, 2015; Liddle, 2013; Solarin and Shahbaz, 2013; Liu, 2009). These previous studies have also included in their estimations variables such as the total energy consumption, primary energy consumption, fossil fuels consumption, and renewable energy consumption, to proxy for the energy consumption, and the Gross Domestic Product (GDP) in US dollars or in constant local currency units (LCU) to proxy for economic growth. In what regards to environmental degradation, the authors usually go with CO2emissions to represent for this phenomenon (e.g., Koengkan et al., 2019a; Koengkan et al., 2019b; Koengkan, 2018a; Fuinhas et al., 2017).

Although several authors have used different variables to inquire about the relationship between CO2 emissions, energy consumption, economic growth, and urbanisation, the answer to the question of what is the best approach to investigate this relationship remains an enigma. In this sense, it is essential to understand what were the conclusions which have been reached regarding the relationships between these variables. However, the answer to this question is far from being consensual, given that the previous literature has produced a wide range of results and conclusions about this topic (see **Table 1**).

Table 1. Literature focused on the relationships between CO2 emissions, energy consumption, economic growth, and urbanisation.

Author (s)	Methodology (ies)	Time Span	Country (ies) /region (s)	Main Findings
Wang et al., (2018)	PVAR and Granger causality tests	1980 to 2011	170 countries	Existence of a bi-directional relationship between energy consumption and CO2 emissions in the high income countries; a bi-directional relationship between economic growth and CO2 emissions in the low-high-income, upper-middle-income, and low-income countries; a uni-directional causality between economic growth and CO2 emissions in the middle-income countries; a bi-

				directional relationship between urbanisation and CO_2 emissions in the low-high-income, upper-middle-income, and low-income countries.
Sun et al., (2018)	DOLS, FMOLS, and Granger causality tests	1995 to 2015	30 Chinese provinces	Existence of a long-run relationship between economic growth, energy consumption, CO_2 emissions, and urbanisation in all Chinese provinces; economic growth, energy consumption, and urbanisation contributed to increasing CO_2 emissions.
Faisal et al., (2018)	PARDL bounds testing and Granger causality tests	1965 to 2013	Iceland	Economic growth, trade, and urbanisation exerted a positive impact on the short-run energy consumption of Iceland. Existence of a bi-directional relationship between urbanisation and energy consumption.
Koengkan (2017c)	PVAR and Granger causality tests	1980 to 2014	21 Latin America and Caribbean countries	Existence of a uni-directional relationship between energy consumption and urbanisation and of a bi-directional relationship between energy consumption and economic growth.
Behera and Dash (2017)	DOLS, FMOLS, and cointegration tests	1980 to 2012	17 Asian countries	Existence of a cointegrated relationship between non-renewable energy consumption, urbanisation, economic growth, FDI, and CO_2 emissions in the middle-income countries of their sample. Primary energy consumption, non-renewable energy consumption, and FDI exerted an impact on the SEA region emissions.
Sbia et al., (2017)	PARDL bounds testing and VECM	1975 to 2011	United Arab Emirates	Existence of a bi-directional relationship between financial development and electricity consumption, economic growth, urbanisation, and energy consumption.
Wang et al., (2016)	FMOLS and causality tests	1980 to 2009	ASEAN countries	Existence of a long-run relationship between urbanisation, CO_2 emissions, and energy consumption. Existence of unilateral causal relationships running from urbanisation to energy, and from urbanisation to CO_2 emissions.
Destek et al., (2016)	FMOLS, VECM, and Granger causality tests	1991 to 2011	10 Central and Eastern European countries	Existence of bi-directional causal relationships between CO_2 emissions, economic growth, energy consumption, urbanisation, and trade openness.
Fakhri et al., (2015)	DOLS, FMOLS, cointegration tests	1990 to 2010	10 Middle East and North African countries	CO_2 emissions exerted a positive impact on economic growth, energy consumption, and urbanisation, and a negative impact on life expectancy.
Zhao and Wang (2015)	VECM and Granger causality tests	1980 to 2012	China	Existence of bi-directional causality between energy consumption and economic activity, and of two uni-

				directional causalities: one running from urbanisation to energy consumption, and another one running from economic growth to urbanisation.
Kasman and Duman (2015)	OLS and panel causality tests	1992 to 2010	New European Union members and candidates	Existence of uni-directional causalities running from energy, trade openness, and urbanisation to environmental degradation, from economic growth to energy consumption, from economic growth, energy consumption, and urbanisation to trade openness, from urbanisation to economic growth, and from urbanisation to trade openness.
Liddle (2013)	Heterogeneous Panel Estimates	1971 to 2010	70 countries	Existence of a positive relationship between economic growth, energy consumption, and urbanisation.
Solarin and Shahbaz (2013)	Gregory-Hansen structural break cointegration, ARDL model, and VECM Granger causality	1971 to 2009	Angola	Existence of bi-directional causality between energy consumption and economic growth, and between urbanisation and economic growth.
Liu (2009)	ARDL model	1987 to 2008	China	Existence of a long-run relationship between energy consumption, economic growth, population growth, and urbanisation.

Notes: Meaning of acronyms, Dynamic Ordinary Least Squares (DOLS); Fully Modified Ordinary Least Squares (FMOLS); Foreign Direct Investment (FDI); Association of Southeast Asian Nations (ASEAN); South-East Asia (SEA); Panel Autoregressive Distributed Lags (PADL); Vector Error Correction Model (VECM); Ordinary Least Squares (OLS); and Autoregressive Distributed Lags (ARDL).

