Universidade de Évora - Instituto de Investigação e Formação Avançada

Universidade da Beira Interior - Faculdade de Ciências Sociais e Humanas

Programa de Doutoramento em Economia

Tese de Doutoramento

Globalisation and the paradigm of renewable energy transition in the Latin American and the Caribbean (LAC) countries

Matheus da Costa Koengkan

Orientador(es) | Isabel Maria Pereira Viegas Vieira

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Dedicatória

Aos meus pais que com sacrifício tentaram me ajudar o máximo possível para manter a minha estabilidade necessária em Portugal para a realização do Doutoramento. Ao meu professor e amigo José Alberto Fuinhas que me ajudou dando abrigo e suporte quando mais precisava no decorrer da minha estada em Portugal e no processo de desenvolvimento da tese. Ao meu melhor amigo Fábio Sousa que sempre esteve ao meu lado em todo processo, me apoiando, incentivando e inspirando todos os dias. Sou muito grato a todos vocês, sem a vossa existência eu não seria nada. Muito obrigado!

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Preface

This thesis experienced several phases of development and maturation levels until reaching its final state. Indeed, the kick start of this thesis or the first investigation that approach the effect of globalisation on energy issues, began in 2017 at the University of Beira Interior in Covilhã – Portugal in my master's degree in Economics with the publication "**Is globalisation influencing primary energy consumption? The case of Latin American and Caribbean countries**" (1). From the results of this first investigation, emerged the curiosity and need to study in deep form the effects of this process on energy issues, mainly in the process of the renewable energy transition.

The second phase of deepening of this issue or second investigation that is the result of this curiosity approached this same effect but was used the trade openness index that is a proxy of globalisation. This investigation was entitled: "**The positive impact of trade openness on the consumption of energy: Fresh evidence from Andean community countries**" (2) at Energy Journal in 2018. This research was done in my PhD Study in Economics at the Federal Fluminense University in Niterói - Rio de Janeiro - Brazil that was interrupted. In this period, Professor Dr José Alberto Fuinhas and Professor Dr Luciano Dias Losekann were my doctoral advisors. From this second investigation, a series of studies were initiated, approaching the effect of the globalisation and their proxies on energy and environmental issues.

Several investigations arose from this research. For instance, based on **Chapter 2**, was investigated the effect of the globalisation process or their proxies on investment of renewable energy sources, one journal article that approaches this issue was published:

Koengkan M., Poveda Y.E., Fuinhas J.A., (2019). **Globalisation as a motor of renewable energy development in Latin America countries**. GeoJournal, p.1-12. doi: 10.1007/s10708-019-10042-0.

From the effect of globalisation or their proxies on the consumption of renewable and non-renewable energy consumption on **Chapters 3** and **4**, emerged two journal articles, one book chapter, and two conference papers, that approached these issues:

Notes (1): Koengkan M., (2017). Is globalization influencing primary energy consumption? The case of Latin American and Caribbean countries. Cadernos UniFOA, 12(33):59-69. ISSN:1809-9475.

Notes (2): Koengkan M., (2018).The positive impact of trade openness on the consumption of energy: Fresh evidence from Andean community countries.Energy,158:936-943. doi: 10.1016/j.energy.2018.06.091.

Koengkan M., Santiago R., Fuinhas J.A., (2019). **The impact of public capital stock on energy consumption: Empirical evidence from Latin America and the Caribbean region**. Workshop Program: Economic Development thinking the Environment. Faculty of Economics, University of Coimbra, 9-10 May 2019. URL: http://www.uc.pt/en/feuc/wsinfer2019/Program_File.

Koengkan M., Fuinhas J.A., Marques A.C., (2019). **The relationship between financial openness, renewable and non-renewable energy consumption, CO2 emissions, and economic growth in the Latin American countries: An approach with a PVAR model**. The Extended Energy–Growth Nexus 1st: Theory and Empirical Applications. Edition Publisher: Academic Press, 200-225. ISBN: 9780128157190.

Koengkan M., Fuinhas J.A., Vieira I., (2019). **A contribution of trade openness to the consumption of non-renewable energy sources in Latin American & Caribbean countries: a PARDL and PNARDL approach.** Efs Research Day 2019, Coimbra, Portugal, p.6. URL: https://agenda.uc.pt/wp-event/efs-research-day-29th-may-2019/.

Koengkan M., Fuinhas J.A., Santiago R., (2019). **The role of financial openness and China's income on fossil fuels consumption: Fresh evidence from Latin American countries**. GeoJournal, p. 1-15. doi: 10.1007/s10708-019-09969-1.

Koengkan M., (2018). **The positive impact of trade openness on the consumption of energy: Fresh evidence from Andean community countries**. Energy, 158:936-943. doi: 10.1016/j.energy.2018.06.091.

Based on **Chapter 5**, where was studied the effect of the energy transition on environmental degradation, four journal articles, one book chapter, and two conference papers, that approached this subject, such as:

Koengkan M., Santiago R., Fuinhas J.A., (2019). **The relationship between CO2 emissions, renewable and non-renewable energy consumption, economic growth, and urbanisation in the Southern Common Market**. Workshop Program: Economic Development thinking the Environment.

Faculty of Economics, University of Coimbra, 9-10 May 2019. URL: http://www.uc.pt/en/feuc/wsinfer2019/Program_File.

Koengkan M., (2019). **The Impact of Renewable Energy Policies on Carbon Dioxide Emissions in the Latin American countries-A PVAR approach**. Revista Brasileira de Energias Renováveis, 8(1):12-28. doi: 10.5380/rber.v8i1.49819.

Koengkan M., Santiago R., Fuinhas J.A., Marques A.C., (2019). **Does financial openness cause the intensification of environmental degradation? New evidence from Latin American & Caribbean countries**. Environmental Economics and Policy Studies, p.1–26. doi: 10.1007/s10018-019-00240-y.

Koengkan M., Fuinhas J.A. Losekann L.D., (2019). **The relationship between economic growth, consumption of energy, and environmental degradation: renewed evidence from Andean community nations**. Environment Systems and Decisions, 39(1):95–107. doi: 10.1007/s10669-018-9698-1.

Koengkan M., Fuinhas J.A., Marques A.C., (2019). **The effect of fiscal and financial incentive policies for renewable energy on CO2 emissions: the case for the Latin American region**. The Extended Energy–Growth Nexus 1st: Theory and Empirical Applications. Edition Publisher: Academic Press, p. 141-172. ISBN: 9780128157190.

Koengkan M., Fuinhas J.A., Marques A.C., (2018). **The Effect of Hydroelectricity Consumption on Environmental Degradation-The Case of South America region**. 3º Congresso de Engenharia e Ciências Aplicadas nas Três Fronteiras MEC3F-2018, 46-67. URL: http://mec3f.spo.ifsp.edu.br/.

Koengkan M., Fuinhas J.A., Marques A.C., (2018). **Does financial openness increase environmental degradation? Fresh evidence from MERCOSUR countries**. Environmental Science and Pollution Research, 25(30): 30508–30516. doi: 10.1007/s11356-018-3057-0.

After writing this thesis, more empirical results will be continued to generate. Moreover, it is planned to continue to disseminate these results in scientific conferences, and meetings in energy economics, environmental degradation, and globalisation fields. In this thesis was opted to use the structure of the compilation of the articles in order to accommodate some essays that were submitted in several international journals and others that were already published, such as:

- "**Effects of Financial Openness on Renewable Energy Investments Expansion in Latin American Countries**" published in The Journal of Sustainable Finance and Investment, p. 1-19, 2020. doi: 10.1080/20430795.2019.1665379.
- "**The Interactions Between Renewable Energy Consumption and Economic Growth: Fresh Evidence from the Mercosur Countries**" in under review process at The Journal of International Trade & Economic Development.
- "**The Reaction of the Consumption of Fossil Fuels to Trade Openness in Latin America & the Caribbean Countries**" in under review process in International Journal of Ambient Energy.
- "**The Asymmetric Impact of the Energy Paradigm Transition on Environmental Degradation of Latin America & the Caribbean Countries**" in under review process in Energy Sources, Part A: Recovery, Utilization, and Environmental Effects.

Moreover, this structure allows each essay developed to interacts with each other; that is the results found in the first essay will help in the development of second and so on.

Resumo

Esta tese investiga o efeito positivo da globalização no processo de transição energética nos países da América Latina e Caraíbas (LAC) e como esse impacto contribui para a mitigação das emissões de dióxido de carbono (CO2). No primeiro ensaio investiga-se o efeito positivo da abertura financeira no investimento em energia renovável, em um painel de dez países da América Latina com dados coletados para o período de 1980 a 2014. O modelo *Panel Autoregressive Distributed Lags* (PARDL) indica que a abertura financeira tem um impacto positivo de longo prazo no investimento em energia renovável. Os resultados da análise de causalidade de Granger indicam que existem vínculos causais bidirecionais de Granger entre todas as variáveis. O segundo ensaio estuda a relação entre o consumo de energia renovável, combustíveis fósseis, crescimento económico e globalização em cinco países do Mercosul entre 1980 a 2014. O modelo *Panel Vector Autoregression* (PVAR) e o teste de Granger Causality Wald indicam a presença de uma relação bidirecional entre consumo de energia (fontes renováveis e fósseis) para o crescimento económico. O processo de globalização nos países do Mercosul tem uma efeito positivo no consumo de energia renovável, enquanto no consumo de energia fossíl existe um efeito negativo. O terceiro ensaio abordou o impacto positivo da abertura comercial e negativo do consumo de energias renováveis sobre o consumo de energia fóssil para um painel de catorze países da LAC no período de 1990 a 2014. O modelo PARDL aponta que o impacto do crescimento económico e a elasticidade da abertura comercial contribuem para o aumento de consumo de combustíveis fósseis nos países da LAC. No entanto, o impacto e a elasticidade do consumo de energia renovável contribui para a diminuição do consumo de combustíveis fósseis. O quarto ensaio estuda o impacto assimétrico positivo da transição energética para as energias renováveis sobre a degradação ambiental de dezoito países da LAC no período de 1990 a 2014. O modelo *Panel Non-linear Autoregressive Distributed Lag* (PNARDL) indica que a assimetria positiva e negativa da relação entre a energia renovável e a energia fóssil no curto e no longo prazo tem impacto negativo de -0,0601, nas variações positivas, e -0,0792, nas variações negativas, no curto prazo; e -0,0281, nas variações positivas, e -0,0339, nas variações negativas no longo prazo.

JEL Codes: E6; F1;F40, F62; Q43;Q50.

Palavras-chave: Abertura comercial; Abertura financeira; América Latina e Caraíbas; Economia da energia; Econometria; Globalização; Investimentos; Mercosul; Macroeconomia; Transição energética.

Abstract

This thesis investigates the positive effect of globalisation on the process of the energy transition in Latin America and the Caribbean (LAC) countries and how this impact contributes to the mitigation of Carbon Dioxide (CO2) emissions. In the first essay investigates the positive effect of financial openness on renewable energy investment to this end, a panel of ten Latin American countries and data collected for the period from 1980 to 2014 were used. The Panel Autoregressive Distributed Lags (PARDL) model indicates that financial openness has a positive long-run impact on renewable energy investment. The results of the Granger causality analysis indicate that bi-directional Granger causal links exist between all the variables. The second essay studies the relationship between renewable energy consumption, fossil fuels, economic growth, and globalisation in five Mercosur countries from 1980 to 2014. The Panel Vector Autoregression (PVAR) model and the Granger Causality Wald test indicate the presence of a bi-directional relationship between energy consumption (renewable and fossil sources) for economic growth. The process of globalisation in the Mercosur countries has a positive impact on the consumption of renewable energy, while in consumption of fossil fuels has a negative one. The third essay approached the positive impact of trade openness and the negative impact of renewable energy consumption on the consumption of fossil fuels for a panel of fourteen LAC countries over the period from 1990 to 2014. The PARDL model points out that the economic growth and elasticity of trade openness contribute to increasing of consumption of fossil fuels in the LAC countries. However, the elasticity of consumption of renewable energy contributes to decreases of fossil fuels energy consumption. The fourth essay studies the positive asymmetric impact of the energy's paradigm transition on environmental degradation of eighteen LAC countries in the period from 1990 to 2014. The Panel Non-linear Autoregressive Distributed Lag (PNARDL) model indicates that the positive and the negative asymmetry of the ratio of renewable energy on fossil energy in the short- and long-run has a negative impact of -0.0601, on positive variations, and -0.0792, on negative variations, in short-run; and -0.0281, on positive variations, and -0.0339, on negative variations, in the long-run.

JEL Codes: E6; F1; F40, F62; Q43;Q50.

Keywords: CO2 emissions; Energy economics; Energy transition; Econometrics; Environmental degradation; Financial openness; Globalisation; Investment; Latin America & Caribbean; Mercosur; Macroeconomics; Trade openness.

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List of Acronyms

ARDL	Autoregressive Distributed Lags
B.C.	Before Christ
BRICS	Brazil, Russia, India, China, and South Africa
CAN	*Comunidad Andina*
CCS	Carbon Capture and Storage
CIPS	Cross-sectionally Augmented, Pesaran and Shin
CO2	Carbon Dioxide Emissions
COP21	2015 United Nations Climate Change Conference
CSD	Cross-Section Dependence
DK	Driscoll Kraay
DOLS	Dynamic Ordinary Least Squares
ECM	Error Correction Model
FDI	Foreign Direct Investment
FE	Fixed Effects
FEVD	Forecast Error Variance Decomposition
FMOLS	Fully Modified Ordinary Least Squares
FTAA	Free Trade Area of the Americas
G20	Group of Twenty
G7	Group of Seven
GDP	Gross domestic product
GHG	Greenhouse gas
GMM	Generalized Method of Moments
ICT	Information and communications technology
IEA	International Energy Agency
IMF	International Monetary Fund
IRENA	International Renewable Energy Agency
IRF	Impulse-Response Functions
Kt	Kiloton
Kwh	Kilowatt-hour
LAC	Latin America and the Caribbean
LCU	Local Currency Unit
LLC	Levin–Lin–Chu

MAIC	MMSC-Akaike information criterion
MBIC	MMSC-Bayesian information criterion
MENA	The Middle East and North African region
MG	Mean Group
MQIC	MMSC-Hannan and Quinn information criterion
MTOE	Million Tonnes of Oil Equivalent
NAFTA	North American Free Trade Agreement
NEG	Negative
NGOs	Non-Governmental Organisations
NHREC	Non-Hydroelectric Renewable Energy Consumption
NREC	Non-Renewable Energy Consumption
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Squares
PARDL	Panel Autoregressive Distributed Lags
PMG	Pooled Mean Group
PNARDL	Panel Non-linear Autoregressive Distributed Lag
POS	Positive
PVAR	Panel Vector Autoregression
R&D	Research and Development
RB	*Republica Bolivariana*
RE	Random Effects
TEC	Total Primary Energy Consumption
TREC	Total Renewable Energy Consumption
UAE	United Arab Emirates
UECM	Unrestricted Error-Correction Model
UN	United Nations
US	United States
US$	United States dollar
USAN	Union of South American Nations
VECM	Vector Error Correction Model
VIF	Variance Inflation Factor

Chapter 1

General Introduction

1.1. Introduction

This thesis arises in a moment in which the renewable energy transition has accelerated and becomes a policy arena, i.e. an area of concern for many governments. Energy transition does not arise in a vacuum. It was shaped and influenced over time by a broader shift and deep. The energy transition is not just about energy or change in energy sources or a simple replacement of technology for another more efficient. It is a paradigm shift that has been changing profoundly in the energy world, where there exists a change in the values of security, robustness, and reliability. Therefore, the existing energy systems that were rooted in these values have been replaced by new systems based on the values of sustainability, affordability, and flexibility, allowing new ways of producing and consuming energy (World Energy Council, 2019a, p. 5).

The literature does not offer a precise definition for "energy transition". Smil (2010) points out that the expression does not have a precise or widely accepted signification. However, it is often used to describe changes in the energy matrix from fossil to renewable sources. This change has been taking place progressively from an established energy system (fossil) to a new one (renewable). Such a transition can be analysed from a global perspective or a local one. Hauff et al. (2014) have used the "energy transition" term as a structural transformation in the energy sector, indicating a growing trend of the share of renewable energy sources combined with the promotion of energy efficiency to reduce the consumption of non-renewable energy. In this sense, it gives a clear objective of reducing environmental degradation. However, this definition is misinterpreted, reducing the conceptual scope of the term, consequently by emphasising one type of change, namely from non-renewable energy sources to renewable ones. There is no single energy transition but rather various local experiences.

Renewable energy transition and energy efficiency have been the two main international action priorities to mitigate the effects of global warming and climate changes (World Energy Council Report, 2019b, pp. 6-10). The two are related to the uncontrolled increase in the level of carbon dioxide emissions (CO2) that consequently have set off a worldwide alarm signal (Fuinhas et al., 2017). This increase is a significant contributor to greenhouse gas emissions (GHGs) and consequently, to global warming and climate change (Koengkan et al., 2019a). The three leading greenhouse gases that contribute to climate change are carbon dioxide (77%), nitrous oxide (8%), and methane (14%) (Khan et at., 2014).

The global GHGs, mainly the CO2 emissions, has been increasing since the 1970s (IPCC, 2014, p. 5). However, during the period between 1990 to 2014, these emissions grew most rapidly, from 33 megatons of CO2 equivalent (MtCO2eq) in 1990 to 48 MtCO2eq in 2014, an increase of 1,5% during this period (Bárcena et al., 2019, p. 19). Bárcena et al. (2019, p. 23), points out that 78% of this increase is related to the consumption of energy (69%) and industrial processes (9%). Khan et at. (2014) confirm this affirmation, indicating that most of these emissions emanate from the residential and industrial sectors that are a direct result of the consumption of energy. GHGs take place through direct emissions from the combustion of fossil fuels for cooking, heating, cooling, and providing power.

In Latin America and the Caribbean (LAC) region, the situation in this respect is no different from that of the rest of the World. GHGs had an increase of 0.7% between 1990 to 2014 (from 3,414 MtCO2eq in 1990 to 4,020 MtCO2eq in 2014). Indeed, 70% of this increase is related to the consumption of energy (35%) and changes in land use and forestry (35%) (Bárcena et al., 2019, p. 23). This has also been found by Koengkan et al. (2019a), where in the LAC region, the liquid fuels account for 60.8% of total CO2 emissions, with coal being only a modest contributor, with 7.6% in 2013.

Regarding the structure of GHGs in the LAC region, the energy sector had in 1990 a participation of 28%, change in land use and forestry 45%, agriculture 21%, industrial processes 2%, waste 4%, and boiler fuels 1%, while in 2014 the consumption of energy had a participation of 46%, agriculture 23%, changes in land use and forestry 19%, in industrial processes 4%, waste 6%, and boiler fuels 2% (Bárcena et al., 2019, p. 23). Despite the growth in emissions between 1990 to 2014, the region is a small contributor per capita to the world's GHG, accounting for about 11% of total global emissions (Fuinhas et al., 2017).

This increase of GHGs in the LAC region is directly related to economic growth in the region. The latter increases the consumption of energy and consequently, the emissions. According to World Bank Open Data (2019), the LAC's GDP per capita growth (annual %) had an average annual growth rate of approximately 1.44% between 1989 to 2014 (see **Figure 1.1A** in **Appendix A**, p. 200). In 1989 the GDP per capita (current US$) was US$ 2,319.10, and in 2014 it was US$ 10,405.50 (see **Figure 1.2A** in **Appendix A**, p. 200). This increase in GDP per capita is related to the structural and stabilisation programs imposed on Latin American countries by the International Monetary Fund (IMF). These programmes of adjustment are basically neoliberal policies that consist mainly of the complete opening of their economies to international capital and trade, reduction of public expenditures, deregulation of the economy, privatisation, the retreat of the role of the state, and the creation of appropriate conditions for foreign investment (Ahumada and Andrews,1998). The "commodity boom" that occurred between 2004 to 2014 has also accelerated the process of insertion of LAC economies with the rest of the World and the economic growth in the region (Carneiro, 2012).

The consumption of energy followed the same trend of GDP per capita growth, where according to World Bank Open Data (2019) in 1989 the electric power consumption (kWh per capita) was 1175,35 (kWh per capita), and in 2014 the consumption had reached 2155,70 (kWh per capita) (see **Figure 1.3A** in **Appendix A**, p. 201). Balza et al. (2016) point that the total energy consumption increased from 190 Million Tonnes of Oil Equivalent (MTOE) in 1971 to 610 MTOE in 2013, which is 220% higher than in the early 1970s and represented an average annual growth rate of 2.8%. Indeed, the transport and industrial sector accounted for more than 302 MTOE of this increase. Balza et al. (2016) complement yet that the transport sector has the largest share of energy use, increasing per year by around 3.5%, and reaching 210 MTOE in 2013. The energy consumption in the industrial sector followed the same way and grew 3% between 1971 to 2013. However, due to access to more efficient energy sources, the residential sector's share of total final consumption dropped from 29% in 1971 to less than 17% in 2013. The indication that the economic growth in the LAC region increases the consumption of energy was found by Koengkan et al. (2019a) where, between 1971 and 2013, the gross domestic product (GDP) from the LAC countries had an average annual growth rate of approximately 3.0%, while energy consumption grew about 5.4%. According to World Bank Open Data (2019) in 1989 70.84% of this electric power consumption comes from fossil fuels energy sources, and in 2014 this value reached 73.3% of the total of energy consumption (see **Figure 1.4A** in **Appendix A**, p. 201).

All this made clear the importance of the energy sector for initiatives to mitigate these emissions. Therefore, energy planning must consider a scenario of climate change, where it is necessary additional efforts directed to limiting the emissions from the energy sector, especially in developing countries such as the LAC countries, where there are expectations of an increase in the energy demand. Indeed, the renewable energy transition energy is a part of the solution, that will play an essential role in mitigating the energy consumption from fossil fuels that are responsible by GHGs emissions, environmental degradation and the global climate changes increase.

In the LAC region, the renewable energy transition began in the 1970s in Brazil with the *Proalcool* programme was started in 1975 after the first oil shock in 1973 (Gielen et al., 2019). This programme is a mix of policy instruments that evolve and are mainly used to substitute for imported petroleum and to address the needs of both supply and demand sides (Gielen et al., 2019; Solomon and Krishna, 2011). Moreover, this programme driving biomass-based ethanol demand, but the sector's long-term success continues to be impacted by economic cycles and changing government priorities (Gielen et al., 2019). Other initiatives of energy transition arose in the region in the same decade such as, the geothermal programme in Costa Rica in 1976 and Nicaragua in 1977 (Fuinhas et al., 2017), the development of large hydropower in Brazil and Paraguay in 1971-1984 with binational *Itaípu* dam and other small hydro projects (Flavin et al., 2014), and Argentina with biomass, biogas, hydropower plants, geothermal, wind, wave, and photovoltaic plants in 1998, and Venezuela (RB) with hydropower plants in 2001 (Koengkan et al., 2019c).

The Latin American 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% (Koengkan et al., 2018). Flavin et al. (2014) point that in the 1970s the participation of hydroelectricity (e.g., small and large hydro) in the total electricity generation in the LAC region was 55%, in the 1990s the participation increased to 67 %, and in 2013 the participation decreases to 51%. However, the share of electricity from hydro has declined since to the end of the 1990s due to the development of other energy sources from natural gas and new renewable energy sources (e.g., geothermal, solar, small hydro, wind, waste, and marine) (Flavin et al., 2014).

The new renewable energy sources have rapid growth since the end of the 1990s and in 2012 comprised only 9% of total installed power capacity in LAC region, where 4% biomass and waste, 3% geothermal, and 2% wind. Moreover, the installed capacity of these energy sources more than doubled between 2006 and 2012, where the installed capacity in 2006 was 11.3 gigawatt (GW) and in 2012 reached 26.6 GW. This increase was driven by biomass and waste make up most of this growth and by the significant development of small hydro and wind (Flavin et al., 2014). Indeed, this increase is a result of high investments that were made in renewable energy (e.g., marine, wind, solar, small hydropower, geothermal, solid biofuels and waste, and liquid biofuels), where in 2005 was 4.6 US$ Billion and in 2015 reached 16.4 US$ Billion (IRENA, 2016). In this period, the investments in renewable energy sources grew 13% between the 2000s and 2013 (Koengkan et al., 2019c). Moreover, according to World Bank Open Data (2019) the consumption of renewable energy in the LAC region was 32.43% of total energy consumption in 1990 and in 2014 reaches a value of 27.08% (see **Figure 1.4A** in **Appendix A**, p. 201).

This rapid expansion of renewable energy in the LAC region is associated to the fast process of globalisation in the region that exerts a positive impact on economic growth and consequently increase the energy demand and in order to meet the energy demand, new investments in renewable energy technologies are necessary (Koengkan et al., 2019c). Moreover, the globalisation also has facilitated the access to technological advances via trade and financial liberalisation that consequently contribute to the increase of renewable energy capacity in the region (Koengkan et al., 2019a). Namely, the financial development increases the capital stock and consequently reduces the cost of financing, facilitating the investment in renewable energy technologies (Koengkan et al., 2019a; Mazzucato and Semieniuk, 2018; Kim and Park, 2016; Sbia et al.,2014). This reduction in costs is one of the driving forces that encourage investment in renewable energy sources in recent years has been a significant reduction in their costs (Griffith-Jones et al., 2017). Furthermore, Mazzucato and Semieniuk (2018) indicate that financial development increases public and private capital stocks. However, they conclude that only public capital can promote renewable energy investment, as the private sector is more risk-averse in this context, and that public policies have not been capable of mobilising the private.

Additionally, the trade openness allows the developing countries to import energy-saving technologies, products and/or processes from developed countries that consume less energy. That is, in developing countries, the reduction of energy consumption is more visible than in developed countries because the developing countries have more capacity to absorb the transferred technologies than developed ones (Ghani, 2012). The economic integration in the Latin American countries allows access to new energy technologies and consequently adopted them in their industries. However, this technology transfer to renewable energy in the Latin America region depends on the production and absorption capacity and the path dependency of significant investment in new technologies (Koengkan et al., 2019a).

However, this globalisation mentioned before is defined by Dreher (2006, p.1092) as:

> "The process of creating networks of connections among actors at multicontinental distances, mediated through a variety of flows including, goods, capital, people, information and ideas. Moreover, this process erodes national boundaries, integrates national economies, cultures, technologies, governance, and consequently produces a complex relation of mutual interdependence."

Based on the definition of Dreher (2006), one can understand that the globalisation has some dimensions such as economic, social, and political. Indeed, the globalisation that we view today is the reflection of the intensity of contact of these dimensions at such large distances.

Scholte (2008, p.1473) has suggested that globalisation differs from similar concepts (e.g., internationalisation, liberalisation, universalisation or Westernisation). Internationalisation refers to an increase in transactions and interdependencies between countries or nations (Gygli et al., 2019). Scholte (2008, pp. 1473-1474), add yet that a more global world is one, where more investments, money, merchandise, ideas, messages, pollutants and people cross borders between national-state-territorial units. Liberalisation is the process of removing officially imposed restrictions on movements of resources between countries or nations (Gygli et al., 2019). This explanation agrees with the vision of Scholte (2008, pp. 1473-1474), where the globalisation occurs as authorities reduce or abolish regulatory measures such as foreign-exchange restrictions, trade barriers, visa requirements, and capital controls.

Universalisation is the process of dispersing of various objects and experiences to all people in the World (Gygli et al., 2019). Scholte (2008, p.1476), explains that the "global" means "worldwide" and "everywhere". Therefore, exist a worldwide "universalisation" of culture, economy, and politic. Moreover, there exist the Westernisation that is interpreted as a type of universalisation, in which the social structures of Western societies are spread worldwide and destroying the pre-existent cultures and local self-determination (Gygli et al., 2019). Scholte (2008, p. 1477), complements that the phenomenon of Westernisation as colonisation, Americanisation and "westoxification". Although all these concepts are close to each other and occasionally used interchangeably, it is difficult to achieve a clear and simple concept that could be helpful. By this reason, we agree with the explanation of Figge and Martens (2014, p. 878), that the distinction of all these concepts are not necessary when a multiscalar and pluralistic concept of globalisation is used.

In the LAC region, this process of globalisation began with the trade and financial liberalisation in the 1970s in Chile with the profound shift toward free-market economies during the dictatorship of Pinochet (Ahumada and Andrews, 1998, p. 452). On the other hand, in many other countries from the region, the implementation of the neoliberal economic model has taken place during the process of the "Washington consensus" that is a combination of measures to promote the "macroeconomic adjustment" and by "Brady plan" that is an external debt restructuring plan (Koengkan et al., 2019b). This adjustment occurred between 1989 and 1992, where Costa Rica and Mexico in (1989), Venezuela (RB) (1990), Uruguay (1991), Argentina (1992), and Brazil (1992) passed schemes of deep trade and financial liberalisation, with the privatisation of significant portions of the public sector, liberalisation of foreign investment, reduction of import barriers, and with the development of economic stabilisation programs (Aizenman, 2005; Vásquez, 1996). These schemes were developed in order to put the LAC economies "back on track" (Koengkan et al., 2019b). Indeed, before this adjustment, the average annual compound growth rate approximately was about -0.5% between 1980 to 1989 and after with "macroeconomic adjustment", the LAC's GDP per capita had an average annual compound growth rate of 2.2% between 1989 to 1994 (Hofman, 2000, p. 32). In the 1990s, as mentioned before, the LAC region grew and integrated into the World. Indeed, in the first half of the 1990s, most of LAC countries adopted unilateral opening policies, reducing their tariffs and eliminated other trade restrictions. Moreover, in this period several regional agreements within the framework of *Asociación Latinoamericana de Integración* (ALADI) were strengthened, for example, Mexico joined North American Free Trade Agreement (NAFTA), the Common Market of the South (Mercosur) was created. Between 1990 to 1999, the LAC imports grew at an average rate of 11% while its exports increased at an average rate of 8.1%, improving its share in world trade (Terra, 2003, p. 138). Hence, the trade-in LAC region in the 1990s has been characterised by imports growing at rates highly superior to those of exports. It should be recalled that imports had been drastically reduced in the wake of the debt crisis that followed the Mexican financial crisis of 1982 (Ventura-Dias et al., 1999, p. 20). Then, in this period the imports had a vital role to play in the modernisation of the production process, where the modern machines and better industrial inputs contribute to the technological upgrading of the industrial basis in the region (Ventura-Dias et al., 1999, p. 20). According to World Bank Open Data (2019) in 1989 the Trade (% of GDP) in the region was 31.7% and the end of 2003 the value arose to 42.8% (see **Figure 1.5A** in **Appendix A**, p. 202), an increase of 35.01% between 1989 to 2003.

The financial liberalisation in the LAC region followed the same way of trade liberalisation, where the inflow of capital in the LAC region resumption after the Brady plan in the early 1990s. The magnitude of the financial liberalisation in the LAC region can be grasped with the index of capital mobility, where in the 1980s the index capital mobility was 40 and in 1990s arose to about 75 in a normalising completely free capital mobility at 100 (Aizenman, 2005, p. 4). Moreover, the financial liberalisation caused by Brady plan promoted the entrance of Foreign direct investments (FDI) flows. The FDI flows in worldwide have grown dramatically between 1990 to 1997. Indeed, were the developing countries that received the most of these flows, where their share of these flows was 15% in 1990 and reached a value of 38% in 1997. In Latin America was no different; these flows have an increased from US$ 8 billion in 1988 to $55.3 billion in 1997 (Birch and Halton, 2008, p. 15). The increase of FDI flows in the region aligns with World Bank Open Data (2019), where in 1989 these flows were US$ 18 billion and reached a value of US$ 93 billion in 2003 (see **Figure 1.6A** in **Appendix A**, p. 202).

The FDI inflows to the LAC region in the 1990s have evolved in three phases (Birch and Halton, 2008, p. 18). Between 1990 to 1993, the investors have seemed to favour acquiring already existing assets. However, between 1994 to 1996, the majority of the investment was directed to large scale projects via restructuring of existing foreign firms or modernising recently privatised firms. In 1997, the acquisition of existing assets, this time to consolidate the market power became the most common form of foreign investment in the region. In this period, more money was spent on the purchase of already existing private assets than on privatisation.

Moreover, during the 1990s, the LAC region had registered an increase in FDI in the industries related to natural resources and energy sector (Birch and Halton, 2008, pp. 18-20). For example, in Argentina between 1990 to 1996, the energy sector, gas and water industry was the leading FDI recipient, where the country received 26%; the petroleum and natural gas industry received 15%, the chemical products industry sector 11%; food, beverages and tobacco and financial services, each with a 10%; Brazil in 1990, the chemical industry accounted for 14% falling to 11% in 1995. Between 1996 to 1997, the investments in electricity, water, and gas soared to 23% of total FDI inflows, mainly due to privatisation over the last three years. The financial sector accounted for 10%, reflecting the restructuring of the Brazilian banking system; Chile accounted for 47% of total FDI inflows between 1974 to 1996 in the mining and quarrying sector. Other services received 25% while manufacturing received 16% of all inflows between 1990 to 1996. The energy, gas, and water sector soared from a 3% share between 1990 to1996 and reached 27% in 1997. This change is due to the large part to the acquisition of part of the Chilean electric company Enersis by the Spanish company Endesa-España; Mexico received 49% of inflows between 1981 to 1993, and that was evenly divided between manufacturing and services sector.

Indeed, between 1994 to 1996 the machinery and equipment sector received 24% of these inflows, reflect of the substantial investment in the automotive, electronics and electrical equipment industries. The food, beverages and tobacco sector received 12%; the finance and insurance sector 11% and other services received 10% of these inflows. In 1997, food, beverages and tobacco received 36 % of the total of these inflows. Indeed, the entrance of these FDI inflows during the 1980s to 1990s for the energy sector in Latin America reduced the high investment and maintenance costs of renewable energy projects via public-private partnerships (PPP) in order to narrow the gap in financing (Coviello et al., 2012). The reduction of these costs increased the generation of electricity from renewable energy plants, where the electricity generation from the small and large hydro dam in the LAC region was 55% in the 1970s and reached 67% in the 1990s as mentioned before by Flavin et al. (2014).

However, this process of globalisation that began in the 1970s by trade and financial liberalisation intensified with “commodities boom” that occurred between 2004 to 2014, where the region had an average growth rate of 7.40% (Santos, 2015). According to Carneiro (2012), the cycle of commodity prices on Latin American economies impacted the degree of economic openness or more precisely, in the degree of dependence of external demand *vis-à-vis* domestic demand or markets. The same author complements that between 1990 to 1993 the degree of economic openness was 28.6, between 1998 and 2001 was 38.5, and between 2006 to 2009 was 44.7 in a scale of 0 until 100, where 100 represent an economy open. That is, in this period between 1990 to 2009, the degree of economic openness had a growth grows 50.71%.

Furthermore, this fact seems to have allowed the region to surpass the problems generated by the 2008-2009 financial crisis (Koengkan et al., 2019b). Indeed, the growth in the degree of economic openness was caused by an increase in the exports and imports in the region, where according to World Bank Open Data (2019) in 2004 the exports of goods and services (BoP current US$) was US$ 1,091.28 and reached a value of US$ 2,218.43 in 2014, while the imports in 2004 was US$ 983,47 and reached a value of US$ 2,348.50 in 2014 (see **Figure 1.7A** in **Appendix A**, p. 203); and by increase in FDI inflows ,where according to World Bank Open Data (2019) in 2004 the FDI inflows in the region was US$ 193 Billion and reached a valued of US$ 420 Billion in 2014 (see **Figure 1.6A** in **Appendix A**, p. 202). Indeed, according to ECLAC (2018), the growth in the manufacturing sector caused by commodities boom led the FDI inflows in the largest economies in the region, where 61% of total FDI inflows in Mexico and 38% in Brazil. The renewable energy sector received 5% of these FDI inflows from 2005 to 2007. However, it was from 2015 to 2017 that this sector that the main recipient of new FDI inflows, receiving 26% of these inflows. The investments in new renewable energy, domestic and foreign, in 2017reached US$ 6.2 Billion each in Brazil and Mexico, US$ 1.8 Billion in Argentina, and US$ 1.5 Billion in Chile. Most projects in these countries have involved foreign companies. Moreover, most of these investments were made in the solar (35%) and wind (32%) technology between 2005 to 2017.

These two phases in the process of insertion of LAC economies that occurred between 1989 to 1992 and 2004 to 2014 influenced the degree of globalisation of economies of the region. The KOF Globalisation index, created by Dreher (2006), measures globalisation, based on economic, social and political dimensions on a scale from 1 to 100, where 100 indicate a country totally globalised, indicates that in 1989 the degree of globalisation *De facto* in the LAC region was 43.80, and reached a value of 60.5 in 2014, an increase of 38.12% between 1989 to 2014 (see **Figure 1.8A** in **Appendix A**, p. 203). Moreover, as can observe the process of renewable energy transition followed the same trend of the globalisation process, where according to IEA (2018) in 1989 the installed capacity of renewable energy from biomass, hydropower, solar, photovoltaic, wind, wave, and waste in million kilowatts was 12,935 (Million Kilowatts), and reached a value of 38,648 (Million Kilowatts) in 2014 (see **Figure 1.9A** in **Appendix A**, p. 204). Indeed, the increase in the renewable energy exerts a positive effect on environmental with the reduction of CO2 emissions from the consumption of fossil fuels that are responsible for environmental degradation, global warming, and climate change (Koengkan et al., 2019d).

1.2. Research questions

The evidence that the renewable energy transition followed the same trend of the globalisation process in the LAC region as mentioned before, motivated the realisation of the following central question of this thesis – **Does the process of the renewable energy transition in the LAC countries is influenced positively by globalisation?** – In literature, the effect of globalisation on renewable energy transition has been few explored. Koengkan et al. (2019a) point out that the current literature has focused on understanding the influence/or effect of globalisation in a specific industry or at the national level and left aside the issue of how globalisation impacts the renewable energy progress. In the globalisation literature, includes a diversity of sub-topics, for example, economics, energy, culture, social relations, politics, migration, and technology (Overland, 2016). However, specifically renewable energy topic is lacking in the globalisation literature (Koengkan et al., 2019a).

Also, in the energy economics literature, this topic is lacking, although the conclusions about the link between energy and globalisation are not recently (Koengkan et al., 2019a). Indeed, Sovacool (2014), with their seminal work, investigated the state of art of energy studies and recognised that there is a lack in the literature about the relationship between globalisation and renewable energy. As mentioned by Overland (2016), the existing literature about energy and globalisation is vast. However, exist few studies in the literature that approaches specifically globalisation and renewable energy transition.

Of these few studies in the literature that investigated approximately about this topic have explain the effect of globalisation or their proxies (e.g., FDI, trade openness, trade liberalisation, financial development, financial openness, financial liberalisation, KOF Globalisation index, exports and imports) on renewable energy or their proxies (e.g., Installed capacity, consumption and production of renewable energy sources, and also renewable energy technologies) (e.g., Koengkan et al., 2019a; Mazzucato and Semieniuk, 2018; Roubaud and Shahbaz, 2018; Koengkan, 2018; Bosupeng, 2017; Koengkan, 2017; Kim and Park, 2016; Dogan and Deger, 2016; Al-Mulali and Ozturz, 2015; Sbia et al., 2014; Rodríguez et al., 2014; Sadorsk, 2012; Dong, 2012; Jenner et al., 2013). These studies are part of a big puzzle about this topic that needs to be assembled in order to explain this phenomenon. However, exist missing pieces in this puzzle that are related to the lack of explanations about the impact of globalisation on renewable energy progress as well as to their effects on environmental degradation.

In order to answer the central question of this thesis, and contribute to the construction of this puzzle about this topic, some specific questions were made. Those questions were based on three aspects related to renewable energy transition (e.g., investment, consumption of energy, and environmental degradation), that are interconnected to each other. Indeed, these specific questions focused on three aspects are related to the investment of renewable energy, consumption of renewable and fossil energy, and CO2 emissions. For example, we have four questions that need an answer. **(a) Does financial openness encourage investment in renewable energy in Latin American countries?** If financial openness encourages investment in renewable energy sources. These investments will increase economic growth and consequently, the energy demand. **(b) Does globalisation exert a positive impact on the consumption of renewable energy and negative impact on the consumption of fossil fuels in Mercosur countries?** If the globalisation encourages the investment in renewable energy sources and consumption of renewable energy, and decrease the consumption of fossil fuels. **(c) Does renewable energy consumption exert a negative effect on the consumption of fossil fuels in LAC and Mercosur countries?** Finally, if the globalisation and renewable energy consumption decrease the consumption of fossil fuels by investment and consumption of renewable energy, consequently reduces environmental degradation. **(d) Does the process of renewable energy transition encouraged by globalisation decrease the environmental degradation in the LAC countries?** In this specific question will be made the confirmation if renewable energy transition encouraged by globalisation mitigate the environmental degradation, as mentioned by Hauff et al. (2014).

1.3. Objective of this thesis

The main objective of this thesis is to identify the positive effect of globalisation on renewable energy transition in LAC countries. However, to identify this positive effect, it is necessary to the realisation of in-depth analysis in three aspects through the empirical studies and by literature review. This analysis is based on four specific questions created from three aspects. Beyond the main objective, this thesis has four specific objectives that will allow achieving the main objective, as well as contribute to the construction of this puzzle about this topic. Therefore, the first specific objective of this thesis is to assess the positive effect of financial openness on renewable energy investment diffusion in Latin American countries. Second, to assess the positive effect of globalisation in interactions between consumption of renewable energy and economic growth, as well as the negative effect of globalisation and renewable energy on the consumption of fossil fuels in the Mercosur countries. Third, to assess the positive reaction of the consumption of fossil fuels to trade openness and negative reaction from renewable energy consumption in LAC countries, as well as extend and confirm some results from the analysis carried out before. Fourth, to assess the negative effect of the renewable energy transition on environmental degradation in the LAC countries, as well as extend and confirm some results from the analysis developed before. Moreover, of these four specific questions originated four empirical essays that will answer each raised specific question and the central question of this thesis.

1.4. Motivation of this thesis

The motivation that promotes the realisation of this thesis is related to the process of globalisation of LAC countries that have been represented by numerous integration associations, trade blocs, free trade agreement, and trade, financial and economic liberalisation have growth in the last thirty years. This process of integration and openness with the rest of the world is a potential factor that induces higher economic growth and consequently, the consumption of energy and environmental degradation.

However, the LAC countries have adopted mechanisms with the purpose of reducing the consumption of non-renewable energy and CO2 emissions caused indirectly by globalisation. For this reason, it is necessary to understand how this same globalisation interacts with these mechanisms; in other words, “renewable energy transition”. That is, to show that the globalisation can help the process of economic transition from one based on hydrocarbon consumption to one based on renewable energy sources, as well as their contribution in reducing the environmental degradation.

The realisation of this thesis becomes stronger in a moment that protectionist and anti-globalisation movements have been growing significantly in the entire world that began in the 1990s and intensified after the global financial crisis that occurred in 2007-2008. Moreover, in the last years the role of the globalisation and their impact in related issues, such as energy, environment, income, and inequality, have been discussed in several international forums and initiatives, for example (e.g., G20 (Group of Twenty) Buenos Aires summit 2018, World Economic Forum Annual Meeting 2018 in Davos; and COP21 (2015 United Nations Climate Change Conference) in Paris in 2015).

1.5. Innovation and contributions of this thesis

This thesis uses well-established and relatively new methodological approaches to produce innovative and relevance empirical analysis in all three aspects considered. This thesis contributes to energy economics, environmental economics, and globalisation literature with four inter-related essays on renewable energy transition and globalisation. Moreover, this thesis adds knowledge to specific streams of energy economics, environmental economics, and globalisation literature that are explored in each of the four essays.