As it can be seen in **Table 1** the past literature has used a diverse range of variables, countries, methodologies, and time horizons, to try to clarify the relationship between CO2 emissions, economic growth, energy consumption, and urbanisation. However, there are still some gaps in the literature which need to be filled. As an example, we can mention the use of LCU as an alternative to constant US dollars, a method which has been used in a few number of studies with the intention of avoiding the influence of exchange rates (e.g., Fuinhas et al., 2017; Koengkan, 2017a; Koengkan, 2018a; Koengkan, 2018b). Another example of a gap is the non-utilization of the PVAR model, with the exception of Wang et al. (2018). Although, we should note that this author has only estimated the Granger causality tests and the impulse response functions, leaving tests as the eigenvalue stability condition, the forecast error variance decomposition (FEVD), and the panel VAR lag-order selection aside. Moreover, until this date, we do not have any examples of studies focused on the specific case of the Southern Common Market countries. The studies that were displayed in this literature review were mainly focused on African, Asian, European, and Middle Eastern countries.

In order to fill the previously mentioned gaps, this investigation will adopt a new approach which includes: (i) the use of the GDP in constant local currency units (LCU); (ii) the performance of the PVAR lag-order selection test, the eigenvalue stability condition test, and the forecast error variance decomposition test; and (iii) the use of a group of countries which were not addressed in this specific literature (Southern Common Market countries). Finally, it is important to emphasise that this literature review was based on a comprehensive review of the most important studies that approach this same topic, highlighting their key findings. In the next section, the data, the method, and the conceptual framework of this study will be presented.

3. Data, method and conceptual framework

3.1. Data

In order to accomplish the purpose of this study, we used annual data for a group of five countries from the Southern Common Market, namely: Argentina, Brazil, Paraguay, Uruguay, and Venezuela (suspended from this trade bloc in 2016 due to its political crisis), with a time span ranging from 1980 to 2014. The data availability is the main justification for choosing this time horizon. The Southern Common Market is a sub-regional bloc created in 1991 to encourage the fluid movement of goods, currency, and people, and to promote the free trade between its members, associated members, and observer countries. The selection of these countries was mainly linked with the fact that they have experienced a rapid increase in their economic growth in the last three decades, as well as a fast rise in both their energy consumption and their urbanisation levels. To evaluate the relationship between CO2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation in this group of countries, the following variables were used:

(i) **Carbon dioxide (CO2)** emissions from energy consumption (million metric tons), available at the International Energy Administration (IEA) (2018);
(ii) **Gross Domestic Product (GDP)** in constant local currency units (LCU), available at the World Bank Data (WDB) (2018);
(iii) **Fossil fuels energy consumption (Fossil)** in billions of kilowatt-hour (kWh), from oil, gas, and coal, available at the International Energy Administration (IEA) (2018);
(iv) **Renewable energy consumption (Rene)** in billions of kilowatt-hour (kWh), from hydropower, solar, photovoltaic, wind, waste, biomass, and wave, available at the International Energy Administration (IEA) (2018);
(v) **Urbanisation index (Urba)** that refers to people living in urban areas as defined by national statistical offices, available at the World Bank Data (WDB) (2018).

All the variables included in this investigation were transformed into *per capita* values – with the exception of the variable "Urbanisation index" - using the total population of each country. This transformation allows to reduce the effects of population disparity (e.g., Koengkan, 2018a; Koengkan, 2018b). Moreover, the use of constant GDP in local currency units (LCU), instead of constant US dollars, permits to remove the influence of the inflation (otherwise present in the variables) and of the deviation of the exchange rates from their fundamentals (the exchange rates often deviate from their long-run fundamental equilibrium for long-time spans), a fact which was already pointed by some previous authors (e.g. Santiago et al., 2018; Koengkan et al., 2019d). Additionally, as the phenomenon that this study investigates is related with "domestic variables", measuring all of them in US dollars could exacerbate the cross-sectional dependence phenomenon and add exogenous disturbances to the panel, facts which could compromise the estimation. After presenting the variables, it is also necessary to present the method that will be used along with its conceptual framework.

3.2. Method and conceptual framework

The methodology applied in this study was based on the panel vector autoregression (PVAR) model. Holtz-Eakin et al. (1988), created this method as a substitute for the multivariate simultaneous equation models. This method has been used to address a variety of issues with particular interest to policymakers, economists, and environmentalists (Antonakakis et al., 2017). Moreover, it presents several advantages (see Antonakakis et al., 2017), such as: (i) is extremely useful when some theoretical information exists on the relationship between the variables; (ii) is able to address the endogeneity problem; (iii) can determine if the effects of the variables occur in the short-run, long-run, or both; (iv) permit to include country fixed-effects that capture the time-invariant components; and (v) work well with relative short-time series, due to the possible efficiency gained from the cross-sectional dimension. The specification of the PVAR model is shown in **Equation (1)**:

$$A_{it} = A_{it-1}e_1 + A_{it-2}e_2 + \cdots + A_{it-p+1}e_{p-1} + A_{it-p}e_p + x_{it}b + u_{it} + \varepsilon_{it} \quad (1)$$

Where, A_{it} is the vector of the dependent variables, represented by the variables in their first-differences (e.g., DLnCO2; DLnGDP; DLnFossil; DLnRene; DLnUrba). The use of first-differences is due to the PVAR requirement that all variables should be I (0) and stationary (see Table 4); x_{it} represents the vector of exogenous covariates; μ_{it} and ε_{it}, represent, respectively, the vectors of the dependent variables in a panel with fixed effects and the idiosyncratic errors. The matrices $e_1, e_2, \ldots, e_{p-1}, e_p$ and matrix b are parameters to be estimated. The following conceptual framework (**Figure 1**) highlights the methodological approach that will be used.