The first essay is innovative and adds to the literature in various ways. For instance, by considers financial openness as globalisation measures in order to identify their effect on the installed capacity of renewable energy; by the use of fixed effects techniques in order to explain how the interactions of Latin American countries with the rest of the world act on the development of renewable energy technologies via financial markets; by utilisation of Panel Autoregressive Distributed Lags (PARDL) in the form of a Unrestricted Error-Correction Model (UECM) as a general model, and a Panel Vector Autoregression (PVAR) model and a Panel Granger causality Wald test as robustness checks; by focusing on Latin America and investigates a group of countries not previously considered in similar research efforts; by being added the value “1” to the variable financial openness index , and its subsequent logarithmisation, where allows us to capture the effect of a per cent changes this variable on a per cent change in the installed capacity of renewable energy; and by the inclusion of shift-and impulse dummies to test the robustness of models to economics, political or social shocks. This approach, it is not common in similar studies.

The second essay is pioneering and contributes to the literature for several reasons. For example, it considers the possible overall impact of the globalisation process. Previous studies have considered economic growth, investment, trade and industrial production to explain the increasing consumption of energy, but have not used a comprehensive globalisation indicator. Nevertheless, globalisation’s many facets are potential drivers of economic growth and may thus exert significant impacts on energy consumption; By the use of the PVAR model as the basis of the econometric analysis. Other studies have examined the causal link of interest with models such as Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS) or PARDL; and by the geographical focus of the analysis, as previous studies addressing this topic, did not study the Mercosur countries.

The third essay is innovative by the combination use of PARDL model in the form of UECM as our central model estimation, and a Panel Non-linear Autoregressive Distributed Lag (PNARDL) model as the robustness check of the results. Moreover, this essay contributes to the literature for several reasons. First, it sheds light on how economic growth and trade openness increases the consumption of fossil fuels in the LAC. Second, it shows how the consumption of renewable energy decreases the consumption of fossil fuels. Third, the empirical results of this essay have critical consequences for governments and policymakers with respect to the current model of trade openness, where LAC countries do not take advantage of liberalisation to bring more investment that encourages the Research and Development (R&D) in energy efficiency technologies, and equipment that reduces the consumption of energy. Moreover, this study is an opportunity for policymakers and governments to reflect on the current mechanisms that are used in trade liberalisation and which are not beneficial for the environment. Fourth, this study can open a new field of research about the effects of trade openness on technological progress in the energy sector, in order to identify whether the process of trade liberalisation brings energy efficiency and encourages the process of the energy transition.

The fourth essay is innovative because the study of the effect of the renewable energy transition on environmental degradation requires the use of new variables that are few explored by literature. For instance, the creation of ratio of renewable energy variable that measure the process of energy transition, the imports of Information and communications technology (ICT) goods imports in (current US$) variable that measure the imports of information and communication technology goods in order to identify the effect of globalisation on technological efficiency, and the renewable energy policies variable in accumulated form, where each policy that was created is represented by (1) accumulated over other policies throughout its useful life /or end (e.g. 1, 1, 2, 2, 2, 3, 3, …); and by the use of shift-and impulse dummies to test the robustness of models to economics, political or social shocks as mentioned before.

Therefore, thee essays in this thesis have already been submitted for publication in different journals, and one essay has been published. For this reason, although they read as independent items, they display a degree of repetition on an overall assessment.

1.6. Structure

The organisation of the thesis is as follows: this introduction is followed by four chapters with the described empirical essays. **Chapter 2** contains the study of the impact of financial openness on the expansion of renewable energy investment. **Chapter 3** contains the study of the role of globalisation in interactions between renewable energy consumption, economic growth, as well as consumption of fossil fuels. **Chapter 4** assesses the reaction of the consumption of fossil fuels to trade openness and renewable energy consumption. **Chapter 5** comprises the asymmetric impact of the energy paradigm transition on environmental. Finally, **Chapter 6** presents the conclusions remarks and policy implications of this thesis.

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Chapter 2

Effects of Financial Openness on the Expansion of Renewable Energy Investment in Latin American Countries

Abstract

This chapter investigates the impact of financial openness on renewable energy investment in Latin American countries in the period from 1980 to 2014. To this end, a PARDL model in the form of a UECM is estimated, and robustness checks and causality analysis are performed with a PVAR model and a Panel Granger causality Wald test. The PARDL estimates indicate that financial openness has a positive long-run impact on renewable energy investment, proxied by the installed capacity of renewable energy. Such investment is also positively affected by per capita economic growth (in the short run) and by per capita general government's capital stock (in the long run). The robustness assessment confirms positive causalities between per capita economic growth, financial openness and per capita general government capital stock. The results of the Granger causality analysis indicate that bi-directional Granger causal links exist between all the variables in the model.

JEL Codes: F40, F62; Q43.

Keywords: Energy economics; Econometrics; Financial openness; Investment; Renewable energy; Latin America.

2.1. Introduction

This chapter assesses the impact of financial openness on the dissemination of renewable energy investment in Latin American countries. Non-renewable resources, such as coal and oil, have long been used as sources of energy and were considered key for long-term economic growth. However, the intensive use of such resources has adverse environmental consequences, among other things fuelling climate change. In order to achieve sustainable development without compromising the environment, it is crucial to be able to count on reliable, affordable and economically viable renewable energy services (UN Commission on Sustainable Development, 2007). To this end, financial funds are required, and thus, financial liberalisation may play a significant role.

The development of renewable energy sources enhances the diversification of the energy matrix and mitigates the consumption of non-renewable energy resources and CO2 emissions while increasing energy security (Rifkin, 2011). The improvement of renewable energy technologies is considered an ideal solution for achieving sustainable development without degrading the environment. Many countries have been promoting the development of renewable energies.

In Latin America, the process began in the mid-1970s, in Brazil with hydropower plants in 1973 and biofuels in 1975; in Uruguay and Paraguay with hydropower plants also in 1973, followed by Argentina with biomass, biogas, hydropower plants, geothermal, wind, waves and photovoltaic plants in 1998, and Venezuela (RB) with hydropower plants in 2001 (IRENA, 2016). In Latin America, the consumption of energy from renewable sources represented 35% of the total energy consumption in 2013 (Koengkan, 2018), and investment in renewable energy sources grew by 13% between 2000 and 2013 (Koengkan et al., 2019).

The increase of investment and consumption of renewable energy is related to the rapid process of economic growth, financial liberalisation, and capital stock accumulation resulting from several economic reforms and political transitions in the last forty years which, to some extent, are still ongoing in the region (Koengkan et al., 2019). Latin American countries' per capita GDP has registered average annual growth rates of approximately 3.0%. The consumption of energy has followed a similar path, evolving from a value of 471,53 (kWh per capita) in 1970 for 2155,70 (kWh per capita) in 2014

(World Bank Open Data, 2019). Between 1971 and 2013, the consumption of energy grew by approximately 5.4% (Balza et al., 2016).

Financial liberalisation in Latin America has undergone distinct stages. In the 1960s, a period of import-substitution industrialisation economic policies with state control over the financial sector prevailed, leading to significant financial costs related to the mismanagement of public banks and atrophied financial systems (La Torre et al., 2012).

The 1980s, a period of economic stagnation and accelerated inflation coined “the lost decade”, which comprised the 1982 to 1989 debt crisis (Aizenman, 2005) and witnessed changes in the management of economic policies. The Brady plan, designed in the US to address Latin America’s debt crisis, restored the inflow of foreign capital to the region in the early 1990s. A set of comprehensive economic reforms were pursued. For example, Argentina, Brazil and Mexico introduced economic stabilisation programmes and initiated a process of trade and financial liberalisation with the privatisation of some state-owned companies (Aizenman, 2005). The adoption of such reforms boosted capital mobility in Latin America (from about 40% in the 1980s to 75% in the 1990s) (Aizenman, 2005).

These developments motivated the central question of this chapter: What is the effect of financial openness on renewable energy investment diffusion in Latin American countries? The more specific issues resulting from this main interrogation are:

(a) What are the possible explanations for the identified effects?

(b) What is the causality nexus underlying the links between the assessed variables in Latin American countries?

To answer such questions, the impact of financial openness on the installed capacity of renewable energy will be examined using a dataset comprising ten Latin American countries in the period from 1980 to 2014 and using PARDL in the form of UECM. A panel PVAR model and panel Granger causality Wald tests are used as robustness tests. This chapter is innovative and adds to the literature in various ways:

(a) it considers financial openness as globalisation measures in order to identify their effect on the installed capacity of renewable energy aiming at explaining the diffusion of investment in this kind of source;

(b) The use of fixed effects techniques in order to explain how the interactions of Latin American countries with the rest of the world act on the development of renewable energy technologies via financial markets. Of the few investigations that exist, none approaches the short- and long-run effects of these interactions;

(c) it uses PARDL in the form of a UECM as a general model, and a PVAR model and a Panel Granger causality Wald test as robustness checks; and

(d) It focuses on Latin America and investigates a group of countries not previously considered in similar research efforts. Previous assessments have solely studied countries in Asia, the Middle East and Europe. Latin America is of interest not only because it was not studied before, but also for its social, political and economic specificities that may help to explain the relationships between the variables of interest in this chapter. Other than its academic interest, our empirical analysis is also of use for Latin American policymakers as it may help in the design of effective policies aimed at promoting the development of renewable energy technologies.

After these introductory remarks, the chapter is organised as follows: **Section 2.2** reviews the relevant literature; **Section 2.3** presents the data and the adopted methodology; the results of the empirical analysis and the robustness checks are presented in **Sections 2.4** and **2.5**, respectively, and discussed in **Section 2.6**; and **Section 2.7** concludes and debates policy implications.

2.2. A brief debate on the effect of financial openness on renewable energy investment

The impact of financial openness on the diffusion of renewable energy investment has not received much attention from researchers, and the scarcity of academic studies impairs understanding of how the two interact. In the few existing assessments, the choices for the dependent variables have been the consumption and/or the production of renewable energy, renewable energy technologies, and the installed capacity of renewable energy, whereas financial development, financial flows and FDI are examples of independent variables (e.g., Mazzucato and Semieniuk, 2018; Roubaud and Shahbaz, 2018; Kim and Park, 2016; Sbia et al., 2014; Rodríguez et al., 2014).

Distinct proxies have been chosen for investment in renewable energies, and no consensus has been reached concerning the best choice in this regard. Concerning financial openness, the proposal of a financial openness index by Chinn and Ito (2008) has increased the number of proxy possibilities.

The absence of studies considering financial openness as a possible determinant of the diffusion of renewable energy investment leads to the consideration of proximate analyses when attempting to survey the relevant literature. This is the case, for instance, of Kim and Park (2016), who investigated the effects of financial development on the expansion of the renewable energy sector. The authors used ordinary least squares (OLS) and considered a sample of data comprising thirty countries and the period from 2000 to 2013. They concluded that financial development promotes renewable energy investment by reducing financing costs and overcoming adverse selection and moral hazard problems, an impact that is especially relevant for energies which are more intensive in capital, and therefore more dependent on external funds.

Mazzucato and Semieniuk (2018) studied the influence of public and private financing of renewable energy projects in China, Spain, the US and Kenya, from 2004 to 2014. Although both sources appeared to be relevant, the authors suggested that a finer distinction of funding suppliers would be needed to understand their importance fully. The study also pointed out that financing by public investors had played an increasingly significant role in the development of renewable energy technologies in the countries assessed and that it was the sole reason for the growth of asset financing in that context. In comparison with private investors, public actors tended to choose higher-risk technologies. Rodríguez et al. (2014) added that public investment supported renewable energy projects that failed to attract private financing and that public policies appeared to have had a small impact on mobilising the financing capacity of the private sector.

Sbia et al. (2014) investigated the impact of FDI, renewable energy, trade openness, CO_2 emissions and economic growth on energy demand in the United Arab Emirates. The study covered the period between 1975 and 2011, and the methodologies implemented were ARDL bounds testing and vector error correction model (VECM) Granger causality. Results suggested that FDI had a positive impact on renewable energy consumption via financial development. The latter boosted public and private capital stocks, decreased financing costs and stimulated economic activity and, subsequently, the consumption of renewable energy. These results confirm those of Kim and Park (2016).

Other authors, as Koengkan et al. (2018), Shahbaz et al. (2013), and Islam et al. (2013), concur in defending that reduced financing costs resulting from financial openness increase households' purchasing power and firms' investment. Both of these stimulate economic activity and, subsequently, the consumption of energy. In order to meet such increased demand, new investment in renewable energy is required. Financial openness, therefore, exerts an indirect positive impact on the development of renewable energies.

This review of studies on proximate topics indicates that various questions are still unanswered. The first and most significant gap in the literature is the absence of studies addressing the impact of financial openness on renewable energy investment diffusion. Indeed, apart from the previously cited analyses, there are studies focusing solely on the effects of financial development on the consumption of energy.

The possible relationship between financial openness and the installed capacity of renewable energy is thus still unexplored. The second identified gap is the non-consideration of the stock of public capital as a determinant of the diffusion of renewable energy. Another gap, which naturally runs from the small number of empirical analyses, is the limited methodological spectrum of existing research. For instance, the ARDL approach in the form of the UECM model was not previously considered. Moreover, due to the inexistence of studies that approached directly on this topic made impossible to raise possible hypotheses regarding the relationship between financial openness and installed capacity of renewable energy.

There is also a lack of robustness procedures, such as the use of a PVAR model and Panel Granger causality Wald test, which are especially appropriate in this context. Indeed, in **subsection 2.3.1**, we will detail the use of PVAR models to realisation the robustness check. Finally, researchers have mainly focused on Asia, Europe and the Middle East, disregarding Latin American countries. There are, hence, various reasons justifying the interest of the empirical assessment developed in the next sections.

2.3. Methodology and data

Section 2.3 is divided into two parts: the first describes the adopted methodological strategy, and the second presents the data and the variables used in the search for answers to our research questions.

2.3.1 Methodology

The PARDL model, in the form of a UECM, is used to decompose the total effects of the variables into their short- and long-run components (Koengkan et al., 2019). This model was developed by Granger (1981) and by Engle and Granger (1987) and was upgraded by Johansen and Juselius (1990), who introduced cointegration techniques that allow the identification of long-run relationships among non-stationary series and their parametrisation into an error correction model (ECM) (Nkoro and Uko, 2016).

Indeed, the PARDL methodology approach was used in this investigation because in panels with long time-spans (macro panels), cointegration generally exists between the variables and then endogeneity in the model. However, if one does not use the appropriate econometric techniques to cope with the endogeneity and cointegration problem, it can lead to estimation errors and misinterpretation of results. Therefore, in order to handle the problem of endogeneity and cointegration, the literature has recommended the use of PARDL models as an econometric estimation technique robust to deal with the presence of endogeneity and cointegration between the variables. Then, the PARDL in the form of a UECM was used to cope with endogeneity and cointegration that is expected in this investigation.

Moreover, the PARDL model was also preferred in this study for its many advantages, namely: **(a)** it is suitable to deal with cointegration; **(b)** it allows the analysis of I(0) and I(1) variables; **(c)** it can produce efficient parameter estimates with relatively small samples; **(d)** it is robust in the presence of endogeneity. The model is also more flexible than the alternatives such as the generalized method of moments (GMM), dynamic OLS (DOLS), and FMOLS (Koengkan et al., 2019). The general PARDL model follows the specification of **Equation (2.1)**:

$$DLnIREC_{it} = \alpha_i + \beta_{1i1} DLnGDP_{it-1} + \gamma_{1i1} LnIREC_{it-1} + \gamma_{1i2} LnFOPI_{it-1} + \gamma_{1i3} LnKPUBLIC_{it-1} + \varepsilon_{1it}, \tag{2.1}$$

where α_i represents the intercept, β_{ik} and γ_{ik}, with k = 1, …, 3, denote the estimated parameters and ε_{it} is the error term. The prefixes “Ln” and “DLn” denote natural logarithms and first-differences, respectively.

Before the estimation of the PARDL model, it is necessary to examine the characteristics of the cross-sections and time series, as well as to check for the existence of specificities which, if not considered, may produce inconsistent and incorrect results. To this end, the best econometric practices recommend performing a set of preliminary and specification tests before estimating the model of interest. The following tests are thus executed:

(i) Preliminary tests:

(a) Variance inflation factor (VIF) to check for the existence of multicollinearity; **(b)** cross-sectional dependence (CSD) test (Pesaran, 2004);

(c) 2nd generation unit root test (CIPS-test) (Pesaran, 2007) for the presence of unit roots;

(d) 2nd generation cointegration test (e.g., Aydin, 2019 and Westerlund, 2007) to assess if the series are cointegrated; (e); mean group (MG), fixed effects (FE), and pooled mean group (PMG) estimators; and

(f) the Hausman test to identify heterogeneity, i.e., whether the panel has random effects (RE) or fixed effects (FE).

(ii) Specification tests:

(a) Modified Wald test (Greene, 2002) to check for the presence of group-wise heteroscedasticity;

(b) Wooldridge test (Wooldridge, 2002) to confirm the existence of serial correlation; and

(c) Breusch and Pagan Lagrangian multiplier test (Breusch and Pagan, 1980) for cross-sectional correlation in the fixed-effects model. The latter is used due to the large T (number of time-series observations) and the small N (number of cross-sectional observations) in the panel.

To appraise the robustness of the model, panel vector autoregression (PVAR) is run to assess Granger causality amongst variables (via Wald test). This model was proposed by Holtz-Eakin et al. (1988) as a substitute for multivariate simultaneous equation models. According to Antonakakis et al. (2017), PVAR presents various advantages:

(i) It permits endogeneity and cointegration problems to be addressed;

(ii) It allows country fixed-effects to be included that capture the time-invariant components;

(iii) It is useful when there is poor information concerning the relationships amongst variables;

(iv) It can determine whether the impact of the variables is felt in the short-run, in the long-run or both; and

(v) It takes into account global shocks that simultaneously impact all the countries in the sample. PVAR thus complements PARDL.

Indeed, this technique was selected because it shares the same characteristics of the ARDL model when referring to the presence of endogeneity and cointegration. The general PVAR model is represented by the following linear **Equation (2.2)**:

$$\chi_{it} = \Gamma_0 + \Gamma_1 \chi_{it-1} + \Gamma_2 \chi_{it-2} + \mu_i + e_{c,t} + \varepsilon_t \, , \tag{2.2}$$

where, χ_{it} is the vector of the dependent variable in first-differences and natural logarithms (e.g., **LnIREC**, **DLnGDP**, **LnFOPI**, and **DLnKPUBLIC**). The use of variables in first-differences and natural logarithms follows from PVAR's prerequisite that all variables must be I(0) (see **Table 2.3** below); Γ_1, Γ_2 are the parameters to be estimated, and ε_t is the vector of dependent variables in a panel of fixed effects and idiosyncratic errors.

Before the realisation of PVAR regression, it is advisable to check the properties of the variables. To this end, some preliminary tests were applied, namely:

(a) Panel VAR lag-order selection that reports the overall model coefficient of determination (Hansen, 1982).

After the PVAR regression, it is good practice to apply the specification tests to verify the characteristics of the model. To this end, some diagnostics tests by Abrigo and Love (2015) will be applied, namely:

(a) Granger causality Wald test, which analyses the causal relationship between variables. Indeed, the null hypothesis of this test is that the excluded variable does not Granger-cause equation variable;

(b) Eigenvalue stability condition, which verifies the stability condition of PVAR estimates by computing the modulus of each eigenvalue of the model;

(c) Forecast-error variance decomposition (FEVD), which computes the forecast-error variance decomposition based on the Cholesky decomposition of the underlying PVAR model. In this test, the standard errors and the confidence intervals are based on the Monte Carlo simulation;

(d) Impulse-response function (IRF). The confidence bands of IRFs are estimated using Gaussian approximation and are based on the Monte Carlo simulation.

Moreover, the estimation and testing procedures are accomplished using **Stata 15.0**.

2.3.2 Data

To investigate the impact of financial openness on the installed capacity of renewable energy, a panel of ten Latin American countries (**Argentina**, **Bolivia**, **Brazil**, **Chile**, **Colombia**, **Ecuador**, **Mexico**, **Nicaragua**, **Peru**, and **Uruguay**) is considered and data collected for the period from 1980 to 2014. The period is determined by data availability (the ARDL model requires balanced panels).

The choice of this group of countries is justified not only by the lack of previous research on Latin America but also because they have experienced processes of rapid growth during the analysed time frame in both economic terms and as regards the installed capacity of renewable energy, They have also been experiencing increasing financial integration.

The raw data utilised in the empirical analysis is as follows:

(a) Dependent variable – the installed capacity of renewable energy (from biomass, hydropower, solar, photovoltaic, wind, wave, and waste) in million kilowatts (**IREC**) is a proxy for renewable energy investment – data retrieved from the International Energy Agency (IEA, 2018).

(b) Independent variables - **(i)** GDP in constant local currency units (LCU),(3) (**GDP**) retrieved from World Bank Open Data (2019); **(ii)** the financial openness

Notes (3): **GDP** is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant local currency.

index (**FOPI**) (whose impact on installed capacity of renewable energy is of utmost interest in this study) is available in the Chinn-Ito Index (2019). This index is based on the binary dummy variables that codify the tabulation of restrictions on cross-border financial transactions reported in the International Monetary Fund (IMF) Annual Report on Exchange Arrangements and Exchange Restrictions. This variable is one of the subcomponents of globalisation. Moreover, in order to identify the effect of capitalised values of this variable, we work with a transformed set of values obtained by adding 1 to the original financial openness index;(4) and **(iii)** general government capital stock (**KPUBLIC**) in billions of constant 2011 US dollars, available from the "Investment and Capital Stock Dataset" released by the IMF (2019).

In the literature, there are several ways to measure renewable energy development (Kim and Park, 2016). For example, through the installed capacity or generation (Kim and Park, 2016). However, the use of renewable energy generation is influenced by meteorological conditions and equipment performance as well as technical problems, making it biased by external forces that the investor cannot control (Kim and Park, 2016; Jenner et al., 2013; Müller et al., 2011). For this reason, the option was taken to use the installed capacity of renewable energy that reflects high levels of deployment. Moreover, the use of the installed capacity of renewable energy is used by other authors, such as Kim and Park (2016), Jenner et al., (2013) and Dong (2012).

The financial sector, according to modern contract theories, has its importance, where overcome the moral hazard and adverse selection problems; Consequently, this reduces the cost of firms by raising external capital (Kim and Park, 2016). Then, financial openness becomes disproportionately positive for the renewable energy sector, which needs the flow of large amounts of funds from outsiders (Kim and Park, 2016). That is, renewable energy technologies use a large amount of external financing, and this implies that investment in this kind of resource grows faster in countries with financial markets

Notes (4): Regarding adding the value "1" to the variable **FOPI**, and its subsequent logarithmization, this is because it lets us capture the effect of per cent changes in this variable on a per cent change in the installed capacity of renewable energy. Indeed, a variable computed in this was the compound rate associated with the raw variable. The nature of **FOPI** variable (that has values ranging from zero to one), economically behaves like a mix between a stock and a flux variable. Please note, that it modelled an impact (a short-run effect) as well as an elasticity (a long-run effect) of these variables on the explained variable. Thus, the log of that variable plus 1 gives us something like a compound tax rate of financial openness on the installed capacity of renewable energy. The use of this variable is an innovation because it allows a novel explanation of the relationship between **FOPI** and **IREC**.

that are more open, developed and globalised (Kim and Park, 2016). This is the justification for our study using the variable **FOPI** as the independent variable.

The installed capacity of renewable energy may depend not only on external financing but also on each nation's economic level. Therefore, economic growth and general government capital stock are likely to be positively correlated with renewable energy development. Indeed, higher economic growth increases the consumption of energy, and as the energy demand expands, the investment of renewable energy also increases. In the case of public capital stock, economic growth promotes the increase of capital stock and consequently a decrease in financing costs. Consequently, it stimulates energy consumption, as well as encouraging investment in renewable energy.

Generation of renewable energy is conditioned by technical problems, capacity factors, and other technology-specific characteristics along with the installed capacity level, which consequently impacts the return of renewable energy investment, and the decision to invest. This justifies our study using the variables **GDP** and **KPUBLIC** as independent variables.

The use of time-series from 1980 to 2014 is due to the availability of data for the variable **IREC** for all selected countries. The variable **IREC** was retrieved from the IEA in May 2018. The lack of available data does not allow us to extend our database. Indeed, it is worth making clear that the variables **GDP**, **FOPI**, and **KPUBLIC** were updated every six months. Indeed, the last update of these variables was in March 2019. However, in the case of the variable **IREC,** it was not possible to update this data, because the IEA site no longer provides open access data. Therefore, the last update of the variable **IREC** was in November 2018.

The choice of the ten Latin American countries as previously mentioned follows the same logic as for the time-series, i.e. only countries with availability of the data from 1980 to 2014 were selected. Indeed, of the 32 countries in the Latin American region, only 10 had a complete database that can be used for the realisation of this chapter.

Most of the countries that were excluded in this study had a short period of time and one or more holes on the time-series for all variables (e.g., Antigua and Barbuda, Barbados, Belize, Costa Rica, Dominican Republic, Dominica, El Salvador, Guatemala, Grenada, Guyana, Haiti, Honduras, Jamaica, Panama, Paraguay, Saint Lucia, Saint Kitts and Nevis, Suriname, Saint Vincent and the Grenadines, Trinidad and Tobago, the

Bahamas and Venezuela (RB). These 22 countries were not used because the methodology that will be used requires balanced panel data, and the use of this database makes the model estimation impracticable. Therefore, the descriptive statistics of variables can be seen in **Table 2.1B** in **Appendix B** (p. 206).

The variables **IREC**, **GDP**, and **KPUBLIC** are in per capita values. This allows for disparities in population growth to be controlled over time and within countries (e.g., Koengkan et al., 2019; Fuinhas et al., 2017). The use of constant GDP in LCU, rather than in constant US dollars, reduces the effects of inflation and foreign exchange variability (Koengkan et al., 2019a; Koengkan et al., 2019b).

Moreover, the Latin American economies are examples of low sophisticated economies plagued by frequent shocks, both internal and external ones (Koengkan et al., 2019a). As it is accepted more often than not, exchange rates often move away from their fundamental equilibriums for long periods (Koengkan et al., 2019b). The option of using data converted to US dollars would possibly increase the extent of the cross-sectional dependence problem that was already detected in the model estimations. The purchasing power parity approach could also be a valid alternative. Indeed, in several cases, it is capable of producing excellent results. However, in this investigation, we chose not to follow this method.

2.4. Empirical results

This section presents the results of the preliminary and specification tests and the estimated models. Indeed, these tests are important in order to identify if the PARDL and PVAR models are the correct methodologies for the realisation of our investigation. The first step was the computation of the VIF and CSD-tests. The VIF test informs on the level of multicollinearity. The main objective of the CSD-test is the identification of variables' cross-section dependence (its null hypothesis is the presence of CSD). The results of both tests are displays in **Table 2.2**.

Table 2.2. Variance Inflation Factor (VIF) and Cross-section Dependence (CSD) tests

Variables	VIF	1/VIF	CD-test	p-value		Corr	Abs (corr)
LnIREC	n.a.		29.17	0.000	***	0.735	0.735
LnGDP	1.04	0.9646	30.95	0.000	***	0.780	0.780
LnFOPI	1.08	0.9293	21.11	0.000	***	0.532	0.570
LnKPUBLIC	1.07	0.9379	4.24	0.000	***	0.107	0.612
Mean VIF	1.06						
DLnREC	n.a.		-0.280	0.780		-0.007	0.191
DLnGDP	1.02	0.9759	13.39	0.000	***	0.342	0.344
DLnFOPI	1.07	0.9357	3.27	0.001	***	0.084	0.168
DLnKPUBLIC	1.04	0.9583	12.12	0.000	***	0.310	0.392
Mean VIF	1.05						

Notes: *** denotes statistically significant at 1% level. The Stata commands *estat vif* and *xtcd* were used; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

The results in **Table 2.2** indicate that multicollinearity is not a concern. VIF and mean VIF values are lower than the usually accepted benchmark of 10 (in the case of the VIF, values are lower than 6). The null hypothesis for the CSD-test is not rejected in most cases (the exception being **IREC** in first-differences).

When CSD is present, it is necessary to assess the order of integration of the variables. To this end, a second-generation unit root test, robust in the presence of CSD, is computed. We did not opt for a first-generation test because it is inefficient when CSD exists. The rejection of the null hypothesis leads to the conclusion that the variable is I(1). The results of this test can be seen in **Table 2.3**.

Table 2.3. 2nd generation unit root test (CIPS-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	
LnIREC	1	-2.725	0.003	***	-2.815	0.002	***
LnGDP	1	-1.234	0.109		-1.224	0.111	
LnFOPI	1	-1.745	0.040	**	0.037	0.515	
LnKPUBLIC	1	1.240	0.893		-0.983	0.163	
DLnIREC	1	-10.360	0.000	***	-9.084	0.000	***
DLnGDP	1	-5.418	0.000	***	-4.887	0.000	***
DLnFOPI	1	-7.815	0.000	***	-6.089	0.000	***
DLnKPUBLIC	1	-5.853	0.000	***	-5.708	0.000	***

Notes: ***, ** denote statistically significant at 1%, and 5% level, respectively; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively The Stata command *multipurt* was used; The null for the CIPS test is: series are I(1); the lag length (1) and trend were used in this test.

The CIPS test indicates that none of the variables seems to be I(2), although it shows that some are borderline between I(0) and I(1). Indeed, in first-differences, all variables seem to be stationary. The same occurs for **IREC** and **FOPI** in natural logarithms. Furthermore, the non-stationarity of some variables, such as **GDP** and **KPUBLIC** in natural logarithms is an indication of potential "spurious correlation". Therefore, it is recommended to apply the second-generation cointegration test of Westerlund in order to check for cointegration between the variables which are not stationary. This test's null hypothesis is no-cointegration, and it requires that all variables are I(1). The results from Westerlund cointegration test can be seen in **Table 2.4B** in **Appendix B** (p.206). The results, displayed in **Table 2.4B**, suggest that there is no cointegration between the assessed variables, as expected.

Following the cointegration check, the next step is to assess the existence of individual effects. The Hausman test, confronting random (RE) and fixed effects (FE), is thus performed. The null hypothesis of this test is that the difference in coefficients is not systematic, i.e. random effects are the most suitable estimator. The results of the Hausman test indicate that the null hypothesis should be rejected (**Chi2 (4) = 58.33**, statistically significant at 1% level) (see **Table 2.5B** in **Appendix B**, p.206) and that a fixed-effects model is the most appropriate for this analysis.

Assessment of panel heterogeneity/homogeneity is performed with mean group (MG), pooled mean group (PMG), and fixed effects (FE) techniques. Indeed, the MG estimator computes the average of coefficients of all individuals, with no restrictions regarding the homogeneity of the short and long run. This estimator was developed by Pesaran and Smith (1995).

The PMG estimator, created by Pesaran et al. (1990), allows for differences in error variances, short-run coefficients, speed of adjustment and intercepts (i.e. these parameters may be country-specific), but it imposes a homogeneity restriction on the long-run coefficients (i.e. they should be equal across countries). The PMG estimator combines the "pooling" from the FE estimator with the "averaging" from the MG estimator. In the case of panel homogeneity, this estimator is more efficient in the long-run in comparison with MG. The outcomes from the three specifications (MG, PMG, and FE) can be seen in **Table 2.6B** in **Appendix B** (p.207).

Finally, the last of the preliminary tests consists of assessing panel heterogeneity/homogeneity with the Hausman test. Results are displayed in **Table 2.7**, for the above-mentioned specifications (e.g., MG vs PMG; PMG vs FE; and MG vs FE) and suggest that the panel is homogeneous, and that the FE is the most appropriate estimator.

Table 2.7. Hausman test

MG vs PMG	PMG vs FE	MG vs FE
Chi2(5) = 1.72	Chi2(5) = 0.55	Chi2(5) = 25.35 ***

Notes: *** denotes statistically significant at 1%; Hausman results for H_0: difference in coefficients not systematic; the Stata commands *xtpmg*, and Hausman (with the options, sigmamore alleqs constant) were used.

Before model estimation, the following specification tests are performed: (a) the Modified Wald test; (b) the Wooldridge test; and (c) the Breusch and Pagan Lagrangian multiplier test. Results are presented in **Table 2.8**.

Table 2.8. Specification tests

	Modified Wald test	Wooldridge test	Breusch and Pagan LM test
Statistics	chi2 (10) =3914.91***	F(1,9) = 12.542 ***	chi2(45) = 79.734 ***

Notes: *** denotes statistically significant at 1% level; H_0 of Modified Wald test: sigma(i)^2 = sigma^2 for all i; H_0 of Wooldridge test: no first-order autocorrelation; H_0 of Breusch and Pagan LM test: residuals are not correlated.

The null hypotheses of these tests are all rejected at the 1% level, indicating that heteroscedasticity, first-order autocorrelation, and cross-sectional correlation exist. The FE-DK (Driscoll and Kraay) technique is thus adapted to estimate the model of interest in this empirical study. To obtain the long-run elasticities, each variable coefficient is divided by the **LnIREC** coefficient (in both cases lagged once). This ratio is then multiplied by (-1). **Table 2.9** displays the short-run impacts, the long-run elasticities and the speed of adjustment.

Table 2.9. Model estimation

Independent variables	**Dependent variable (DLnIREC)**
	FE D.-K.
Constant	2.4368 **
	Short-run (impacts)
DLnGDP	0.2868
	Long-run (elasticities)
LnFOPI (-1)	0.6284 ***
LnKPUBLIC (-1)	0.7094 ***
	Speed of adjustment
ECM	-0.2209 ***

Notes: ***, ** denote statistically significant at 1% and 5% level, respectively; The ECM denotes the coefficient of the variable **LnIREC** lagged once; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

Results in **Table 2.9**, indicate that, in the short run, the impact of the per capita **GDP** does not contribute to increasing the installed capacity of renewable energy. In the long run, the elasticities of financial openness (**FOPI**) and of per capita general government capital stock (**KPUBLIC**), are statistically significant at 1%. Regarding their long-run effects, both financial openness and general government capital stock contribute to increasing the installed capacity of renewable energy.

The ECM term is negative and statistically significant at the 1% level, indicating the presence of cointegration/long memory in the variables. This coefficient depicts the speed of the dependent variable’s return to equilibrium, which, in this case, is moderate.

During the period of analysis, Latin America experienced shocks that, if not taken into account, may produce inaccurate results. Indeed, dummy variables were introduced to account for shocks (peaks and breaks of significant magnitude) which occurred in some Latin American countries, identified in the analysis of the residuals. However, the inclusion of these dummies following triple criterion was thus used: **(a)** the occurrence of international events known to have disturbed the Latin American region; **(b)** the potential relevance of recorded economic, social, and political events at the country level; and **(c)** significant disturbances in the estimated residuals.

The Latin American region experienced social and economic crises during the 1980s, 1990s and 2000s. For instance, in 1981, Ecuador entered a brief territorial dispute with Peru (Villamar, 1981). This coincided with problems in the Ecuadorian economy, following a decline in international oil prices (Hanratty, 1989).

In 1982, the economy of Ecuador was hit by dramatic climate events triggered by El Niño which produced torrential rains, coastal floods, and a severe drought, with profoundly negative consequences for crops, infrastructures, and transportation. The country's external debt grew (reaching US$8.4 billion in 1984), and the foreign sources of credit dried up in 1982, leaving the national government and hundreds of state-owned companies without capital (Hanratty, 1989).

The Latin American debt crisis, which began in 1982 with Mexico's announcement of incapacity to service its debt, reached Uruguay in 1983. External suppliers of capital became increasingly challenging to find and, in November of that year, a stabilisation plan was abandoned. The peso was devalued by 149% against the US dollar, and annual inflation climbed from 20.5% in 1982 to 51.5% in 1983. The large stock of dollar-denominated debt of the private sector quickly caused solvency problems, triggering a banking crisis (Marandino and Oddone, 2018). The country eventually recovered, and the span from 2004 to 2014 is considered as a golden period for the Uruguayan economy. During this period, the GDP annual growth rate reached 5.4%, three times the growth registered in the second half of the twentieth century, fuelled by a super cycle of commodity prices, good financial conditions in emerging markets, and strong external demand, especially after the 2008 international financial crisis (Marandino and Oddone, 2018).

In 2006, the GDP annual growth rate was 4.09%, rising to 6.54% in 2007, 7.17% in 2008, and 7.80% in 2010 (World Bank Open Data, 2019). All these events were represented by the following dummy variables: **IDECUADOR1981** (Ecuador, year 1981); **IDECUADOR1982** (Ecuador, year 1982); **IDURUGUAY1983** (Uruguay, year 1983); **IDURUGUAY2006** (Uruguay, year 2006); **IDURUGUAY2007** (Uruguay, year 2007); **IDURUGUAY2008** (Uruguay, year 2008); and **DURUGUAY2010** (Uruguay, year 2010). **Table 2.10** shows the results of the corrected model, i.e. the short- and long-run elasticities, and the ECM for the FE D.-K. estimation after the inclusion of dummy variables.

Table 2.10. Model estimation corrected

Independent variables	Dependent variable (DLnIREC) FE D-K.
Constant	2.7653 ***
	Shocks
IDECUADOR1981	-0.7003 ***
IDECUADOR1982	-0.4698 ***
IDURUGUAY1983	0.8936 ***
IDURUGUAY2006	-0.6055 ***
IDURUGUAY2007	0.6541 ***
IDURUGUAY2008	-0.3808 ***
IDURUGUAY2010	0.4249 ***
	Short-run (impacts)
DLnGDP	0.2318 **
	Long-run (elasticities)
LnFOPI(-1)	0.6371 ***
LnKPUBLIC (-1)	0.7040 ***
	Speed of adjustment
ECM	-0.2528 ***

Notes: ***, ** denote statistically significant at 1% and 5% level, respectively; the ECM denotes the coefficient of the variable **LnIREC**, lagged once; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

The results indicate that, in the short run, the impact of the per capita **GDP** is statistically significant at the 10% level, and thus that it contributes to increasing the installed capacity of renewable energy. In the long run, the elasticities of **FOPI** and per capita **KPUBLIC** are statistically significant at 1%, and thus, both variables contribute to increasing the installed capacity of renewable energy in Latin American countries. Regarding the ECM term, it continues to be negative and statistically significant at the 1% level.

2.5. Robustness check

To evaluate the robustness of the analysis developed so far, a PVAR model is estimated, and Panel Granger causality Wald tests are computed. Moreover, the preliminary tests that check the characteristics of variables point to the presence of low-multicollinearity, cross-section dependence, such that none of the variables seems to be I(2), although it shows that some are borderline between I(0) and I(1), the fixed effects in the model. These results can be seen in **Tables 2.2**, **2.3**, and **2.5B** in **Appendix B** (p.206). Therefore, the results of the preliminary test in PARDL and PVAR are the same. The results of the PVAR lag order selection point to the need to use the lag length (1) in the PVAR regression (see **Table 2.11B** in **Appendix B**, p. 207). Estimates for the PVAR model coefficients (lag length = 1) are shown in **Table 2.12**.

Table 2.12. Results of PVAR from robustness check

Response of	Response to							
	LnIREC$^{(t)}$		**DLnGDP**$^{(t)}$		**LnFOPI**$^{(t)}$		**DLnKPUBLIC**$^{(t)}$	
LnIREC$_{(t-1)}$	0.8107	***	0.0034	*	-0.0682	***	0.0064	***
DLnGDP$_{(t-1)}$	0.5709	***	0.7460	***	0.2521	***	0.1319	***
LnFOPI$_{(t-1)}$	0.1932	***	-0.0221	***	0.9340	***	0.0013	
DLnKPUBLIC$_{(t-1)}$	1.3914	***	-0.2195	***	0.0210		0.9661	***
***N.* obs**	**210**							
***N.* panels**	**10**							

Notes: *** denotes statistical significance level of 1%; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively; the Stata command *pvar* with one lag was used. Instruments: l (1/13).

All variables in this model are I(0), and therefore, only short-run effects may be identified. The regression indicates that endogeneity exists. For **DLnFOPI** all estimates are statistically significant at 1% and 5%. **Table 2.13** displays the results for the Panel Granger causality assessment performed with a Wald test.

Table 2.13. Panel Granger causality Wald test from robustness check

Equation \ Excluded		chi2	Df.	Prob > chi2
LnIREC	**DLnGDP**	129.278	1	0.000
	LnFOPI	72.985	1	0.000
	DLnKPUBLIC	86.582	1	0.000
	All	252.414	3	0.000
DLnGDP	**LnIREC**	2.748	1	0.097
	LnFOPI	19.995	1	0.000
	DLnKPUBLIC	39.569	1	0.000
	All	50.843	3	0.000
LnFOPI	**LnIREC**	664.102	1	0.000
	DLnGDP	165.402	1	0.000
	DLnKPUBLIC	0.220	1	0.639
	All	1289.596	3	0.000
DLnKPUBLIC	**LnIREC**	143.158	1	0.000
	DLnGDP	2613.123	1	0.000
	LnFOPI	1.214	1	0.271
	All	2819.118	3	0.000

Notes: (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively; the Stata command *pvargranger* was used.

These results indicate rejection of the null hypothesis indicating the presence of bi-directional causality between: **(i)** the installed capacity of renewable energy and per capita economic growth; **(ii)** financial openness and the installed capacity; **(iii)** financial openness and per capita economic growth; **(iv)** the installed capacity of renewable energy and per capita general government capital stock; and **(v)** per capita general government capital stock and per capita economic growth. **Figure 2.1** summarises the causalities between the variables. Indeed, this figure was based on results of the Panel Granger causality Wald test (see **Table 2.13**) and on the results of the PVAR estimation (see **Table 2.12**).

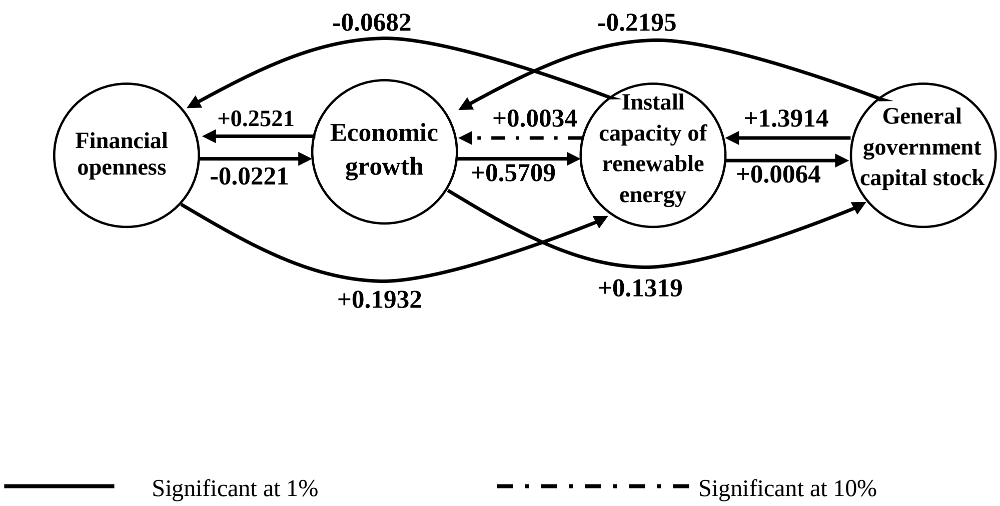

Figure 2.1. Summary of causality of the variables

Moreover, the results of specification tests show that the PVAR model is stable; that one period after the shock, the variables themselves explained almost all the forecast error variance, and the impulse – response functions that all variables converge to equilibrium, supporting that the variables of the model are I(1) (see **Tables 2.14B**, **2.15B**, and **Figure 2.2B** in **Appendix B**, pp.207-209). The next section will show the discussions of empirical results.

2.6. A brief debate about the results

The effect of financial openness on renewable energy investment diffusion in ten Latin American countries was investigated. The results of the developed preliminary tests suggest that low multicollinearity and CSD are present in the data, in the latter case, except the variable **IREC** in first-differences (see **Table 2.2**). Despite the absence of CSD in the last case, we conclude that there is a correlation amongst series across the countries comprised in the panel of data. This runs mainly from the interdependence of the examined countries' economies.