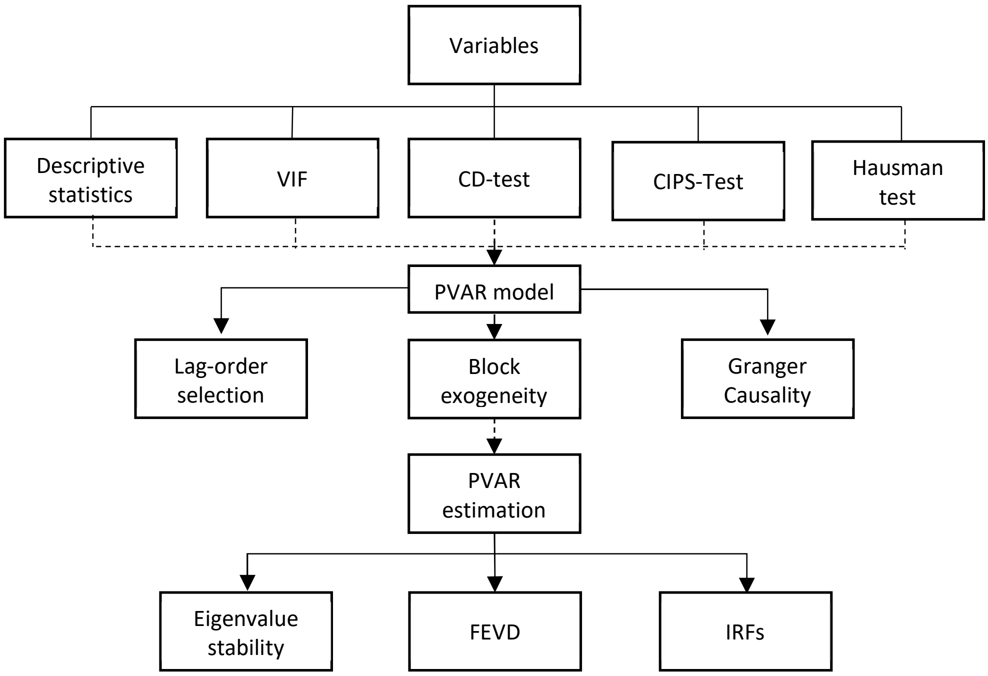


Figure 1. Conceptual framework of the empirical research

Before the estimation of the PVAR regression, it is recommended to check the properties of the variables to be included in the model. To this end, some preliminary tests were computed, namely:

(i) Variance Inflation Factor test (VIF-test) (Belsley et al., 1980) in order to verify the degree of multicollinearity between the variables and between the regression coefficients (O'Brien, 2007);
(ii) Cross-sectional dependence test (CSD-test), to check for the presence of cross-sectional dependence in the panel time-series data (Pesaran, 2004);
(iii) 2nd generation unit root test, which includes the Pesaran (2007) panel unit root test (CIPS-test) for multiple variables and lags, in order to test for the existence of unit-roots in the variables - the rejection of the null hypothesis means that all variables are stationary, i.e. I(0);
(iv) Hausman test (Hausman, 1978), which indicates whether the panel has random effects (RE) or fixed effects (FE) - the null hypothesis of this test is that the best model is the RE – the literature mostly uses estimations with FE, but the use of the RE specification is also admissible (e.g., Sigmund and Ferstl, 2017; Binder et al., 2005);
(v) PVAR lag-order selection which allows determining the optimal lag-order specification for the PVAR model (Andrews and Lu, 2001; Hansen, 1982).

Moreover, after the PVAR regression, it is necessary to compute a group of specification tests in order to check the properties of the model. With this in mind, some diagnostic tests created by Abrigo and Love (2015) will be used, namely:

(i) Granger causality Wald test, which verifies the causal relationships between the variables;
(ii) Eigenvalue stability condition, which checks the stability condition of the PVAR model by computing the modulus of each eigenvalue;
(iii) Forecast-error variance decomposition (FEVD), which calculates the forecast-error variance decomposition based on the Cholesky decomposition of the underlying PVAR model. The confidence intervals and the standard errors are based on Monte Carlo simulations;
(iv) Impulse-response functions (IRF's), which compute the plots of the impulse-response functions, revealing the behaviour of one variable when faced with a shock or innovation in another variable. This test, as in the case of the FEVD, is also based on Monte Carlo simulations.

In this study, the Stata 15.1 statistical software was used to perform the empirical approach. In this section, the selection of both countries and time-span, the data and method which were used in this analysis, and its conceptual framework (preliminary tests and diagnostic tests), were all explained. In the following section, the results from the estimation will be presented, along with their discussion.

4. Results and discussion

Given that the PVAR model requires that all variables be I(0), in this study, we will only use the variables in their first-differences. To evidence the characteristics of the variables and to check for the presence of cross-sectional dependence, the descriptive statistics and the CSD-test were computed. The outcomes of both tests can be seen in **Table 2**.

Table 2. Descriptive statistics and CSD test.

	Descriptive Statistics					CSD-test			
Variables	Obs.	Mean	Std.-Dev.	Min.	Max.	CD-test	p-value	Corr	Abs (corr)
DLnCO2	170	0.0221	0.0772	-0.2758	0.2920	1.53	0.126	0.083	0.186
DLnGDP	169	0.0102	0.0500	-0.1264	0.1504	7.29	0.000 ***	0.397	0.397
DLnFossil	170	0.0217	0.0991	-0.2095	0.6857	1.73	0.084 *	0.094	0.128
DLnRene	170	0.0424	0.2279	-0.6136	1.4757	0.51	0.611	0.028	0.144
DLnUrba	170	0.0204	0.0107	0.0022	0.0459	16.54	0.000 ***	0.903	0.903

Notes: *** and * denote statistical significance at the 1%, and 10% level; the command *sum* of Stata was utilized to compute de descriptive statistics; Obs. denotes the number of observations in the model; Std.-Dev., denotes the Standard Deviation; Min. and Max., denote Minimum and Maximum, respectively; the command *xtcd* of Stata was used to compute the CSD-test.

Before we can proceed, we should explain why the descriptive statistics only present 169 observations for the variable DLnGDP. This situation was due to the unavailability of data on GDP for Venezuela in 2014, mainly because this country has been suffering from a severe economic and political crisis which led its central bank to not release the country's GDP data for 2014.