All variables in first-differences, and also the levels of **IREC** and **FOPI** in natural logarithms, are stationary (see **Table 2.3**), indicating that the ARDL is the best regression methodology as it allows working with series displaying distinct orders of integration. The variables **GDP** and **KPUBLIC** in natural logarithms are not cointegrated (see **Table 2.4**). This was assessed to prevent a "spurious correlation" problem in the estimated model. The results of this test supported the use of a less stringent econometric technique concerning the order of integration of the series, i.e. the PARDL methodology. The FE technique was selected as the most appropriate for the fixed effects homogeneous model (see **Tables 2.6** and **2.7**).

The specification tests indicated that heteroscedasticity, first-order autocorrelation, and cross-sectional correlation exist (see **Table 2.8**). Therefore, the FE-Driscoll and Kraay (1998) estimator was used as it produces standard errors which are robust to the identified problems (and is superior to both FE and FE robust estimators).

The estimated general model (including the dummies) suggests that the impact of the variable per capita **GDP** has a positive impact of 0.2318 on the installed capacity of renewable energy, while the elasticities of the variables **FOPI** and per capita **KPUBLIC** have positive impacts of 0.6371 and 0.7040, respectively (see **Table 2.10**).

According to Koengkan (2017b), the possible explanation for the positive effect of economic growth on the installed capacity of renewable energy is the latter's sensitivity to changes in the economic dynamics of Latin American countries. Higher economic growth in these countries has a positive impact on the consumption of energy. To meet such increased energy demand, promoted by the enhanced economic activity, more investment in renewable energy sources is required. Another possible justification is that the abundance of renewable energy resources in the region stimulates investment in this kind of technology and, consequently, positively impacts economic activity and the consumption of energy (Koengkan, 2017b).

The robustness analysis, with the estimation of a PVAR model and Panel Granger causality testing, are in line with these justifications. The estimated PVAR model indicates that per capita economic growth has a positive impact of 0.5709, while the installed capacity of renewable energy has a positive impact of 0.0034 (short-run impacts in both cases) (see **Table 2.13**). The causality assessment points to positive bi-directional links between the variables (see **Table 2.13**, and **Figure 2.1**).

Some explanations that have been put forward to justify the positive effect of the capital stock on the installed capacity of renewable energy may also be of use when considering, as we do here, the public stock of capital. Thus, a possible reason for its positive impact on the installed capacity of renewable energy follows from the fact that increased capital supply reduces financing costs, promoting economic activity and energy consumption. To meet the increase in energy demand, investment in installed capacity of energy also grows (e.g., Lee and Chien, 2010; Lee et al., 2008).

In this line of reasoning, economic dynamics channels the impact of the capital stock to the installed capacity of renewable energy. We tried to corroborate this with a PVAR model and with the Panel Granger causality testing, but the results indicate that economic growth has a positive impact of 0.2521 on financial openness, while financial openness has a negative impact of -0.0221 on economic activity (both are short-run impacts). Granger causality analysis indicates that there is a bi-directional relationship (see **Tables 2.12** and **2.13**, and also **Figure 2.1**). A positive impact from financial openness on economic activity was anticipated for the Latin American region, given that in this area, public capital drives economic growth.

Other possible explanations for the context of the Latin American region have been pointed out. According to Lee (2005), the capital stock has an indirect effect on consumption and investment in energy. This is also defended by Lee and Chien (2010) and Lee et al. (2008). The stock of capital positively impacts investment and industrial production, which, in turn, increases the demand for energy and investment in installed capacity.

Narayan and Smyth (2008) and Apergis and Payne (2010) have a different vision of this positive impact. According to them, the capital stock encourages investment in renewable energy because the supply of cheaper credit makes alternative energy sources more feasible. This can lead to an acceleration of economic growth and of energy consumption, and consequently to more investment in installed capacity.

Finally, although no studies have previously assessed the link between financial openness and the installed capacity of renewable energy, some justifications have also been put forward concerning the positive effect exerted by financial development and its proxies. Kim and Park (2016) and Sbia et al. (2014) claimed that financial development increases the capital stock and consequently reduces the cost of external financing, encouraging investment in renewable energy technologies.

Mazzucato and Semieniuk (2018) concur and state that financial development increases public and private capital stocks. However, they conclude that only public capital is capable of promoting renewable energy investment, as the private sector is more risk-averse in this context, and that public policies have not been capable of mobilising the private sector (Mazzucato and Semieniuk, 2018; Rodríguez et al., 2014). The positive effect of public capital on the installed capacity of renewable energy is also a result of our empirical analysis.

Koengkan et al. (2018), Shahbaz et al. (2013), and Islam et al. (2013) defended a slightly different point of view, stating that the impact of financial openness on the installed capacity of renewable energy is indirect. The reduced cost of credit resulting from more financial integration boosts the consumption of goods and services and, consequently, the dynamics of economic activity and the consumption of energy.

To meet this increased energy demand, more investment in installed capacity of renewable energy is made. We used our robustness check and causality analysis to examine this line of reasoning but, as mentioned above, our results indicate that there is a negative impact (of -0.0221) from financial openness on economic growth and a positive effect of 0.1932 on installed capacity of renewable energy (both are short-run effects see **Table 2.12**). Granger causality points to the existence of bi-directional relationships between the variables (see **Table 2.13**, and **Figure 2.1**).

Regarding the ECM, it is negative and statistically significant at the 1% level, which indicates that the model is robust (see **Table 2.10**). Moreover, the statistical significance of the dummy variables supports the decision to include them. They improved the quality of the estimated model and showed the real effects of the independent variables.

2.7. Conclusions and policy implications

This empirical analysis aimed to assess the impact of financial openness on renewable energy investment diffusion. Ten Latin American countries were considered, and data was collected for the period 1980 to 2014. Results of a PARDL model estimation suggest that, in the short run, per capita, economic growth has a positive impact on the installed capacity of renewable energy.

The elasticities of financial openness and the general government capital stock per capita exert positive effects on the installed capacity of renewable energy. A possible explanation for the positive effect of financial openness is the decrease in financing costs it causes. Less expensive credit increases consumption of goods and services, thus enhancing economic activity and energy consumption, which in turn boosts investment in the installed capacity of renewable energy.

The estimated PVAR model and Panel Granger causality assessment were performed as robustness checks and pointed to the same results (although solely in the short run). Bi-directional causality was identified between the following variables: installed capacity of renewable energy and per capita economic growth; financial openness and installed capacity; general government capital stock per capita and installed capacity of renewable energy; per capita economic growth and financial openness; and finally, per capita general government capital stock and per capita economic growth.

This study suggests that financial institutions in the Latin American region should take advantage of the increase in the stock of public capital promoted by financial openness and promote investment in research and development activities related to renewable energy sources. This could lead to an increase in the connection of domestic financial institutions in environmentally relevant activities. Additionally, policymakers in Latin American countries should implement policies aimed at not only encouraging the participation of financial institutions in the funding of small and micro firms dedicated to low environmental impact projects but also at increasing households' preferences towards sustainable consumption.

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Chapter 3

The Interactions Between Renewable Energy Consumption and Economic Growth: Fresh Evidence from the Mercosur Countries

Abstract

The relationship between the consumption of renewable energy, economic growth, and globalisation is investigated in this chapter. Data for five Mercosur countries in the period between 1980 and 2014 and the PVAR methodology are used. The estimated model and the results of a Granger causality Wald test indicate that a bidirectional relationship exists between the consumption of energy (from both renewable and fossil sources) and economic growth, and suggest that the assessed countries' economic growth is dependent on fossil fuels. There is also evidence of substitutability in the consumption of energy from renewable and fossil sources in periods of drought, and that the process of globalisation has a positive indirect influence on the Mercosur countries' consumption of renewable energy. The results obtained can be of use for local governments, not only as a basis for further examinations of the nexus between economic growth and energy consumption but also for the design of new policies aiming at increasing consumption of energy from renewable sources and promoting economic development.

JEL Codes: F43; F62; Q43.

Keywords: Energy economics; Energy; Economic growth; Econometrics; Renewable energy.

3.1. Introduction

The consumption of electricity from renewable and fossil sources has more than tripled in Latin America between 1989 and 2014 (see **Figure 1.4A** in **Appendix A**, p. 201). Renewable energy sources (e.g., biofuels, biomass, hydropower, wind and photovoltaic) have as a result reached a substantial weight in the energy matrix of the region, making it the most relevant in the world concerning the share of green energy in the energy matrix (Koengkan, 2018a).

The Latin American market for renewable energy is also the most dynamic, having experienced rapid growth in both investment in and consumption of this kind of energy sources (Fuinhas et al., 2017). This trend has been enhanced by, inter alia, the abundance of natural resources, the rapid increase in energy demand, the significant dependence on fossil fuel, high energy prices and energy security concerns (Koengkan, 2018a). Increases of energy consumption in the Latin American region have been accompanied by the rapid growth of GDP per capita and by the globalisation process, in turn, enhanced by several political liberalisation episodes and economic reforms occurred in the last forty years.

Average annual growth rates have been of approximately 3.0% between 1989 and 2014 (see **Figure 1.1A** in **Appendix A**, p. 200), with GDP per capita (current US$) evolving from US$ 2319,05, and in 2014, it was US$ 10,405,48 in the period that the process of opening intensified in the region (see **Figure 1.2A** in **Appendix A**, p. 200). Regarding globalisation, the first evidence in this area emerged in Chile in the 1970s. Nevertheless, in Latin America, that decade was still a period of low economic growth and high inflation (Haggard and Kaufman, 2008), during which most governments were conservative, nationalistic and not receptive to the social and economic changes inherent to the emerging globalisation process (Rojas, 2017). Between 1974 and 1979 a large number of tariff and non-tariff barriers were eliminated or reduced in Chile. In 1983, Costa Rica initiated a gradual process of economic liberalisation, followed by Bolivia and Mexico in 1985. Other countries, such as Argentina, Brazil, Colombia, Peru, and Venezuela (RB) joined the liberalisation trend in the early 1990s, (Pinto and Lahera, 1993).

In 1991, the Mercosur trade-bloc, established by the Asunción Treaty, was created with the objective of promoting the free trade of goods and services, and the free flow of capital and people across the associate countries – Argentina, Brazil, Paraguay, Uruguay and Venezuela (RB) (Koengkan, 2018a). The latter country was excluded in 2014 following the still ongoing political and economic crises (Theodore, 2015). In these countries, the consumption of renewable energy began in the 1970s in Brazil, with hydropower in 1973 and biofuels in 1975. Paraguay and Uruguay started in 1973 with hydropower; Argentina in 1998 with hydropower, biomass, biogas, geothermal, wind, waves and photovoltaic; and Venezuela (RB) in 2001 with hydropower (IRENA, 2016).

The consumption of energy from this kind of sources represented 20% of total energy consumption in 2009 (Santos, 2015). The investment in renewable energy, which grew 13% between 2000 and 2013, is related to the inflow of foreign direct investment (FDI) to the region. In 2016 the Mercosur bloc received 47.4% of the FDI flows (Mercosul, 2019).

The relevance of the events described has inspired the main research questions of this chapter, namely: Are there causal links between consumption of renewable energy and economic growth in the Mercosur countries? The specific questions resulting from the deepening of the central questions are objective ones: What is the causality between the consumption of renewable energy and globalisation? Do globalisation and renewable energy consumption decrease the consumption of non-renewable energy?

To answer these questions, potential relationships between economic growth, consumption of renewable and non-renewable energy sources, and globalisation are investigated, using data for the five Mercosur countries from 1980 to 2014, estimating the PVAR model developed by Holtz-Eakin et al. (1988) and performing a Granger causality assessment with a Wald test.

The links between the consumption of renewable energy and economic growth have received considerable attention from researchers. The recent literature has produced results that may be classified into four strands, with different explanations and assumptions. The first concludes that there are no significant links between the two variables (e.g., Menegaki, 2011). The second, that such a relationship exists and is unidirectional, running from economic growth to renewable energy consumption (e.g., Caraiani et al., 2015). The third, that the unidirectional link has the opposite direction, i.e. it runs from renewable energy consumption to economic growth (e.g., Bélaïd and Youssef, 2017; Destek and Aslan, 2017; Aslan, 2016; Zeb et al., 2014; Ocal and Aslan, 2013; Pao and Fu, 2013; Menyah and Wolde-Rufael, 2010). The fourth, that the link between the variables exists and is bidirectional (e.g., Amri, 2017; Sebri and Ben-Salha, 2014; Lin and Mubarak, 2013; Al-Mulali et al., 2013; Apergis and Payne, 2012; Tugçu et al., 2012; Apergis and Payne, 2011; Apergis and Payne, 2010; Apergis et al., 2010).

The diversity of the results obtained justifies the development of further research. In this chapter, we add to the existing literature by developing an assessment that is innovative for the following reasons:

(i) It considers the possible overall impact of the globalisation process. Previous studies have considered economic growth, investment, trade and industrial production to explain the increasing consumption of energy, but have not used a comprehensive globalisation indicator. Nevertheless, globalisation's many facets are potential drivers of economic growth and may thus exert significant impacts on energy consumption;

(ii) The PVAR model is the basis of the econometric analysis. Other studies have examined the causal link of interest with models such as DOLS, FMOLS or PARDL. PVAR is a new technique that, as explained below, is more robust than the available alternatives;

(iii) The geographical focus of the analysis, as previous studies addressing this topic, did not study the Mercosur countries;

(iv) The thorough explanation of the relationships between the variables. Previous studies have produced results for links between variables but have not explained how these variables interact with each other.

The obtained results are of relevance for the following reasons: **(i)** they may be of use for policymakers involved in the development of renewable energy policies; **(ii)** they provide information on how the assessed variables interact with each other in the Mercosur countries. Understanding of such links is essential for the design of macroeconomic policies that promote economic growth without provoking environmental degradation; and **(iii)** they add to the scarce literature examining such relationships in the Latin American region and in the Mercosur countries.

The chapter is organised as follows: **Section 3.2** reviews the relevant literature; **Section 3.3** presents the data and the method; **Section 3.4** describes the empirical analysis; **Section 3.5** discusses the obtained results, and **Section 3.6** presents the conclusions and policy implications.

3.2. Literature review

The nexus between the consumption of energy and economic growth has received considerable attention in the energy economic literature (Koengkan et al., 2018). The relationship between these two variables got stronger with the industrial revolution when energy consumption became an important part of the production process. Nevertheless, in the early literature, the energy was considered as an intermediate production input, as many economists grounded their assessments on the neoclassical growth model proposed by Solow (1956) (Fuinhas and Marques, 2019, p. 15). In this model, capital and labour were the only primary inputs for growth (Romer, 2012, p. 10).

Later, economists in the areas of ecological economics and energy economics recognised energy as an important production factor and this variable was included in studies investigating economic growth (e.g., Fuinhas and Marques, 2019, p. 15; Stern, 1993).

The relationship between economic growth and consumption of energy had a period of increase with the occurrence of the world oil crisis in 1973 that impacted the energy supply (Fuinhas and Marques, 2019, p. 15). For this reason, the role of energy in the economy become more conscious. The other motive that led to an increase in the attention towards the relationship between energy and economic growth was the concern with global warming and climate changes that are related to consumption of energy; these concerns have been materialized for example, with the examination of Environmental Kuznets Curve (Fuinhas and Marques, 2019, p. 15).

The first study investigating the relationship between economic growth and consumption of energy was produced by Kraft and Kraft (1978), where the authors concluded the existence of a unidirectional relationship running from economic growth to consumption of energy. The publication of their seminal paper inspired many others and the survey by Ozturk (2010) concludes that the obtained results have been far from consensual.

This lack of consensus may be due to the use of different variables such as primary energy consumption (that includes renewable and fossil), fossil fuels, total energy consumption, oil consumption, nuclear energy, GDP growth (annual %), GDP (current US$) and GDP per capita (current US$). Other studies have used total renewable energy consumption, wind energy consumption, hydroelectricity consumption, and photovoltaic energy consumption as variables (Koengkan, 2018a). There are still other studies that used the variable GDP in constant (LCU) (e.g., Koengkan et al., 2018). The differences in the studies' conclusions make it particularly difficult to make completely reliable policy implications based on their outcomes.

Even though several authors have used different variables to investigate the nexus between economic growth and consumption of energy, there is still a gap in the literature that needs to be filled. Indeed, the relationship between renewable energy consumption and economic growth deserves more research.

For this reason, the focus of this literature review is centred on studies that have used the consumption of renewable energy. Here, the answer to the following two questions is important. What conclusions have been reached by such studies? What innovations do they bring to literature about this relationship? The recent energy economics literature has evolved into four ways. The first argues that there is a neutral relationship between the consumption of renewable energy and economic growth (e.g., Menegaki, 2011). The second argues for the existence of a unidirectional relationship from economic growth to renewable energy consumption (e.g., Caraiani et al., 2015). The third claims that this unidirectional dynamic causality runs from renewable energy consumption to economic growth (e.g., Bélaïd and Youssef, 2017; Destek and Aslan, 2017; Aslan, 2016; Zeb et al., 2014; Ocal and Aslan, 2013; Pao and Fu, 2013; Menyah and Wolde-Rufael, 2010).The fourth points to a bidirectional relationship between economic growth and renewable energy consumption (e.g., Amri, 2017; Sebri and Ben-Salha, 2014; Lin and Mubarak, 2014; Al-Mulali et al., 2013; Apergis and Payne, 2012; Tugçu et al., 2012; Apergis and Payne, 2011; Apergis and Payne, 2010; Apergis et al., 2010).Indeed, at least one author of this literature review found the existence of a neutral relationship between economic growth and consumption of renewable energy. For instance, Menegaki (2011) investigated the nexus between consumption of renewable energy and economic growth for 27 European countries, from 1997 to 2007. The author used a random effect model as a method. The empirical results of this investigation pointed to the existence of a neutrality relationship between the variables.

However, another author that investigated a similar group of countries found the presence of a unidirectional relationship from economic growth to renewable energy consumption. For example, Caraiani et al. (2015) studied the causality between economic growth and the consumption of this kind of source in 28 European Union countries in the period 1980-2013. The Granger causality Wald tests and cointegration tests were used as methodology.

The third group of scholars found the existence of unidirectional causality from consumption of renewable energy to economic growth. For example, Menyah and Wolde-Rufael (2010) studied the causal relationship between CO2 emissions, consumption of renewable energy and nuclear, and GDP in the period from 1960 to 2007. The Granger causality Wald test was used as a method for this investigation. The authors found the presence of a unidirectional relationship between consumption of energy to economic growth. Ocal and Aslan (2013) observed the nexus between renewable energy consumption and economic growth in Turkey. The ARDL bound test and Granger causality were used. The results showed unidirectional causality running from economic growth to renewable energy consumption. Pao and Fu (2013) investigated Brazil in the period from 1980 to 2010, the causal relationship between GDP, non-hydroelectric renewable energy consumption (NHREC), non-renewable energy consumption (NREC), total primary energy consumption (TEC), and total renewable energy consumption (TREC). The cointegration test was used as a methodology. The authors found the presence of a unidirectional relationship from NHREC to economic growth, a bidirectional relationship between economic growth and TREC, and unidirectional causality from economic growth to NREC or TEC. Zeb et al. (2014) analysed the relationship between renewable energy, CO2 emissions, GDP, natural resource depletion and poverty in Bangladesh, India, Nepal, Pakistan and Sri Lanka in the period 1975 to 2010. The Granger causality Wald test was used as the method. The results indicated the presence of unidirectional causality between the variables. Aslan (2016) examined the nexus among biomass energy consumption, economic growth, employment and capital in the United States between 1961 to 2011. The ARDL bound test and Granger Causality test were used. The results suggested the presence of unidirectional causality from biomass energy to GDP. Bélaïd and Youssef (2017) explored the dynamic relationship between emissions of CO2, consumption of renewable and non-renewable electricity, and economic growth in Algeria by using the ARDL cointegration approach over the period from 1980 to 2012. The results revealed the existence of a unidirectional relationship between renewable and non-renewable electricity consumption and economic growth. Destek and Aslan (2017) studied the impact of renewable and non-renewable energy consumption on economic growth in 17 emerging economies in the period from 1980 to

2012. Bootstrap panel causality was used. The empirical results indicated the positive impact of the consumption of energy on economic growth.

Another group of researchers found a bidirectional relationship between economic growth and consumption of renewable energy, such as Apergis and Payne (2010), who investigated the nexus between consumption of renewable energy and economic growth for 13 countries in Eurasia, over the period from 1992 to 2007. The heterogeneous panel cointegration test was used. The authors discovered the existence of bidirectional causality between renewable energy consumption and economic growth in both the short and long run. Apergis et al. (2010) examined the causal relationship between nuclear energy consumption, renewable energy consumption, economic growth, and CO2 emissions in 19 developed and developing countries in the period from 1984 to 2007, using a panel error correction model. The results indicated the existence of a bidirectional relationship between all variables. Apergis and Payne (2011) studied the relationship between the consumption of renewable energy and economic growth for a panel of six Central American countries in the period from 1980 to 2006. The panel cointegration test was used as a methodology. The empirical results of panel error correction model indicated the bidirectional relationship between the consumption of renewable energy and economic growth in the short and long run.

Moreover, the same authors, Apergis and Payne (2012), tested the relationship between the consumption of renewable and non-renewable energy and economic growth of 80 countries over the period from 1990 to 2007. The Pedroni heterogeneous panel cointegration test was used. The test indicated the existence of a bidirectional relationship between the variables. Tugçu et al. (2012) researched the long-run and causal relationship between the consumption of renewable and non-renewable energy and GDP in Group of Seven (G7) countries in the period from 1980 to 2009, using the ARDL bounds test. The authors found the existence of a long-run bidirectional relationship in all countries investigated. Al-Mulali et al. (2013) analysed the bidirectional relationship between the consumption of renewable energy and economic growth in high-income, upper-middle-income, lower-middle-income, and high-income countries. The outcomes indicated that 79% of countries have a bidirectional relationship between the consumption of renewable energy and economic growth. On the other hand, 19% of the countries showed the presence of a unidirectional relationship between consumption of renewable energy to economic growth. Moreover, 2% pointed to the unidirectional relationship from economic growth to the consumption of renewable energy. Sebri and Ben-Salha (2014) studied the causal nexus between consumption of renewable energy and GDP growth in Brazil, Russia, India, China and South Africa (BRICS), over the period from 1971 to 2010. The ARDL bound test approach and VECM were used. The empirical results indicated the presence of a bidirectional relationship between economic growth and consumption of renewable energy, suggesting the feedback hypothesis. Lin and Mubarak (2014) examined the relationship between renewable energy consumption and economic growth in China for the period from 1977 to 2011. The ARDL model was used as a methodology. The outcomes showed that there is bidirectional causality between consumption of renewable energy and economic growth. Amri (2017) analysed the relationship between economic growth, consumption of renewable energy, and trade for 72 countries for the period from 1990 to 2012. The outcomes demonstrate a feedback linkage between income and renewable energy consumption, between trade and renewable energy consumption and between trade and income.

Although the literature has used different variables, methods, countries, regions and time series to explain the relationship between consumption of renewable energy and economic growth, some gaps were identified in the literature review which needs to be filled. Among them is the use of GDP in constant LCU as an alternative to constant US dollars. In this literature review, none of the authors used this same variable. The non-inclusion of the variable globalisation index in the model by other authors is another gap. The inclusion of this variable is essential because the globalisation has a positive impact on factor productivity and economic growth, and consequently exerts a positive impact on energy consumption (e.g., renewable and fossil), and in new investment in renewable technology, where the Mercosur countries have to access new green technology. Another gap that was identified was the non-utilization of PVAR model as methodology. All authors utilised the same methodology, such as the ARDL bunds test and heterogeneous panel cointegration test and complemented with Granger causality test.

Indeed, it is necessary to remember and make to clear that due to the existence of several conclusions it is particularly difficult to come to a single conclusion about the relationship between consumption of renewable energy and economic growth, as well as define set a direction in which these studies lead or what is already understood about the topic. Moreover, as mentioned before, this lack of consensus about the results is due to the use of different variables, time spans, and countries or regions.

In addition, there no investigations that approach the Mercosur countries. Indeed, the investigations that were used in the literature review focused on Africa, Asia, European Union, Middle East countries, and the global scale leaving aside the Mercosur countries and Latin American & Caribbean region. In other words, the literature that approaches the relationship between consumption of renewable energy and economic growth has not presented significant innovations, due to the use of methodologies, variables and countries already explored in the literature. Moreover, the only doubt that remains in this literature review is the role of globalisation in this relationship, that is how globalisation interferes in the nexus between the consumption of renewable energy and economic growth.

In order to fill these gaps this investigation will adopt a new approach that includes: **(i)** the inclusion of GDP in constant LCU; **(ii)** the inclusion of a globalisation index in the model; **(iii)** the use of PVAR model as methodology; and **(iv)** the use of Mercosur countries, given that this group is not addressed in the literature that approaches this topic. Based on the various conclusions and approaches to the literature review, what hypotheses should be raised to answer the central question of this investigation? This paper puts forward the following four hypotheses to deal with the central research question:

Neutrality Hypothesis (1): The absence of a relationship between economic growth and consumption of energy is due to the conservative policies that decrease the energy demand, but this reduction in the energy demand does not impact economic activity. This phenomenon happens principally in developing economies with high energy efficiency;

Conservation Hypothesis (2): The unidirectional relationship from economic growth to consumption of energy. This relationship occurs when the conservation policies do not impact the economic activity, for the reason that these economies are not dependent on energy to grow;

Growth Hypothesis (3): The unidirectional relationship from energy consumption to economic growth. The consumption of energy exerts a positive impact on economic activity, and any conservative policies for energy will impact economic growth;

Feedback Hypothesis (4): The bidirectional relationship between consumption of energy and economic growth. Conservative policies can hurt economic activity and vice versa. This phenomenon happens principally in developing countries.

These hypothesis can be confirmed by Fuinhas and Marques (2019) and by Ozturk (2010). Regarding this literature review, it is necessary make to clear that this chapter opted to discuss and evidence the empirical results in the most important researches into the relationship between the consumption of renewable energy and economic growth, which is our topic of investigation. That is, we focused on a specific consumption of energy to explain the relationship between the variables. Moreover, due to the existence of several conclusions about this relationship, we opted to use this structure of the literature review, where we believe that this structure is most clear to understand. The next section will show the data and method that will be used in this chapter.

3.3. Data and methodology

This section is organised into two parts. In the first is the data that includes the variables and database, and the second part describes the methodology that will be used in this study.

3.3.1 Data

To study the nexus between economic growth and consumption of renewable energy, five countries from the Mercosur bloc were selected, namely **Argentina**, **Brazil**, **Paraguay**, **Uruguay** and **Venezuela (RB)**. Mercosur is a sub-regional bloc that was created in 1991, with the purpose of free trade and the fluid movement of goods, people and currency among the associate countries (Koengkan, 2018a).

The period from 1980 to 2014, available for all variables, was used for this chapter. Finally, the last question. Why were the Mercosur countries and period used for this chapter? The Mercosur countries were chosen because they have experienced rapid economic growth in the last thirty-four years as well as a rapid increase in the consumption of renewable energy. Moreover, another motivation that led us to select this group of countries was the integration of countries with the rest of the world. Indeed, this integration is related to the globalisation process, where, the more a country is integrated with others, the greater is the globalisation. In this case, we could have selected several groups of countries in the LAC region, such as the Andean Community or in Spanish

"*Comunidad Andina*" (CAN), Union of South American Nations (USAN) or Free Trade Area of the Americas (FTAA) and others for the realisation of this investigation. However, the group of countries that are the most dynamic and integrated into the LAC region are the Mercosur countries. This trade bloc covers 72% of the South American territory approximately; 69.5% of South American population, that is (288.5 million) and 76.2% of South America's GDP in 2016, that is ($2.79 trillion out of a total of $3.66 trillion). Together, the Mercosur is the fifth largest economy in the world, with a GDP of $2.79 trillion. Additionally, this bloc is the main recipient of foreign direct investment (FDI) in the LAC region, receiving 47.4% of all FDI flow to South America, Central America, Mexico and the Caribbean in 2016 (Mercosul, 2019). Moreover, this dynamic and integration also are visible in the recent free trade agreement between Mercosur and the European Union in June of 2019 (Ministry of Foreign Affairs of Brazil, 2019).

The period from 1980 to 2014 was used due to the availability of data for the variables **Fossil** and **Renewable** for all countries selected. In the period that the variables **Fossil** and **Renewable** were retrieved from the IEA, that is May of 2018, there were data until 2014. Therefore, this unavailability of data does not allow us to extend our database. This is the same problem that was identified in **Chapter 2** (p. 56), where the database from IEA was used.

The variables used in this chapter are: GDP in constant LCU (**GDP**), available in the World Bank Open Data (WBD, 2019);[(5)] Fossil fuels energy consumption (**Fossil**) in billion kilowatt-hours (kWh) from coal, gas and oil available in the International Energy Agency (IEA, 2018); Renewable energy consumption (**Renewable**) in billion kilowatt-hours (kWh) from biomass, hydropower, solar, photovoltaic, wind, wave and waste in the International Energy Agency(IEA, 2018); a KOF globalisation index *De facto* (**Global**) that measures the economic, social and political dimensions of globalisation on a scale from 1 to 100. This variable is available in the KOF Index of Globalisation (KOF, 2019).The variable can reach three different dimensions, namely economic, political and social, and which are mainly accepted in contemporary theory (e.g., Gygli et al., 2019, p. 546; Dreher, 2006, p. 1092; Caselli, 2012, p. 39; Nye and Keohane, 2000, p. 4). Therefore, according to authors, economic globalisation is characterised as a flow of capital, goods,

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Notes (5): GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant local currency.

and services between countries or nations as well as information and perceptions that accompany market exchanges. In the economic globalisation Gygli et al. (2019, p. 549-550) includes also the financial and trade globalisation. Social globalisation is the process of spread of people, ideas, information, images, and culture. However, Raab et al. (2008) take a more refined look at cultural globalisation. After several sociological studies on international cultural diffusion, the authors passed to include the diffusion of values as globalisation in cultural affairs. Indeed, the diffusion of cultural values is closely related to sharing cultural goods and services (e.g., music, movies, TV series, trade-in newspapers, social networks, and other works of art across borders) (Kluver and Fu, 2004). Political globalisation characterises in the diffusion of government policies. According to Dreher et al. (2008) this diffusion of government policies is summarised in foreign embassies; membership in International Organisations; and the number of signed international treaties.

Therefore, the definition of globalisation that was used by Dreher (2006, p.1092) in **Chapter 1** (p. 28) seems to be suitable because reflects these dimensions. Moreover, the fact that the globalisation enfolds the whole globe needs to be stressed, in order to distinguish the factor between the globalisation and other forms of openness and internationalisation. Indeed, the globalisation that we view today is the reflection of the intensity of contact of these dimensions at such large distances. Therefore, the consumer, for example, can concentrate on finding certain desired goods and services, without concern about their distance. This means that the decision between going to the other country or on the other side of the world in order to purchase a good or service depend increasingly on features other than distance due to the globalisation progress.

In order to identify the role of globalisation in interactions between renewable Energy consumption and economic growth in more details, it is necessary to measure the globalisation. Indeed, regularly some indicators that reflecting openness, such as trade openness, financial openness, and trade as percentage of GDP are used as a proxy for globalisation (e.g., Gygli et al., 2019; Koengkan et al.,2019a; Koengkan et al., 2019b). However, globalisation is much more than trade and financial openness. Globalisation also includes citizens of different countries or nations that communicating with each other and exchanging ideas, information, images, and culture, or government working together to tackle political problems of global reach (Gygli et al., 2019).

As can see by the explanation above the globalisation has several facets. However, in order to account these manifold facets of globalisation, it is necessary a good indicator in order to explain them. The KOF Globalisation index that was introduced by Dreher (2006) and updated in Dreher et al. (2008) is the better indicator to explain these facets because allow combining different variables and measuring different aspects of globalisation, all this into the same index. It is a differential that other indicators do not have, where this globalisation indicator measures as mentioned before by Gygli et al. (2019) Koengkan et al. (2019b), Dreher et al. (2008), and Dreher (2006) the economic, social and political dimension of globalisation since 1970 for almost every country in the world. It makes this indicator the most widely used in the academic literature (e.g., Gygli et al., 2019, p.544; Potrafke, 2014, p. 510). Moreover, the KOF Globalisation index differentiates between *De Facto* and *De Jure* globalisation. According to Gygli et al. (2019) the facto globalisation measures the international flows and the activities, while the jure globalisation measures only conditions and policies that facilitate and foster the international flows and activities. For this reason, this chapter opted to use the KOF Globalisation index *De facto*.

Moreover, there is an economic explanation for the use of variable **Global** in this model. Reseach into the consumption of energy, globalisation process, and economic growth conducted in literature are mainly related to the components of globalisation (e.g., Sami, 2011; Sadorsky, 2012).

Indeed, most of these investigations have use variables such as imports, exports, and trade liberalisation as an indicator of trade openness in a production function (Dogan and Deger, 2016). Conversely, recent investigations have considered only subcomponents of globalisation, for example, capital mobility, economic integration and trade flow openness (e.g., Chang and Berdiev, 2011; Shahbaz et al., 2015; Koengkan, 2018b). In this context, some investigations use the KOF Index of Globalisation (e.g., Dogan and Deger, 2016; Koengkan, 2017a; Koengkan et al., 2019b). The use of this variable, combined with fixed effects techniques, can explain how the interactions of Mercosur countries with the rest of the world via globalisation affect the consumption of energy. Some investigations that used the KOF index Globalisation have presented satisfactory results than those that have used other subcomponents of globalisation (e.g., Dogan and Deger, 2016; Koengkan, 2017a; Koengkan et al., 2019b).

Regarding the globalisation process, the relevant literature has been indicating that the consumption of energy is positively related to the prospects of development of an economy and economic growth (Iheanacho, 2018). Indeed, globalisation is considered one of the potential factors that induces higher economic growth, and energy demand is expected to rise to response to economic growth (Iheanacho, 2018). The globalisation process allows countries to improve their trade and total factor productivity and raises the standards of living, which consequently improves economic growth (Koengkan et al., 2019b). The globalisation index was included in this model because the Mercosur countries are in the process of development and openness, and for this reason, the inclusion of this variable is essential and indispensable for this investigation, because it will evidence the influence of globalisation on economic growth and energy consumption.

All variables in this study were transformed into per capita values using the total population of each country, except the variable "Global". The use of per capita values can reduce the effects of population disparity among the countries of the panel's data (Koengkan, 2018b). The option for using GDP in constant LCU instead of constant US dollars attenuates the influence of both inflation (otherwise present in the variables of the model) and the deviation of exchange rates from their fundamentals. Indeed, we need to consider that the exchange rates often deviate from their long-run fundamental equilibrium for long time spans.

Additionally, as mentioned in **Chapter 2** (pp. 56-57) the phenomenon that we are investigating is related to domestic variables, measuring all variables in US dollars could exacerbate the cross-sectional dependence adds exogenous disturbance to the panel data. This cross-sectional dependence could compromise the estimation of the model. The GDP in constant US dollars was tested on the initial models and presented results slightly different from when constant LCU was used. **Table 3.1** shows the descriptive statistics of all variables.

Table 3.1. Descriptive statistics

Variables	Descriptive Statistics				
	Obs.	**Mean**	**Std.-Dev.**	**Min.**	**Max.**
LnGDP	174	10.5056	2.6257	7.2285	15.2759
LnRenewable	175	-13.2067	0.8657	-15.4224	-11.4340
LnFossil	175	-16.6636	0.5055	-18.6642	-15.9598
LnGlobal	175	3.9562	0.1922	3.3919	4.2093

Notes: (Ln) denotes variables in the natural logarithms; 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 *sum* of Stata was used.

The 174 observations in the variable "**LnGDP**" is due to the unavailability of data in 2014 for Venezuela (RB) when the country suffered a severe financial and political crisis, and their GDP for this year was not made available by the Central Bank. After the choice of variables, it is necessary to show the methodology that will be used in this chapter.

As mentioned before in **Chapter 2** (p.56), all variables are updated every six months. This is good practice to make the investigation updated and consistent. So, in the case of this chapter, only the variables **GDP** and **Global** were updated in June of 2019. However, it was not possible to update date for the variables **Renewable** and **Fossil**, because of the IEA site no longer provides open access data, as mentioned in **Chapter 2** (p.56). Consequently, data collected in November of 2018 was used. Due to this restriction with data from IEA, in the next chapters, the option was taken to use only data from the World Bank Open Data (WBD).

3.3.2 Methodology

The best methodology to analyse the nexus between the variables mentioned in subsection **3.3.1** is the PVAR model. This methodology, as mentioned in **Chapter 2** (p.53), was developed by Holtz-Eakin et al. (1988) as an alternative to multivariate simultaneous equation models. The PVAR model is used in several research fields but is most commonly used by macroeconomists working with data for many countries and with a long-time span (Koop and Korobilis, 2016). Canova and Ciccarelli (2009) emphasise that PVARs are an excellent way to model how shocks are transmitted across the countries. As the Mercosur deepens its integration, the examination of these issues becomes essential for modern applied economists.

According to Abrigo and Love (2015), the PVAR model has an advantage of treating all variables as endogenous, although the existence of restrictions based on statistical procedures may be imposed on disentangling the impact of exogenous shocks on the system.

Why was this methodology used for the realisation of this investigation? As clearly mentioned in the robustness check in **Chapter 2** (pp.53-54), this methodology was applied because in the panels with long time spans (macro panels), as in our case, the presence of cointegration between the variables and the endogeneity is expected. Indeed, in order to handle the problem of endogeneity and cointegration, the literature has recommended the use of PVAR models.

Moreover, the use of this methodology in order to handle these phenomena is confirmed in their advantages, such as: **(i)** the model is useful in the presence of little theoretical information about the relationship between the variables to guide the specification of the model; **(ii)** this model was created to address the endogeneity and cointegration problem among the variables of model, as mentioned in **Chapter 2** (pp.53-54); **(iii)** the PVAR model can account for any delayed effects and of the variables under consideration, and thus determine whether the effects of economic growth and energy consumption are in the short or long run or both; **(iv)** this model allows country fixed-effects to be included that capture the time-invariant components that may affect the consumption of energy or economic growth and global time effects that affect all countries in the same period of time; and **(v)** this model can account for any global shocks that impact all countries at the same time in the model.

For this reason, the PVAR model was chosen for the realisation of this chapter. The PVAR model is represented by the following linear **Equation (3.1)**:

$$a_{it} = a_{it-1}x_1 + f_{it-p+1}x_{p-1} + g_{it-p+1}x_p + d_{it}l + \varepsilon_{it}\ , \qquad \textbf{(3.1)}$$

where, a_{it} is the vector of dependent variables that are represented by variables in the first-differences of natural logarithms (e.g., **DLnGDP**, **DLnRenewable**, **DLFossil**, and **DLGlobal**).

The use of variables in the first-differences of natural logarithms is due to the PVAR model requiring that all variables be I(0) that is stationary. The stationarity of variables can be confirmed by the visual analysis of descriptive statistics and by the 2nd-generation unit root test that will be evidenced in **Table 3.3**.

The g_{it} is the vector of exogenous covariates, and ε_{it} are the vectors of the dependent variable in a panel of fixed effects and idiosyncratic errors respectively, and the matrices x_1, x_{p-1}, x_p and matrix l are parameters to be estimated. The conceptual framework (**Figure 3.1**) highlights the methodological approach that will be used in the PVAR model.

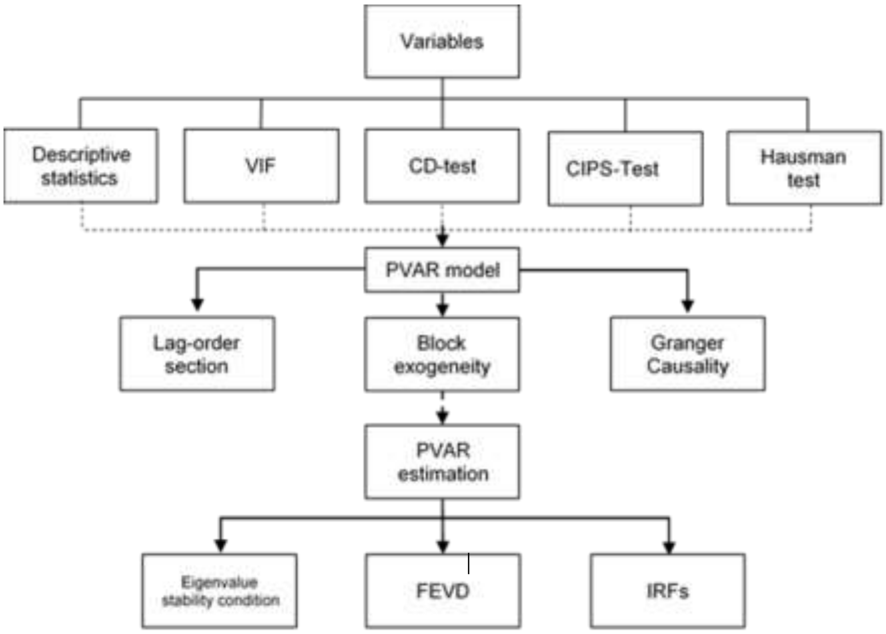


Figure 3.1 Conceptual framework

Before the realisation of PVAR regression, it is advisable to check the properties of the variables. To this end, some preliminary tests were applied, namely:

a) Variance inflation factor (VIF) (Belsley et al., 1980) to check the existence of multicollinearity between the variables in the panel's data;

b) Cross-sectional dependence (CSD-test) to verify the existence of cross-section dependence in the panel data (Pesaran, 2004);

c) 2nd-generation unit root test Pesaran (2007) Panel unit root test (CIPS) to check the presence of unit roots. The null hypothesis rejection is that the variable is I(1);

d) The Hausman test, which determines the presence of heterogeneity, i.e. whether the panel has random effects (RE) or fixed effects (FE) – the null hypothesis of this test is that the best model is RE – the literature mostly uses estimations with FE, but the use of RE is admissible (e.g., Sigmund and Ferstl, 2017; Binder et al., 2005);

e) A Panel VAR lag-order selection that reports the overall model coefficient of determination (Hansen, 1982).

After the PVAR regression, it is necessary to apply the specification tests to verify the characteristics of the model. To this end, some diagnostic tests by Abrigo and Love (2015) will be applied, namely:

- **f)** The Granger causality Wald test, which analyses the causal relationship between variables. The null hypothesis of this test is that the excluded variable does not Granger-cause equation variable;
- **g)** The Eigenvalue stability condition, which verifies the stability condition of PVAR estimates by computing the modulus of each eigenvalue of the model;
- **h)** Forecast-error variance decomposition (FEVD), which computes the forecast-error variance decomposition based on the Cholesky decomposition of the underlying PVAR model. In this test, the standard errors and the confidence intervals are based on the Monte Carlo simulation;
- **i)** Impulse-response function (IRF). The confidence bands of IRFs are estimated using Gaussian approximation and based on the Monte Carlo simulation.

Indeed, the preliminary and specification tests are the same as were used in **Chapter 2** (p.54) in the robustness check. This section shows the data that will be used, the method, and the preliminary and specification tests. In the next section, the results will be shown.

3.4. Results

In line with what was stated earlier, this section shows the outcomes of the preliminary tests, PVAR model, and specification tests. Indeed, the realisation of these tests is essential in order to identify if the PVAR model is an appropriate methodology for the realisation of this study. Then, to verify the level of multicollinearity and the presence of cross-sectional dependence in the panel's data, the VIF and CSD-tests were applied. **Table 3.2** shows the results of VIF and CSD-tests.