The results of the CSD-test revealed the existence of cross-section dependence in the DLnGDP and DLnUrba variables, with 1% of statistical significance, and in the DLnFossil variable, with 10% of statistical significance. The presence of this phenomenon in the data means that the countries share common characteristics and shocks (e.g., Koengkan, 2018b; Koengkan et al., 2019c). A possible explanation for the absence of cross-section dependence in the DLnCO2 and DLnRene variables could be the fact that these variables are determined by political decisions (which are mostly idiosyncratic). Indeed, CO2 emissions and renewable energy generation are usually country-specific and conditional on the intermittence that characterises its generation, i.e., hydro, solar, and wind sources (Fuinhas et al., 2017).

To inquire about the presence of multicollinearity and to determine whether the panel has random effects (RE) or fixed effects (FE), we computed the VIF statistical and the Hausman tests, respectively. **Table 3** shows the outcomes from both the VIF statistics and Hausman tests.

Table 3. VIF statistics and Hausman tests.

Independent variables	Dependent variable				
	DLnCO2	DLnGDP	DLnFossil	DLnRene	DLnUrba
DLnCO2	-	1.43	1.30	1.20	1.57
DLnGDP	1.11	-	1.25	1.25	1.17
DLnFossil	2.23	2.77	-	1.13	2.77
DLnRene	2.10	2.82	1.15	-	2.80
DLnUrba	1.11	1.08	1.15	1.14	-
Mean VIF	1.64	2.03	1.21	1.18	2.08
Chi2 (4)	0.35	4.02	4.15	0.73	59.97***

Notes: *** denotes statistical significance at the 1% level; the Stata command *Hausman* was utilised; the null hypothesis for the Hausman test is the difference in coefficients is not systematic or that the random effects are the best model.

The outcomes of the VIF statistics seem to indicate that multicollinearity is not a problem for our estimation. The results of both individual VIFs and mean VIFs are below the commonly accepted benchmarks of 10 and 6, respectively. Relatively to the Hausman tests results, the outcomes only reject the null hypothesis for one of the five specifications, with urbanisation as the dependent variable. Given the presence of fixed effects, correlation problems between the regressors can arise. Given this issue, the best approach seems to be the use of the PVAR Stata command developed by Abrigo and Love (2015), which allows removing these fixed-effects through the use of the "Hermelet procedure" developed by Arellano and Bover (1995).

In order to check the stationarity of the variables, the 2nd generation unit root test (CIPS-test) was used. The null hypothesis of this test is that the variables are I(1), i.e., integrated of order one. As it can be seen from the results of Table 4, the Pesaran (2007) Panel Unit Root test (CIPS) indicates that all variables are stationary, with lag length one, and with and without a trend.

Table 4. Unit root test.

Variables	2nd generation unit root test						
	Pesaran (2007) Panel Unit Root test (CIPS) (Zt-bar)						
	Without trend				With trend		
	Lags	Zt-bar	p-value		Zt-bar	p-value	
DLnCO2	1	-7.365	0.000	***	-6.779	0.000	***
DLnGDP	1	-5.296	0.000	***	-4.039	0.000	***
DLnFossil	1	-6.060	0.000	***	-5.164	0.000	***
DLnRene	1	-6.440	0.000	***	-5.263	0.000	***
DLnUrba	1	-2.390	0.008	***	-2.453	0.007	***

Notes: *** and **, denote statistically significant at 1%, and 5% level, respectively; null for CIPS tests: series is I(1); the lag length (1) and trend were utilised in this test.

After the CIPS-test, and before the PVAR estimation, it is necessary to compute the PVAR lag-order selection test, which reports the values of the overall coefficients of determination (CD), the Hansen´s J statistic (J), the J-ρ value, and the Bayesian (MBIC), Akaike (MAIC), and Quinn (MQIC) information criterion's. **Table 5** shows the outcomes of the lag-order selection test.

Table 5. Panel VAR lag-order selection

Lags	CD	J	J-ρ value	MBIC	MAIC	MQIC
1	0.9966	111.0227*	0.4280	-422.8419*	-106.9773*	-235.3345*
2	0.9976	76.93577	0.6947	-334.4828	-91.06423	-189.9817
3	0.9944	68.48823	0.1864	-220.4843	-49.51177	-118.9895

Notes: The Stata command *pvarsoc* was utilised.

As the Hansen´s J statistic (J) is higher at one lag, and the MBIC, MAIC, and MQIC information criterion's are lower at one lag, we will estimate a first-order PVAR. **Table 6** shows the outcomes of the first order PVAR regression.

Table 6. PVAR regression

Variables	DLnCO2		DLnGDP		DLnFossil		DLnRene		DLnUrba	
DLnCO2 (-1)	-0.6623	***	-0.0677	***	-0.4538	***	-0.3805	***	-0.0014	***
DLnGDP (-1)	0.6008	***	0.3569	***	0.5596	***	0.1641	**	0.0045	***
DLnFossil (-1)	0.3452	***	0.0625	***	0.4367	***	0.9171	***	0.0018	***
DLnRene (-1)	-0.1345	***	-0.0163	**	-0.1962	***	-0.5395	***	-0.0007	***
DLnUrba (-1)	2.1143	***	-0.7264	***	1.9204	***	-0.4165		0.9915	***
N. obs	134									
N. panels	5									
Ave. no. of T	28.800									

Notes: *** and ** denote statistical significance at the 1%, and 5% level, respectively; instruments: l (1/6).

After the PVAR regression, the Granger causality Wald test was used in order to identify the causal relationships between the variables. **Table 7** shows the outcomes of the Granger causality Wald test.

Table 7. Granger causality Wald test.

Equation \ Excluded		Chi2	Df.	Prob > Chi2	
DLnCO2	DLnGDP	53.263	1	0.000	***
	DLnFossil	148.589	1	0.000	***
	DLnRene	80.079	1	0.000	***
	DLnUrba	34.403	1	0.000	***
	All	210.320	4	0.000	***
DLnGDP	DLnCO$_2$	7.603	1	0.006	***
	DLnFossil	18.209	1	0.000	***
	DLnRene	4.888	1	0.027	**
	DLnUrba	45.453	1	0.000	***
	All	64.499	4	0.000	***
DLnFossil	DLnCO$_2$	124.584	1	0.000	***
	DLnGDP	112.601	1	0000	***
	DLnRene	85.953	1	0.000	***
	DLnUrba	82.301	1	0.000	***
	All	219.501	4	0.000	***
DLnRene	DLnCO$_2$	46.009	1	0.000	***
	DLnGDP	4.183	1	0.041	**
	DLnFossil	76.938	1	0.010	**
	DLnUrba	1.024	1	0.312	
	All	107.335	4	0.000	***
DLnUrba	DLnCO$_2$	27.000	1	0.000	***
	DLnGDP	128.134	1	0.000	***
	DLnFossil	16.971	1	0.000	***
	DLnRene	18.666	1	0.000	***
	All	215.030	4	0.000	**

Notes: *** and ** denote statistical significance at the 1%, and 5% level, respectively; the Stata command *pvargranger* was used.

First, by the blocks of exogeneity (ALL), we see that a high level of endogeneity is present in the system, which leads us to believe that the PVAR methodology is the most appropriate approach for this study. Second, the results of the Granger causality Wald test point to the presence of bi-directional causal relationships between economic growth, CO2 emissions, renewable energy consumption, and fossil fuel energy consumption, with the bi-directional causal relationship between economic growth and renewable energy consumption being the least robust one. Regarding urbanisation, from **Table 4,** it can be seen that this variable seems to have bi-directional causal relationships with all of the other variables, except for the renewable energy consumption variable. In this last case, the results pointed to the existence of a uni-directional causal relationship running from renewable energy consumption to urbanisation. **Figure 2** summarises the statistically significant Granger causalities.

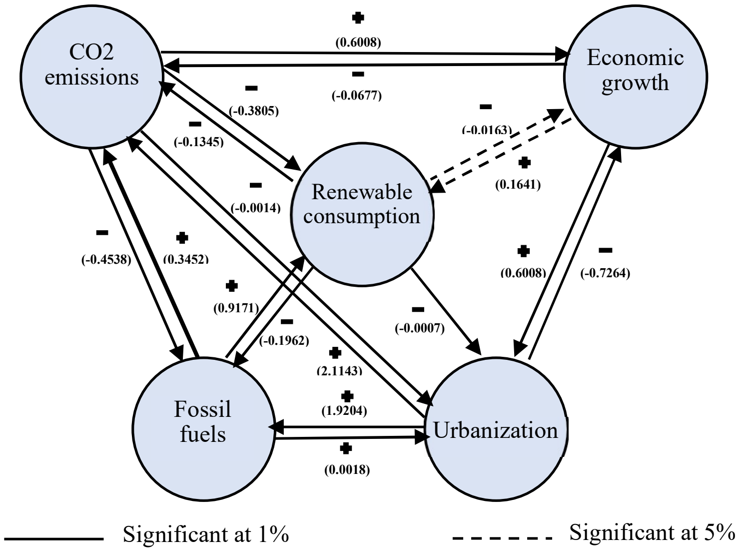
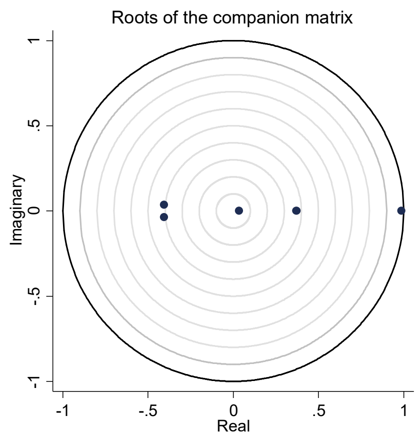


Figure 2 Granger causality

After the estimation of the Granger causality Wald test, the eigenvalue stability condition was computed in order to check the stability of the first order PVAR model. **Table 8** displays both the eigenvalues and the graph of the eigenvalues. The results seem to indicate that the PVAR model is stable (all eigenvalues are inside the unit circle).

Table 8. Eigenvalue stability condition

Eigenvalue			Graph
Real	Imaginary	Modulus	
0.9872	0.0000	0.9872	
-0.4048	0.0361	0.4064	
-0.4048	-0.0361	0.4064	
0.3710	0.0000	0.3710	
0.0348	0.0000	0.0348	



Notes: The Stata command *pvarstable* was used.

After confirming the model stability, the next step was computing the FEVD, following the Cholesky decomposition, using 1000 Monte Carlo simulations for 15 periods. **Table 9** shows the output of the FEVD.

Table 9. Forecast-error variance decomposition (FEVD)

Response variable	Forecast Horizon	Impulse variable				
		DLnCO2	DLnGDP	DLnFossil	DLnRene	DLnUrba
	0	0	0	0	0	0
DLnCO2	1	1	0	0	0	0
	5	0.8600	0.0739	0.0177	0.0478	0.0005

	10	0.8591	0.0740	0.0177	0.0481	0.0009
	15	0.8588	0.0741	0.0177	0.0481	0.0012
	0	0	0	0	0	0
	1	0.1285	0.8714	0	0	0
DLnGDP	5	0.1176	0.8759	0.0040	0.0017	0.0009
	10	0.1174	0.8746	0.0040	0.0017	0.0023
	15	0.1173	0.8734	0.0040	0.0017	0.0035
	0	0	0	0	0	0
	1	0.1205	0.0351	0.8444	0	0
DLnFossil	5	0.1160	0.0941	0.7115	0.0779	0.0007
	10	0.1159	0.0942	0.7108	0.0780	0.0012
	15	0.1159	0.0943	0.7103	0.0780	0.0016
	0	0	0	0	0	0
	1	0.0279	0.0744	0.4090	0.4886	0
DLnRene	5	0.0308	0.0703	0.3509	0.5480	0.0000
	10	0.0308	0.0703	0.3509	0.5480	0.0000
	15	0.0308	0.0703	0.3509	0.5480	0.0000
	0	0	0	0	0	0
	1	0.0231	0.0144	0.0024	0.0002	0.9599
DLnUrban	5	0.0396	0.1449	0.0147	0.0095	0.7913
	10	0.0433	0.1755	0.0168	0.0103	0.7541
	15	0.0445	0.1851	0.0175	0.0105	0.7423

Notes: The Stata command *pvarfevd* was used.