Table 3.2. VIF-test and CSD-test

Variables	VIF	1/VIF	Mean VIF	CD-test	p-value		Corr	Abs (corr)
LnGDP		n.a.		13.74	0.000	***	0.737	0.737
LnRenewable	1.18	0.8443		10.61	0.000	***	0.571	0.571
LnFossil	1.49	0.6694		12.89	0.000	***	0.692	0.692
LnGlobal	1.29	0.7765	1.32	16.21	0.000	***	0.871	0.871
DLnGDP		n.a.		7.29	0.000	***	0.397	0.397
DLnRenewable	2.05	0.4867		0.51	0.611		0.028	0.144
DLnFossil	2.05	0.4882		1.73	0.084	*	0.094	0.128
DLnGlobal	1.00	0.9958	1.70	6.03	0.000	***	0.329	0.329

Notes: ***, * denote statistically significant at 1%, and 10% level; (Ln and DLn) denote variables in the natural logarithms and the first-differences of logarithms; the Stata command *xtcd* was used.

The results of the VIF test indicate the existence of low multicollinearity between the variables because the mean VIF of variables in the natural logarithms was 1.32, while in the first-differences it was 1.70. Both results of mean VIFs are below the benchmark of 10 established by the VIF test. To identify the presence of cross-sectional dependence in the panel's data, the CSD-test was used. The outcome of the CSD-test shows the existence of cross-sectional dependence in all variables in the natural logarithms and the variables economic growth, consumption of fossil fuels, and also the globalisation index in the first-differences.

The econometrics literature recommends that, in the presence of cross-sectional dependence, it is necessary to examine the stationarity of variables with robust tests. For this, the 2nd-generation unit root test (CIPS-test) was applied. The null hypothesis rejection of this test is that all variables are I(0) that is stationary. **Table 3.3** shows the results of the unit root test of the second generation.

Table 3.3. Unit root test

Variables	**2ndGeneration 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**	
LnGDP	1	1.705	0.956		0.208	0.582	
LnRenewable	1	-2.247	0.012	**	-3.608	0.000	***
LnFossil	1	-0.622	0.267		-1.209	0.113	
LnGlobal	1	-0.645	0.259		0.736	0.769	
DLnGDP	1	-5.296	0.000	***	-4.039	0.000	***
DLnRenewable	1	-6.440	0.000	***	-5.263	0.000	***
DLnFossil	1	-6.060	0.000	***	-5.164	0.000	***
DLnGlobal	1	-6.047	0.000	***	-5.662	0.000	***

Notes: ***, **, denote statistically significant at 1% and 5% level, respectively; (Ln and DLn) denote variables in the natural logarithms and the first-differences of logarithms; null for CIPS tests: series is I (0); the lag length (1) and trend were used in this test.

The Panel Unit Root test (CIPS) test was used with lag length (1), without trend and with trend. The results of CIPS-test show the presence of unit roots in the variable consumption of renewable energy in the natural logarithms without trend and with trend and in all variables in the first-differences. The realisation of the unit root test is essential because it is necessary to verify whether the model is heterogeneous. The results of the Hausman test not reject the null hypothesis, i.e. supporting the presence of RE (see **Table 3.4** below).

Table 3.4. Hausman Test

Variables	**(b) Fixed**	**(B) Random**	**(b-B) Difference**	**Sqrt(diag(V_b-V-B) S.E.**
DLnRenewable	-0.0444	-0.0452	0.0007	0.0023
DLnFossil	0.1612	0.1641	-0.0029	0.0113
DLnGlobal	-0.1129	-0.1036	-0.0092	0.0217
Chi2 (3)	**1.94**			

Notes: (DLn) denotes variables in first-differences of logarithms respectively; The Stata command *Hausman* (with the options, sigmamore alleqs constant) was used.

To report the overall model coefficients of determination, the lag-order section was calculated. The overall coefficient of determination (CD), Hansen’s J statistic (J), p-value (Jp-value), MMSC-Bayesian information criterion (MBIC), MMSC-Akaike information criterion (MAIC), and MMSC-Hannan and Quinn information criterion (MQIC) were computed. **Table 3.5** shows the results of lag-order selection.

Table 3.5. PVAR lag-order selection

Lags	CD	J	Jp-value	MBIC	MAIC	MQIC
1	0.5469	99.9960	0.3697*	-366.5467	-92.0039	-203.5559
2	0.4273	77.5961	0.5553	-311.1888	-82.4038	-175.3638
3	0.0403	71.6981	0.2378	-239.3292	-56.3018	-130.6698

Notes: The Stata command *pvarsoc* was used.

One lag was used in the PVAR lag-order, totalizing 129 observations, 5 panels, and an average of number T of 25.800. The results of Hansen's J statistic (J) is higher at one lag, and the MBIC, MAI, and MQIC estimations are lower at one lag. After the realisation of preliminary tests, the PVAR regression was computed. **Table 3.6** shows the results of the PVAR model. The lag length (1), indicated by Panel VAR lag-order selection was used in the PVAR estimation.

Table 3.6. PVAR model outcomes

Response of	Response to							
	DLnGDP$^{(t)}$		**DLnRenewable**$^{(t)}$		**DLnFossil**$^{(t)}$		**DLnGlobal**$^{(t)}$	
DLnGDP$_{(t-1)}$	0.3775	***	0.5150	***	0.1730	***	-0.2249	***
DLnRenewable$_{(t-1)}$	0.0196	***	-0.4068	***	-0.0646	***	0.0140	***
DLnFossil$_{(t-1)}$	-0.1053	***	0.1851	***	-0.0542	***	0.0444	***
DLnGlobal$_{(t-1)}$	0.2259	***	0.2478	*	-0.1881	**	0.4846	***
***N.* obs**	**129**							
***N.* panels**	**5**							

Notes: ***, **, * denote statistical significance level at 1%, 5%, and 10% level; (DLn) denotes variables in the first-differences of logarithms; The Stata command *pvar* with one lag was used. Instruments: l (1/7).

The results of PVAR regression points to the existence of endogeneity in the variables. Indeed, the lagged variables in all PVAR equations are at least statistically significant at 1% level. Additionally, only the variables in the first-differences were used in the PVAR regression because the respective model requires that all variables be I(0) (see **Table 3.3**).

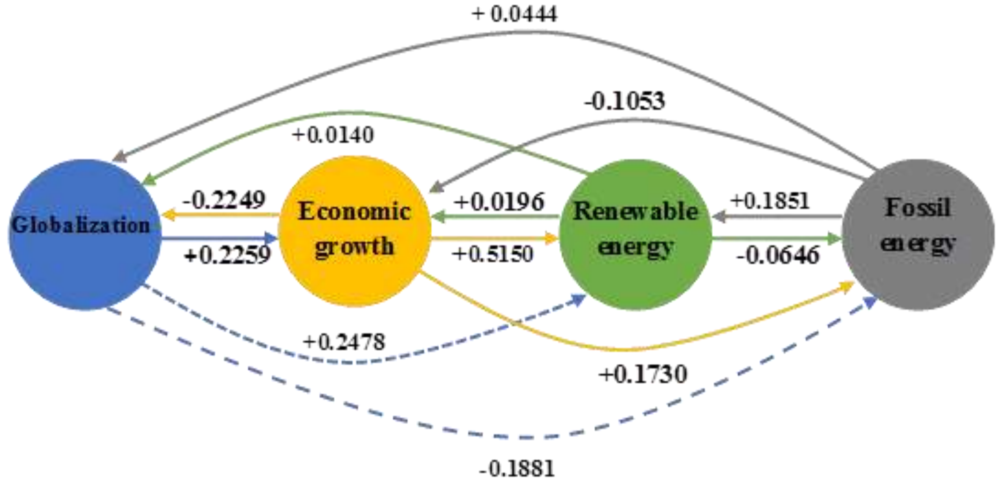
After the PVAR estimation, it is advisable to verify the characteristics of the model. To this end, the specification tests developed by Abrigo and Love (2015) were computed. The Granger causality Wald test was used to analyse the causal relationship between the variables in the PVAR model. **Table 3.7** shows the results of the Panel Granger causality Wald test.

Table 3.7. Panel Granger causality Wald test

Equation \ Excluded		chi2	Df.	Prob > chi2
DLnGDP	**DLnRenewable**	8.458	1	0.004
	DLnFossil	58.145	1	0.000
	DLnGlobal	19.320	1	0.000
	All	158.409	3	0.000
DLnRenewable	**DLnGDP**	25.483	1	0.000
	DLnFossil	10.074	1	0.002
	DLnGlobal	3.084	1	0.079
	All	42.748	3	0.000
DLnFossil	**DLnGDP**	10.347	1	0.001
	DLnFossil	20.917	1	0.000
	DLnGlobal	3.596	1	0.058
	All	33.814	3	0.000
DLnGlobal	**DLnGDP**	64.837	1	0.000
	DLnRenewable	11.534	1	0.001
	DLnGlobal	7.595	1	0.006
	All	149.201	3	0.000

Notes: ***, **, * denote statistical significance level at 1%, 5 %, and 10 % respectively; (DLn) denotes variables in the first-differences of the logarithms; the Stata command *pvargranger* was used.

The results of Granger causality Wald test point to the existence of a bidirectional relationship between economic growth and consumption of renewable energy, economic growth and consumption of fossil fuels, economic growth and globalisation, consumption of renewable energy and consumption of fossil fuels, globalisation and consumption of renewable energy, and globalisation and consumption of fossil fuels. **Figure 3.2** summarises the causalities between the variables. Indeed, this figure was based on results from Panel Granger causality Wald test (see **Table 3.7**) and the results of PVAR estimation (see **Table 3.6**).

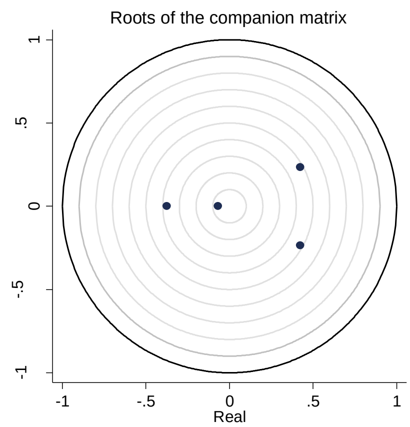


Significant at 1% Significant at 5% Significant at 10%

Figure 3.2 Summary of causality of the variables

Indeed, after the Granger Causality Wald test, the eigenvalue stability condition was applied. **Table 3.8** displays the graph of the eigenvalue stability condition.

Table 3.8. Eigenvalue stability condition

Eigenvalue			Graph
Real	**Imaginary**	**Modulus**	
0.4233	-0.2344	0.4839	
0.4233	0.2344	0.4839	
-0.3752	0.0000	0.3752	
-0.0702	0.0000	0.0702	

Notes: The Stata command *pvarstable* was used.

The eigenvalue test points out that the PVAR model is stable, because all eigenvalues are inside the unit circle, satisfying the stability condition of the test. So, the FEVD needs to be computed after the eigenvalue test. **Table 3.9** shows the outputs of FEVD test.

Table 3.9. Forecast-error variance decomposition

Response variable and Forecast Impulse Variable Horizon	Impulse variables			
	DLnGDP	**DLnRenewable**	**DLnFossil**	**DLnGlobal**
DLnGDP				
0	0	0	0	0
1	1	0	0	0
5	0.9435	0.0005	0.0164	0.0394
10	0.9433	0.0005	0.0164	0.0396
15	0.9433	0.0005	0.0164	0.0396
DLnRenewable				
0	0	0	0	0
1	0.0205	0.9794	0	0
5	0.0256	0.9663	0.0057	0.0022
10	0.0256	0.9663	0.0057	0.0022
15	0.0256	0.9663	0.0057	0.0022
DLnFossil				
0	0	0	0	0
1	0.0324	0.2576	0.7098	0
5	0.0415	0.2756	0.6764	0.0063
10	0.0415	0.2756	0.6764	0.0063
15	0.0415	0.2756	0.6764	0.0063
DLnGlobal				
0	0	0	0	0
1	0.0064	0.0085	0.0004	0.9845
5	0.1625	0.0106	0.0111	0.8156
10	0.1626	0.0106	0.0111	0.8154
15	0.1626	0.0106	0.0111	0.8154

Notes: The Stata command *pvarfevd* was used; (DLn) denotes variables in the first-differences of logarithms.

The FEVD test indicates that one period after the shock, the variables themselves explained almost all the forecast error variance. Then, five periods after a shock on economic growth, the variable explains 94% of forecast error variance, consumption of renewable energy explains 0.05%, consumption of fossil fuels 1.64%, and globalisation after ten periods explains 4%. The consumption of renewable energy one period after a shock explains 98% of forecast error variance, economic growth five periods after a shock explains 2.6%, consumption of fossil fuels five periods after a shock explains 0.06%, and globalisation five periods after a shock explains 0.02%. One period after a shock on the consumption of fossil fuels, the variable explains 71% of forecast error variance, economic growth five periods after a shock explains 4.15%, consumption of renewable energy one period after a shock explains 25.76%, and globalisation five periods after a shock explains 0.06%. Finally, globalisation one period after a shock explains 98% of forecast error variance, the economic growth five periods after a shock explains 16.25%, consumption of renewable energy five periods after a shock explains 1.06%, and consumption of fossil fuels five periods after a shock explains 1.11%. **Figure 3.3** shows the impulse – response functions.

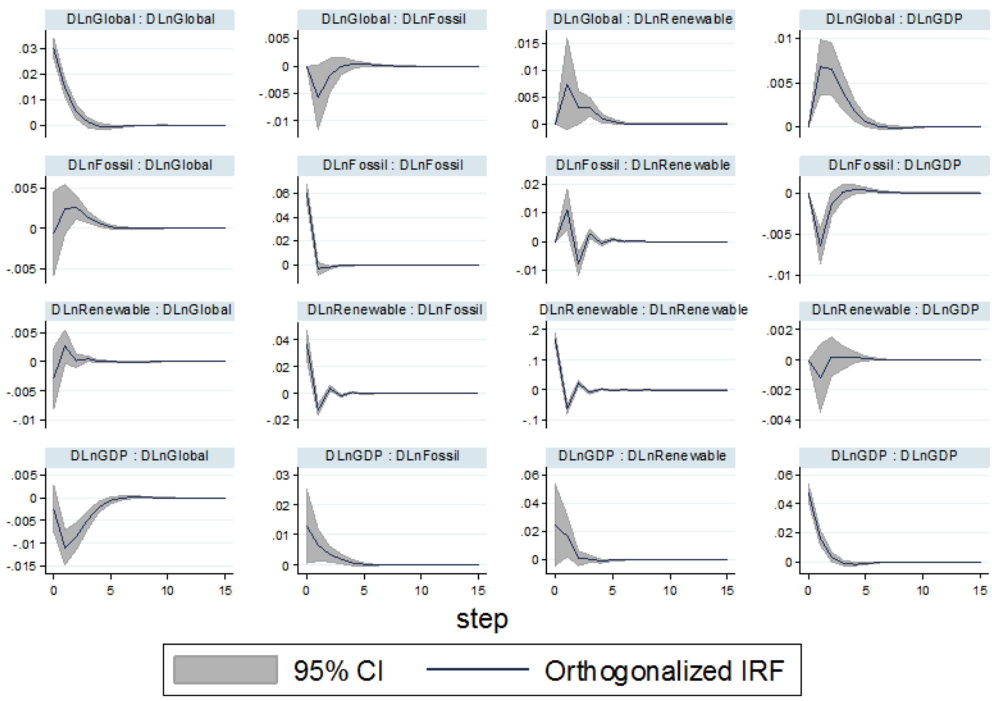


Figure 3.3 Impulse – response functions; the Stata command *pvarirf* was used.

In the long run, all variables converge to equilibrium, supporting that the variables of the model are I(0). Then, the impulse-response functions are in concordance with FEDV test. The next section will show the discussion of the empirical results.

3.5. Discussions

The preliminary tests that check the characteristics of variables point to the presence of low-multicollinearity, cross-sectional dependence, stationarity in the first-differences of variables, the random effects in the model, and the need to use the lag length (1) in the PVAR regression (see **Tables 3.1**, **3.2**, **3.3**, **3.4**, and **3.5**). In the preliminary tests, the variable consumption of renewable energy in the first-differences does not have the presence of cross-sectional dependence.

The answer for the non-existence of cross-sectional dependence in the variable consumption of renewable energy in the first-difference is largely country-specific and conditional on the intermittence that characterises its generation (e.g., biofuels, solar, photovoltaic, hydro and wind sources) (Fuinhas et al., 2017). The existence of cross-sectional dependence in the variables of the panel's data means that the countries of this study share the same characteristics and shocks (Koengkan, 2018a).

The results of the PVAR model indicate that the consumption of renewable energy and globalisation process increase economic growth, while the consumption of fossil fuels reduces it. Economic growth, consumption of fossil fuels and globalisation increase the consumption of renewable energy. Economic growth increases the consumption of fossil fuels, while the consumption of renewable energy and globalisation reduce the consumption of energy from fossil sources. Furthermore, the consumption of renewable and fossil fuel increases the process of globalisation, while economic growth reduces it (see **Table 3.6**).

The outcomes of specification indicated the presence of a bidirectional relationship between economic growth and the consumption of renewable energy, economic growth to the consumption of fossil fuels, economic growth to globalisation, consumption of renewable energy to consumption of fossil fuels, globalisation to the consumption of renewable energy, and globalisation to consumption of fossil fuels. The PVAR model is stable. One period after the shock, the variables themselves explained almost all the forecast error variance, and the impulse – response functions of all variables converge to equilibrium, supporting that the variables of the model are I(0) (see **Tables 3.7**, **3.8**, **3.9**, and **Figure 3.2** and **3.3**).

Are the empirical finds of this investigation in keeping with the literature? What are the possible explanations for the causality between the variables? Do the empirical results confirm one or more of the research hypotheses? Are the empirical results found in **Chapter 2** able to support the results of this investigation?

The bidirectional relationship between economic growth and the consumption of fossil fuels is in line with several studies that approached this nexus (e.g., Chan et al., 2017; Mirza and Kanwal, 2017; Fuinhas et al., 2017; Koengkan, 2017b; Koengkan, 2017c). In Latin American countries, fossil fuels are a vital input. Higher economic growth leads to increases in the consumption of fossil fuels (such as oil, coal and gas) to supply the demand in these countries (Chan et al., 2017). Additionally, Mirza and Kanwal (2017) add that in the Latin American region, fossil fuels are the primary inputs for agriculture and industry, and consequently exert a positive impact on economic activity.

Koengkan (2017b) affirms that South American countries are dependent on the consumption of energy, where an increase of 1% of the consumption of energy makes economic growth increase by 0.5%. Fuinhas et al. (2017) found that the high economic dependency on fossil fuels is because Latin American countries are among the major fossil fuel energy producers (such as Argentina, Brazil, Venezuela (RB)), and others are significant importers, such as Uruguay and Paraguay. Koengkan (2017c) confirms that the bidirectional relationship between consumption of fossil fuels and economic growth is due to energy use in the LAC countries being very sensitive to changes in economic activity, where rapid economic growth exerts a positive influence on energy demand.

Several authors confirm the bidirectional nexus between economic growth and consumption of renewable energy (e.g., Amri, 2017; Destek and Aslan, 2017; Kahia et al., 2017; Koengkan, 2017d; Rafindadi and Ozturk, 2017; Lin and Mubarak, 2014; Al-Mulali et al., 2013; Apergis and Payne, 2012; Tugçu et al., 2012; Apergis and Payne, 2011; Apergis and Payne, 2010; Apergis et al., 2010). The vast abundance of renewable sources (e.g., hydropower, solar, photovoltaic, wind, geothermal and waste) in all countries of the Latin American region stimulate investment in renewable energy and consequently exerts a positive impact on economic activity, and also on the consumption of energy (Apergis and Payne, 2010).

According to Koengkan (2017d), the increase of economic activity exerts a positive impact on renewable energy consumption and in investment in this kind of source to supply the demand in the long run. This evidence is confirmed in **Chapter 2** (p.66), where it was found that the per capita GDP has a positive impact of 0.2318 on the installed capacity of renewable energy. Additionally, the bidirectional relationship between the consumption of renewable energy and fossil fuel is confirmed by Apergis and Payne (2010). The bidirectionality between consumption of renewable energy and fossil fuel is due to both energy sources being substitutes for each other in the energy mix in Latin American countries (Apergis and Payne, 2010).

Finally, the bidirectional relationship between consumption of renewable energy and fossil fuel and globalisation is in line with some authors that studied this nexus (e.g., Koengkan, 2017a; Shahbaz et al., 2015; Leitão, 2014). According to Koengkan (2017a), the globalisation process in Latin American countries has a positive impact on factor productivity and economic growth, and consequently exerts a positive impact on renewable energy consumption, and also in new investment in renewable technology that consequently increases the efficiency technology, where Latin American countries have to access new green technologies via imports. Leitão (2014) confirms that the trade and financial liberalisation, as well as international environmental rules, encourages economies to use renewable energy sources and consequently reduces the consumption of non-renewable energy sources.

Moreover, the idea advanced by Koengkan (2017a) and Leitão (2014) is confirmed in **Chapter 2**, where it was discovered the financial openness is a proxy of globalisation and encourages investment in renewable energy sources. Indeed, financial openness increases the capital stock and consequently reduces the cost of external financing, encouraging investment in renewable energy technologies. Regarding the effect of the globalisation process on the consumption of non-renewable energy sources, the next chapter will carry the knowledge of the interaction between these two variables and confirm the results that were found in this chapter. This section showed the possible explanations for bidirectionality in the Mercosur countries, and the next section will show the conclusion and policy implications of this chapter.

3.6. Conclusions and policy implications

The nexus between the consumption of renewable energy and economic growth was investigated. This chapter focused on five Mercosur countries in the period from 1980 to 2014. The PVAR model was used as a methodology. Thus, the results of preliminary tests indicated the existence of low-multicollinearity between the variables of the model, cross-sectional dependence, the stationarity of all variables in the first-differences of logarithms, and the need to use the lag length (1) in the PVAR regression.