By the results of the FEVD, one can see the percentage of the forecast error variance that a variable explains after one shock or innovation in a given variable (e.g., DLnCO2, DLnGDP, DLnFossil, DLnRene, DLnUrba).

The first thing that should be noticed is that the majority of the variables seem to be self-explanatory. After one period, shocks to DLnCO2 explain 100% of its forecast error variance, shocks to DLnGDP explain 87% of its forecast error variance, shocks to DLnFossil explain 84% of its forecast error variance, and shocks to DLnUrban explain around 96% of its forecast error variance.

The only variable that seems not to be completely self-explanatory is the DLnRene, given that, after one period, shocks to DLnRene explain its forecast error variance in 49%, while shocks to DLnFossil and DLnGDP explain 41% and 7%, respectively, of the DLnRene forecast error variance. After fifteen periods, the percentage that the shocks to DLnFossil and DLnGDP explain of the DLnRene forecast error variance decreases. Still, by these results, it can be seen that the fossil fuels consumption has a high influence on the Southern Common Market renewable energy consumption. Finally, shocks to DLnCO2 explain only 3 % of the DLnRene forecast error variance, from the first to the fifteenth period's, while shocks to DLnUrban explain an even more insignificant percentage of the DLnRene forecast error variance.

Regarding DLnCO2, it can be seen that, after one period, shocks to DLnCO2 explain 100% of its forecast error variance. As we move forward in time, this shock loses some of its importance and, in the fifth period, shocks to DLnCO2 explain around 86% of the forecast error variance, while shocks to DLnGDP and DLnRene explain around 7% and 5%, respectively, of the DLnCO2 forecast error variance. These percentages remain similar until the fifteenth period. Additionally, we see that both shocks to DLnFossil and DLnUrban do not significantly explain the DLnCO2 forecast error variance. In this case, we can conclude that economic growth and renewable energy consumption are the primary influencers of the variability of these countries CO2 emissions.

Turning to the DLnGDP, the results show that, in the first period, its forecast error variance is mainly explained by shocks to itself (87%), and by shocks to DLnCO2 (13%). This scenario remains similar in the fifth, tenth, and fifteenth periods. Regarding the shocks in the remaining explanatory variables, it can be observed that all of them reveal to have a small influence on the DLnGDP forecast error variance. Given these results, it can be said that, among the chosen variables, CO2 emissions appear to be the only one which substantially explains the DLnGDP forecast error variance.

Relatively to the DLnFossil, it can be seen that, in the first period, its forecast error variance is mainly explained by shocks to itself (84%), by shocks to DLnCO2 (12%), and by shocks to DLnGDP (4%). As we move forward in time, these percentages stabilize their values, and in the fifth period and beyond (tenth and fifteenth periods) shocks to DLnFossil explain 71% of its forecast error variance, while shocks to DLnCO2, shocks to DLnGDP, and shocks to DLnRene, explain 12%, 9%, and 8%, respectively, of the DLnFossil forecast error variance. These results reveal that, apart from itself, CO2 emissions, economic growth, and renewable energy consumption, also affect the variance of the fossil fuels energy consumption in the Southern Common Market countries.

Finally, regarding the DLnUrban, the results show that, in the first period, its forecast error variance is mainly explained by shocks to itself (96%). However, shocks to DLnGDP and DLnCO2 seem to gain importance in the explanation of the DLnUrban forecast error variance over time. In the fifteenth period, shocks to DLnGDP and DLnCO2 explain around 19% and 4%, respectively, of the DLnUrban forecast error variance. Additionally, it can be seen that shocks in the remaining variables (e.g., DLnFossil, DLnRene) explain only a small fraction of the urbanisation forecast error variance. By these results, it can be considered that economic growth is the main influencer of the variation in these countries urbanisation.

In the next figure, **Figure 3** can appreciate the outputs of the impulse – response functions which were generated in Stata (the command *pvarirf* was used to compute the IRF's). As can be seen in **Figure 3** in the long run, all variables converge to equilibrium. This detail supports the stationarity of the considered variables. Moreover, the impulse-response functions seem to be in accordance with the FEDV results.

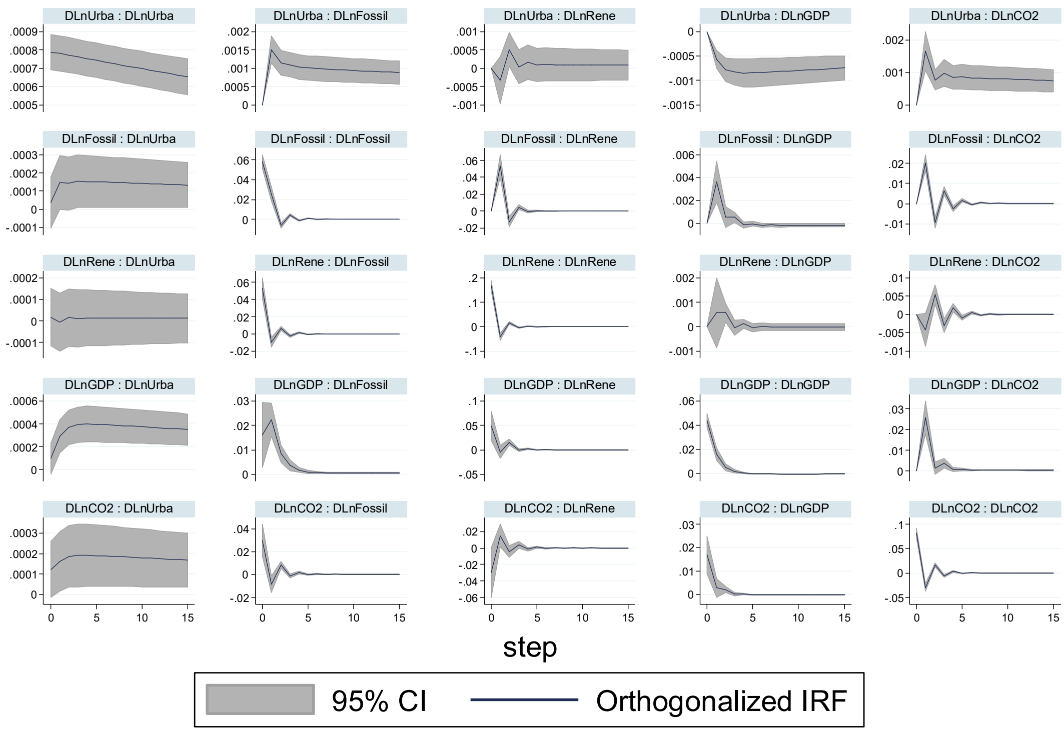


Figure 3. Impulse – response functions

In this study, the causal relationships between CO2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation, in the Southern Common Market countries, were investigated. The preliminary tests evidenced the presence of cross-sectional dependence in some of the variables, a low degree of multicollinearity, and the presence of unit roots in all variables.

Moreover, the preliminary tests also pointed to the presence of fixed effects in the model, and the need to estimate a PVAR model with one lag length (1) (see **Tables 2**, **3**, **4**, and **5**).

The outcomes of the PVAR regression indicated that economic growth, fossil fuel consumption, and urbanisation, increased the CO2 emissions in the Southern Common Market countries, while renewable energy consumption seems to have contributed to the reduction in these emissions. Moreover, the results also pointed out that CO2 emissions appear to have had a depressing effect on these countries economic growth, renewable energy consumption, and urbanisation. Conversely to CO2 emissions, fossil fuels consumption seems to have enhanced the economic output of these countries. The results also showed that both CO2 emissions and renewable energy consumption were able to reduce the use of fossil fuels, while economic growth and urbanisation seem to have led to an increase in the fossil fuels consumption. Regarding renewable energy consumption, the results pointed out that both CO2 emissions and urbanisation contributed to reducing the use of renewables, whereas economic growth and fossil fuels seem to have increased the consumption of this type of energy. Finally, the results also indicate that CO2 emissions and renewable energy consumption were able to reduce these countries urbanisation process, while economic growth and fossil fuel consumption seem to have contributed to its increase (see **Table 6**).

The outcomes of the Granger causality Wald test pointed to the existence of bi-directional causal relationships between economic growth, CO2 emissions, renewable energy consumption, and fossil fuel energy consumption, and of a bi-directional causal relationship between urbanisation and all of the other variables, except for renewable energy consumption. Regarding this last variable, it only showed to have a uni-directional causal relationship with urbanisation (renewable energy consumption granger causes urbanisation, but urbanisation does not Granger cause renewable energy consumption). The results of the Granger causality Wald test can be seen in **Table 7** and **Figure 2**. Moreover, we should refer that in this study we verified the stability of the model (see **Table 8**) and computed both the FEVD (which indicated that the variables themselves explained almost all of their forecast error variance (with the exception of DLnRene) and the IRF's (which showed that all variables converge to equilibrium, which supports their stationarity). To see the results of the FEVD and the IRF's, see **Table 9** and **Figure 3**, respectively.

Turning to the discussion of the results, we can start by referring that the bi-directional causal relationship between economic growth, CO2 emissions and fossil fuels consumption that was found in this investigation is in consonance with the results of several previous authors (e.g., Faisal et al., 2018; Wang et al., 2018; Attiaoui et al., 2017; Mirza and Kanwal, 2017; Destek and Aslan, 2017; Koengkan 2017c; Destek et al., 2016; Sebri and Ben-Salha, 2014). The CO2 emissions are usually associated with the increase in fossil fuels consumption and with other energy-intensive economic activities. Indeed, fossil fuel sources are the primary inputs for agriculture and industry, which, subsequently, can affect both the economic growth and the environmental degradation of the countries' (Mirza and Kanwal, 2017). Based on these facts, it is understandable that the high dependency on fossil fuel sources demonstrates to have effects on both economic growth and CO2 emissions, as well as the other way around. Pablo-Romero and Jésus (2016) state that most Latin American economies are highly dependent on fossil fuels. It is a fact that increases the environmental degradation of this region. The inversion of this situation is not easy given that, as Fuinhas et al. (2017) stressed, some Latin American countries are major fossil fuel producers (e.g. Argentina, Brazil, and Venezuela), while others are significant importers (e.g. Uruguay and Paraguay).

Another relationship that was also confirmed by some previous literature is the bi-directional causal relationship between economic growth, emissions of CO2, and consumption of renewable energy (e.g., Attiaoui et al., 2017; Destek and Aslan, 2017; Koengkan 2017c; Destek et al., 2016). This causality implies that there is an interdependence between the consumption of renewable energy sources, economic growth, and CO2 emissions. The results from this study suggest that the Southern Common Market countries are converging to a greener economy, based on renewable energy without pollution (Attiaoui et al., 2017). The abundance of renewable sources (e.g., wind, solar, hydropower, photovoltaic waste, biomass, and geothermal) in most of these countries probably stimulates the development of renewable energy technologies and the investment in this type of energy, a fact which can positively affect their economies, as well as reduce their emissions (Fuinhas et al., 2017).

In this study, it was also found evidence on the existence of a bi-directional causal relationship between renewables and fossil fuels consumption, a result which was already confirmed in some previous studies (e.g., Apergis and Payne, 2012). This result shows evidence that these energy sources act as substitutes. The substitutability between these energy sources (renewable, fossil) suggests that the adoption of renewable energy may provide some relief from the CO2 emissions generated by fossil fuels consumption (Apergis and Payne, 2012).

The bi-directional causal relationship that was found between economic growth, CO2 emissions, fossil fuel consumption, and urbanisation, is also in line with part of the literature (e.g., Faisal et al., 2018; Wang et al., 2018; Franco et al., 2017; Koengkan 2017a; Sbia et al., 2017; Wang et al., 2016; Al-Mulali et al., 2012; O'Neill et al., 2012). The results from this investigation are in accordance with the idea that economic growth can lead to an increase in the urbanisation process, as also in energy consumption (fossil and renewable) and, consequently, in the CO2 emissions (Franco et al., 2017). These insights are in conformity with the results from Wang et al. (2016), which showed that the urbanisation process could markedly lead to more energy use, enhance economic growth, and increase CO2 emissions.

Finally, the uni-directional relationship between renewable energy consumption and urbanisation is also validated by the literature, with some authors stating that the low-use of renewable energy sources by households in developing countries can be the main reason for the existence of such relationship (e.g. Salim and Shafiei, 2014).

This section showed the empirical results as well as the possible explanations for the presence of these relationships in the Southern Common Market countries based on the ideas of several previous authors, a fact which reinforces the accuracy of the results. The conclusions that can be drawn from this study and their respective policy implications will be presented in the following section.

5. Conclusions and policy implications

In this study, the relationships between CO2 emissions, consumption of renewable and non-renewable energy sources, economic growth, and urbanisation, were investigated for five Southern Common Market countries in the period ranging from 1980 to 2014. A panel vector autoregression (PVAR) model was used to achieve this objective. The results of preliminary tests pointed to the presence of cross-sectional dependence and unit roots in the variables included in this investigation, as well as a low degree of multicollinearity between them. Moreover, the preliminary tests also pointed to the presence of fixed effects in the model and to the need to use one lag length in the PVAR estimation.

The PVAR model results showed that, in the countries from our sample, economic growth, fossil fuels consumption, and urbanisation contributed to the increase in CO2 emissions, while renewable energy consumption contributed to reducing them. They also showed that CO2 emissions, renewable energy consumption, and urbanisation, had growth depressing effects, while fossil fuels consumption was able to enhance the Southern Common Market countries economic growth. The results also support the idea that CO2 emissions and renewable energy consumption contributed to the decrease in fossil fuels consumption, whereas economic growth and urbanisation increased it. Moreover, this investigation also shows evidence that the urbanisation process and CO2 emissions decreased these countries renewable energy consumption, while economic growth and fossil fuels consumption increased it. Finally, the results point to that renewable energy consumption and CO2 emissions reduced the Southern Common Market countries urbanisation process, while economic growth and fossil fuels consumption increased it.

The Granger causality Wald test pointed to the presence of bi-directional causal relationships between economic growth, CO2 emissions, renewable energy consumption, and fossil fuel energy consumption, in these countries, as well as of a bi-directional causal relationship between urbanisation and all of the other variables (except for renewable energy consumption). The results of this test also showed evidence on the existence of a uni-directional causal relationship running from renewable energy consumption to urbanisation.

The specification tests showed that the PVAR model was stable, with the variables explaining almost all of their forecast error variance, except for renewable energy consumption which has a large part of its forecast error variance explained by the consumption of fossil fuels. Also, by the IRF's, it was observed that all variables converge to equilibrium in the long run, supporting the stationarity of the PVAR model. These results evidenced that the Southern Common Market countries are fossil fuels dependent and that the reduction in its consumption can produce depressing effects on their growth. Furthermore, from the estimations, it was also acknowledged that the Southern Common Market countries urbanisation process was highly linked with fossil fuels consumption, with the transport sector, construction sector, industry sector, and households, being the primary consumers of this kind of energy source.

Also, in this investigation, it was verified a possible substitution effect between renewable energy consumption and fossil fuels consumption, in periods of shortage in reservoirs, where the hydropower energy is substituted by thermoelectric plants (powered by fossil fuel sources). This substitutability between hydro and fossil reveals a low energy diversification in the Southern Common Market countries.

Additionally, it was also detected low renewable energy participation in the energy mix, due to its little impact on the reduction of both CO2 emissions and fossil fuels consumption, and by its negative effect on urbanisation and economic growth. All of these results reveal the scarce investment of the Southern Common Market countries on alternative energies.

Based on this study results, two questions were drawn: What should be made to improve the Southern Common Market countries current scenario? What policies should be applied to reverse this situation? This investigation suggests that this country should develop more public policies, incentives, credit with low-interest rates, and tax cuts for investments and consumption of renewable energy sources.

In a more detailed way, we think that they should develop public policies with the aim of promoting the creation of official public banks with low interest rates in order to finance projects in renewable energy, and policies that motivate the private financial institutions to give special loan discounts to firms interested in investing in renewable energy technologies or in the purchase of technologies that increase the energy efficiency and reduce environmental degradation. Moreover, these governments should develop measures that encourage the households to purchase solar or photovoltaic equipment, as also policies that incentive the decentralised generation (e.g. generate renewable energy by photovoltaic systems installed on the roofs of residences), which in Southern Common Market countries has virtually no support and consideration from their governments.

The former policies need to be implanted in order to reduce the dependency of these countries on fossil fuels, to reduce their environmental degradation, and to promote both economic growth and green development. This process can be facilitated, given that these countries can take advantage of their abundance of renewable sources (e.g., wind, solar, hydropower, photovoltaic waste, biomass, and geothermal). Beyond this strategies, it is also necessary that these countries institutions reduce their bureaucracy in order to encourage renewable energy foreign investments, and that they eliminate the political lobbies between their governments and significant polluter firms/fossil fuels producers, which creates barriers to the renewables penetration (e.g. end/limitate the fossil-fuel consumption subsidies).

Finally, we think that if the Southern Common Market countries do not make a deep reform regarding renewable energy, the region will continue to skid, plunged into a government discourse entirely out of touch with reality, and behind the significant renewable energy powers, such as China, United States, Germany, Japan, India, Italy, Spain, United Kingdom.

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