The results of the PVAR model and Granger causality Wald test confirmed hypothesis (4): the existence of a bidirectional relationship between consumption of energy (renewable and also fossil sources) and economic growth. The countries are dependent on fossil fuels to grow due to the bidirectional relationship between the consumption of fossil fuels and economic growth. The existence of substitutability between consumption of renewable and fossil sources in periods of drought in the reservoirs was found. Indeed, hydropower was substituted by thermoelectric plants that are powered by oil or gas. The process of globalisation in the countries has a positive indirect influence on consumption of renewable energy, due to the positive impact of globalisation on economic activity and consequently on energy demand, as well as the globalisation process decreasing the consumption of fossil fuels. Thus, the dependency on fossil fuels for growth and the substitutability between renewable and fossil reveals the existence of low energy source diversification in the Mercosur countries. The low energy diversification in these countries is due to low public and private investment in green energy in order to supply the growing and future demand.

What must be done to reverse this situation in the Mercosur countries? More public policies and incentives should be created in order to attract more investment in renewable energy and increase the consumption of this kind of source. Policies should be advanced that encourage households and firms to purchase appliances with a high energy efficiency standard in order to reduce energy consumption. Policies should be developed that encourage public and private banks to support investment in renewable energy technologies or the purchase of technologies that reduce energy consumption and environmental degradation by firms and households with low-interest rates and credit. The bureaucracy that discourages the renewable energy foreign investment should be reduced, as should the political lobby between governments and large producers of fossil fuels.

These policies need to be implanted with the purpose of reducing the dependency of Mercosur countries on fossil fuels, as well as reducing environmental degradation by increasing the consumption of renewable energy. Also it is advisable to promote economic growth and take advantage of the enormous abundance of renewable energy sources in the Mercosur countries. This study can open a new field of research as its approach analyses the effect of globalisation in the process of energy transition. This new field is relevant because it not enough explanations that approach this issue exist in the literature. Finally, the empirical findings of this study not only help to advance the existing literature but also warrant attention from governments and policymakers.

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Chapter 4
The Reaction of the Consumption of Fossil Fuels to Trade Openness in Latin America & the Caribbean Countries

Abstract

This chapter investigates the impact of trade openness on the consumption of fossil fuels for a panel of fourteen LAC countries over the period from 1990 to 2014. To this end, a PARDL model in unrestricted error-correction form is estimated, and robustness checks are performed by estimating a PNARDL model. The results of the PARDL model point indicate that the impact of economic growth and elasticity of trade openness are statistically significant at the 1% level and contribute to increased consumption of fossil fuels in the LAC countries. However, the impact and elasticity of consumption of renewable energy are statistically significant at 1% and 5% levels and thus contribute to decreasing consumption of fossil fuels. Regarding the ECM term, it is negative and statistically significant at the 1% level. As regards the results of the robustness check, the PNARDL indicates that the impact of economic growth and the positive and negative asymmetry of its elasticity, and the impact of trade openness and its elasticity contribute to increased consumption of fossil fuels. Nevertheless, the asymmetry of the impact of consumption of renewable energy and its elasticity decrease the consumption of fossil fuels. Therefore, the positive impact of trade openness on the consumption of fossil fuels suggests that the process of globalisation by trade liberalisation in the LAC countries is not sufficient to bring more investment that encourages R&D in energy efficiency technologies, and equipment that reduces the consumption of energy from non-renewable energy sources by households and firms.

JEL Codes: E6; F1;Q40;Q43.

Keywords: Energy economics; Econometrics; Fossil fuels; Latin America & the Caribbean; Macroeconomics; Trade openness.

4.1. Introduction

In the LAC countries, the consumption of energy has more than doubled in the last 40 years. However, this growth has not been constant (Koengkan et al., 2019b). Indeed, it was in the 1970s that the consumption of fossil fuels proliferated, as the economic activity and trade openness of the region grew greatly (Koengkan et al., 2019b).

From the 1980s to the 1990s, the economic activity of the region entered into decline with the debt crisis that led the economy of Latin American countries into deep recession followed by a slow recovery (Koengkan et al., 2019a). It was also in this period that, according to Tissot (2012), the consumption of energy from non-renewable sources rapidly expanded in the region.

The prominence of non-renewable energy sources in the energy matrix of LAC countries derives from the fact that some countries are ranked among the most significant oil producers in the world, i.e., Argentina, Brazil, Colombia, Mexico, Venezuela (RB), Ecuador, and others are significant importers, i.e., Brazil, Chile, Dominican Republic, Uruguay, and Paraguay (Fuinhas et al., 2017). These countries are benefiting from plunging oil prices because they will have to pay less for their oil imports, as well as some places where the generation of energy depends on oil products (Koengkan et al., 2019b). According to Jurado (2018), although Brazil is the second major oil producer in the region, the country is the biggest net oil importer as it is the top oil consumer in the LAC region. Moreover, Venezuela (RB), Brazil, Colombia, Argentina, and Ecuador are responsible for 85% of total oil production in the region (IEA, 2018).

Non-renewable energy sources accounted for 46% of the primary energy supply in the LAC region in 2013, while they averaged 31% worldwide (Koengkan et al., 2019b). According to IRENA (2016), natural gas represents 23% of the primary energy consumed in the region. Despite this, the region has one of the most significant shares of renewable sources in the energy mix (Koengkan and Sousa, 2019d).

Moreover, the renewable energy market in the LAC region is also having experienced rapid growth in both investment in and consumption of this kind of energy sources (Fuinhas et al., 2017). This trend has been enhanced by, inter alia, the abundance of natural resources, the rapid increase in energy demand, the significant dependence on fossil fuel, high energy prices and energy security concerns (Koengkan, 2018c). The consumption of energy from this kind of sources represented 20% of total energy consumption in 2009 (Santos, 2015).

The first sustained experience with trade liberalisation in the LAC region was in Chile in the 1970s, when this country became one of the most open in the entire world. In the 1980s, other countries such as Costa Rica in 1993, and Bolivia and Mexico in 1995 followed this trend and gradually opened their markets. In the early 1990s, more countries joined this movement, including Argentina, Brazil, Colombia, Peru and Venezuela (RB) (Agosin and French-Davis, 1993).

These events motivated the central question of this chapter: What is the impact of trade openness on the consumption of non-renewable energy in the LAC countries? The most specific issues resulting from this main question are:

(i) What are the possible explanations for the impact of trade openness on the consumption of non-renewable energy in the LAC countries?

(ii) Are the process of globalisation by trade openness in LAC countries and renewable energy consumption are capable of decreasing the consumption of fossil fuels?

In order to answer these questions, the effect of trade openness and renewable energy on the consumption of energy from non-renewable sources will be analysed using a dataset comprising data for fourteen countries from the LAC region for the period from 1990 to 2014. The PARDL model in the form of UECM is used as our central model estimation, and a PNARDL model will be applied to check the robustness of the results. That is, the main objective of this chapter is to identify the effect of trade openness on the consumption of fossil fuels in the LAC countries. However, another objective of this chapter is to extend and confirm some results from the analysis carried out in **Chapter 3**, where a negative effect of globalisation and consumption of renewable energy on the consumption of fossil fuels was identified. For this reason, we include here the variable trade openness, which is the same used in that chapter to proxy globalisation but considers a larger group of countries and distinct econometric methods.

After these introductory remarks, this chapter is organised as follows: **Section 4.2** reviews the relevant literature; **Section 4.3** presents the data and the adopted methodology; the results of the empirical analysis and the robustness checks are presented in **Sections 4.4** and **4.5**, respectively, and discussed in **Section 4.6**, and **Section 4.7** concludes and debates policy implications.

4.2. Literature review

The classical Heckscher-Ohlin theory of international trade suggests that in the context of free trade, developing countries would specialise in the production of goods that are produced with relatively abundant factors of production (for example, natural resources and labour force), while developed countries would specialise in the production of goods that are more capital and human capital-intensive (Shahbaz et al., 2014). According to the same authors, trade openness is characterised by the movement of goods and services produced in one country and then further processed or consumed in another country. Indeed, without the use of energy, the production of such goods and services would not be possible. This use of energy in the production of goods and services is affected through changes in the growth of the economy (scale effect), through changes in the structure of the economy (composition effect), and through changes in the techniques and technologies that are used for production (techniques effect) (e.g., Jena and Grote, 2008 and Ghani, 2012).

In the scale effect, liberalisation will increase economic activity because of static-dynamic gains from trade. That is, the increase in economic activity will increase energy consumption (Ghani, 2012). The composite effect of the consumption of energy depends on how the structure of the economy is affected by liberalisation. That is, this effect indicates that the use of energy-intensive changes according to the economic development, for example from agriculture to an industrial economy; this change occurs in the initial stages of economic development, where the economy is based largely on the agriculture sector, and consequently the use of energy is relatively less (Shahbaz et al., 2014). The same authors add yet that when the economy changes from agriculture to industrial, the use of energy increases. Moreover, Ghani (2012) adds that, in most cases, the technique effect reduces energy consumption as improvements in technology due to technology transfer improve energy efficiency. Shahbaz et al., (2014) also refer to this as the technique effect, when developing countries import of advanced technologies and consequently increase the production of outputs with low energy consumption.

Indeed, the scale, composition and technique effects are possible through trade openness that allows the developing countries to import advanced technologies from developed countries (Shahbaz et al., 2014). This process of trade openness improves the transfer of new technologies helping technological progress and brings about a consequent improvement in productivity (Zahonogo, 2016). This technological progress, as mentioned before, consists of intermediated manufactured products, capital equipment, technological goods, electronic equipment, and new material that are commercialised in international markets, where it allows countries to import the R&D done by other countries (Henry et al., 2009). Moreover, Zahonogo (2016) adds yet that this consensus rests on the assumption that trade creates economic incentives that boosts productivity, where trade reduces misallocation of resource use in the short run, and in the long run facilitates technology transfer among countries.

Therefore, this technology transfer by international trade takes on even greater importance for productivity growth in developing countries, as this group undertakes little domestic R&D and therefore has few domestic sources of new technology (Henry et al., 2009). According to Coe et al., (1997) thane increase of 1% in the R&D capital stock in industrialised countries raises the output in developing countries by 0.06%. This evidence makes it clear that the importance of international trade is substantial for developing countries.

Moreover, energy affects trade openness in various ways. First, as mentioned in **Chapter 3** (p.104), energy is an important production factor, where the equipment and machinery in the process of production require energy. Second, the exports and imports of manufactured goods or raw material require energy for fuel transportation (Shahbaz et al., 2014). For this reason, the study of this relationship is essential.

This is different from the relationship between economic growth and consumption of energy that started to be investigated in the 1970s by Kraft and Kraft (1978), as mentioned in **Chapter 3** (p.81). The study of the relationship between trade openness and the consumption of energy has a different trajectory. This topic is very recent, with the first study investigating this relationship produced by Coler (2006). The author explored this relationship in 91 high-, middle- and low-income countries in the period 1980–2010. The empirical results of their study pointed to the existence of a feedback effect between trade openness and energy consumption.

Despite the initiative of Coler (2006) in realising the first investigation about the impact of trade openness on the consumption of energy, this topic still has not received much attention from researchers, and the scarcity of academic studies impairs understanding of how trade openness and consumption of energy, in fact, interact with each other (Koengkan, 2018d).

The few studies that investigate this relationship have used primary energy consumption, renewable energy consumption, total energy consumption and national energy use as dependent variables (e.g., Koengkan, 2018d; Bosupeng, 2017; Al-Mulali and Ozturz, 2015; Nasreen and Anwar, 2014; Sebri and Ben-Salha, 2014; Sbia et al., 2014; Shahbaz et al., 2013; Sadorsky, 2012; Ghani, 2012; Managi et al., 2009). Other studies have used trade liberalisation, imports, exports and trade openness as independent variables (e.g., Koengkan, 2018d; Bosupeng, 2017; Al-Mulali and Ozturz, 2015; Nasreen and Anwar, 2014; Sebri and Ben-Salha, 2014; Sbia et al., 2014; Shahbaz et al., 2013;Sadorsky, 2012; Ghani, 2012; Managi et al., 2009).

Although these authors have used different variables to represent trade openness, there are no certainties on which is the best proxy. With the release of the "Trade openness index" by the World Bank Open Data (2019), the research possibilities surrounding this variable significantly increased. However, despite the availability of data for this variable, there is a small number of authors who have already used this variable in their studies.

Most such studies deal with a broader subject, assessing the effect of trade openness on the consumption of energy. Given this fact, we will try to answer two questions. What conclusions have been reached in the literature regarding the effect of trade openness on the consumption of energy? What are the possible explanations for the effects found? Concerning the first question, the literature examining the impact of trade openness on the consumption of energy has evolved into two lines of thought: the first argues that trade openness can lead to an increase in energy consumption, while the second argues that trade openness can lead to a decrease in energy consumption. **Table 4.1** displays the main authors whose results support the view that trade openness increases the consumption of energy.

Table 4.1. Authors who identified a positive impact of trade openness or its proxy on the consumption of energy.

Author (s)	Variable or (Proxy of trade openness)	Methodology (ies)	Time Span	Country(ies) /region(s)
Koengkan (2018d)	Trade openness	Arellano-Bond dynamic and GMM model	1971-2014	Bolivia, Colombia, Ecuador, and Peru
Bosupeng (2017)	Exports	Granger causality test	1980-2012	40 countries
Nasreen and Anwar (2014)	Trade openness	Panel cointegration tests	1980–2011	15 Asian countries
Sebri and Ben-Salha (2014)	Trade openness	ARDL model and VECM	1971–2010	Brazil, China, India, and South Africa
Sadorsky (2012)	Imports and Exports	Granger causality test	1980-2007	Argentina, Brazil, Chile, Ecuador, Paraguay, Peru, and Uruguay

There is a major reason which can be pointed out in order to justify the positive impact of trade openness on the consumption of non-renewable energy. According to Coler (2006), trade liberalisation brings an expansion of industrialisation and consequently encourages investment and economic activity and subsequently the consumption of energy. This line of thought is accepted by Koengkan (2018d), Bosupeng (2017), Nasreen and Anwar (2014), Sebri and Ben-Salha (2014), and Sadorsky (2012), where market liberalisation brings more investment and industrialisation, which affects economic growth and consequently increases energy demand.

After addressing the investigations that support that trade openness increases the consumption of energy, it is necessary to talk about the authors who support that trade openness decreases the consumption of energy. **Table 4.2** displays the authors who support this other view.

Table 4.2. Authors who identified the negative impact of trade openness or its proxy on the consumption of energy.

Author (s)	Variable or (Proxy of trade openness)	Methodology (ies)	Time Span	Country(ies) /region(s)
Al-Mulali and Ozturz (2015)	Trade liberalisation	FMOLS model	1996–2012	MENA (the Middle East and North African) region
Sbia et al. (2014)	Trade openness	ARDL and VECM	1975Q1–2011Q4	United Arab Emirates (UAE)
Shahbaz et al. (2013)	International trade	ARDL model	1975Q1–2011Q4	Indonesia
Ghani (2012)	Trade liberalisation	OLS model	1970-1999	Fifty-four developing countries
Managi et al. (2009)	Trade openness	Arellano-Bond dynamic GMM model	1971–1996	Organization for Economic Co-operation and Development (OECD)

There are some explanations given by the authors for the negative impact of trade openness on the consumption of energy. For instance, Ghani (2012) indicates that trade openness decreases the consumption of energy due to technological transfers. Developing countries import energy-saving technologies, products and/or processes from developed countries (via trade liberalisation) that consume less energy. That is, in developing countries, the reduction of energy consumption is more visible than in developed countries because the former countries have more capacity to absorb the transferred technologies than developed ones. Shahbaz et al. (2013) and Sbia et al. (2014) produced the same conclusion, where the authors claimed that trade liberalisation encourages the introduction of new efficient technologies and consequently reduces energy consumption.

Moreover, the existence of different conclusions by the use of methodologies, different variables, time-spans, and countries or regions leads an non-consensus about the impact of trade openness on the consumption of energy. Indeed, due to this, it is essential to carry out more studies on this topic.

In this review of the literature, we identified some gaps which need to be filled. The first and the most significant is the absence of studies that investigate the impact of trade openness (or one of its proxies) on specific kinds of energy consumption such as that of fossil fuels. All the studies reviewed explored solely this relationship using the total consumption of energy as the dependent variable (e.g., Koengkan, 2018d; Bosupeng, 2017; Al-Mulali and Ozturz, 2015; Nasreen and Anwar, 2014; Shahbaz et al., 2013; Sadorsky, 2012; Ghani, 2012; Managi et al., 2009) and renewable energy consumption (e.g., Sebri and Ben-Salha, 2014; Sbia et al., 2014). This scenario indicates that the relationship between trade openness and the consumption of fossil fuels is still very underexplored and calls for further investigation. Another gap that was identified is the non-utilization of the PARDL and PNARDL methodologies, which bring some advantages to the study of this topic, such as identifying the short- and long-run impacts of trade openness on the consumption of energy as well as producing efficient and robust parameter estimates. Moreover, we also noted that there is a lack of studies focused on the LAC countries, where only two studies were identified that approached the Latin American region (e.g., Koengkan, 2018d; Sadorsky, 2012).

Based on the literature review and the central questions of this study, we developed the following two hypotheses:

- **Hypothesis (1):** Trade openness exerts a positive effect on the consumption of energy, where trade liberalisation brings more industrialisation and investment that affect economic growth and consequently increase the energy demand;
- **Hypothesis (2):** Trade openness exerts a contractionary effect on the consumption of energy, where trade liberalisation brings more investment that encourages research and development (R&D) in energy efficiency technologies, and products with high energy efficiency that reduce the consumption of energy.

Regarding this literature review, this chapter opted to discuss and evidence the empirical results in the most important researches that approached the impact of trade openness or its proxies on the consumption of energy. The next section, we will present/explain the data and methodology which were used in this chapter.

4.3. Data and methodology

Section 4.3 is divided into two parts: (**4.3.1**) presents the data and variables that will be used, and (**4.3.2**) describes the adopted methodological strategy that will be applied in this chapter.

4.3.1 Data

To accomplish the goal of this chapter, annual data was collected from 1990 to 2014 for fourteen countries from LAC region, i.e., **Argentina**, **Bolivia**, **Brazil**, **Chile**, **Colombia**, **Dominican Republic**, **Ecuador**, **El Salvador**, **Guatemala**, **Mexico**, **Nicaragua**, **Panama**, **Peru**, and **Venezuela (RB)**. Why were LAC countries used for this study? LAC countries were chosen on the grounds that: **(i)** they have experienced a rapid process of trade openness that started in the 1970s and intensified at the end of the 1990s (see **Figure 4.1**) below.

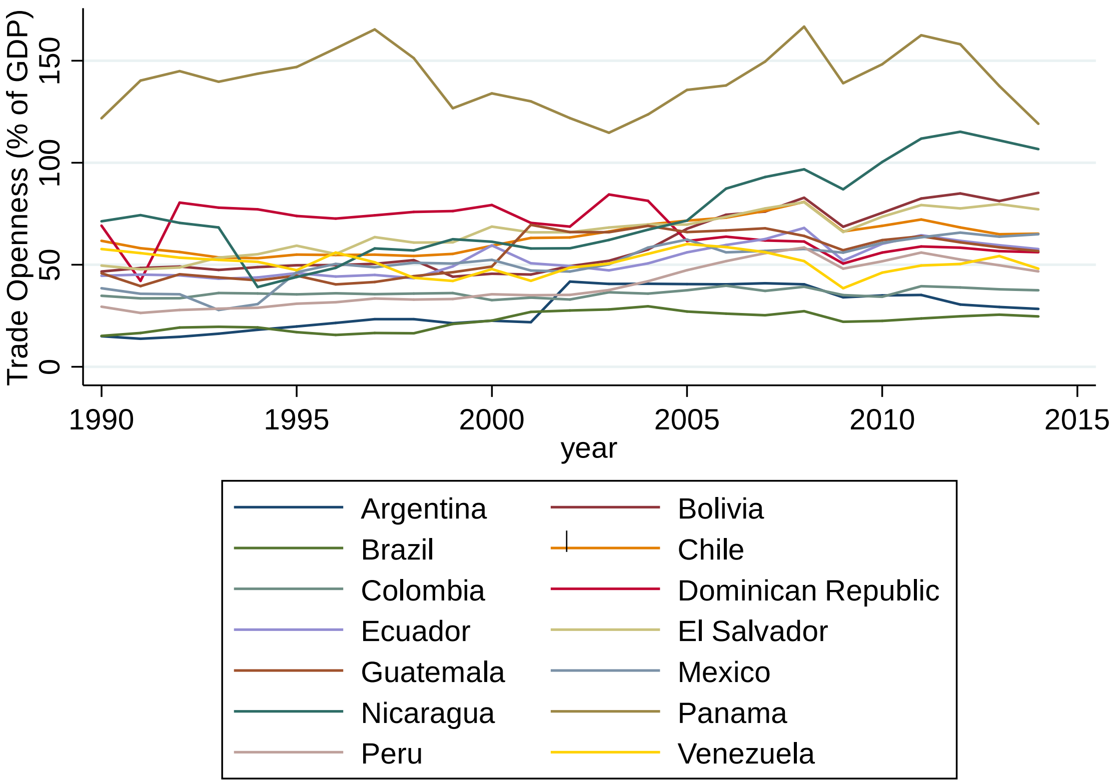

Figure 4.1 Evolution of trade openness between (1990-2014) in LAC countries. This chart was based on the database used in this study. The *xtline* in Stata and option *overlay* were used.

As can be seen in the graph above, the process of trade openness in the LAC countries increased in all countries over twenty-four years. That is, in the LAC countries as mentioned before, the modern process of trade liberalisation began in the 1970s and intensified in the 1980s, in a period of economic stagnation and accelerated inflation coined "the lost decade" that comprised the years between 1980 to 1989 with the debt crisis, as mentioned in **Chapter 2**. Therefore, in order to resolve the problem with the LAC debt crisis, economic reforms such as stabilisation programmes were pursued and a process of trade and financial liberalisation was initiated with the privatisation of some state-owned companies (see **Chapter 2**); and, **(ii)** they registered rapid growth in the consumption of fossil fuels (see **Figure 4.2**) below.

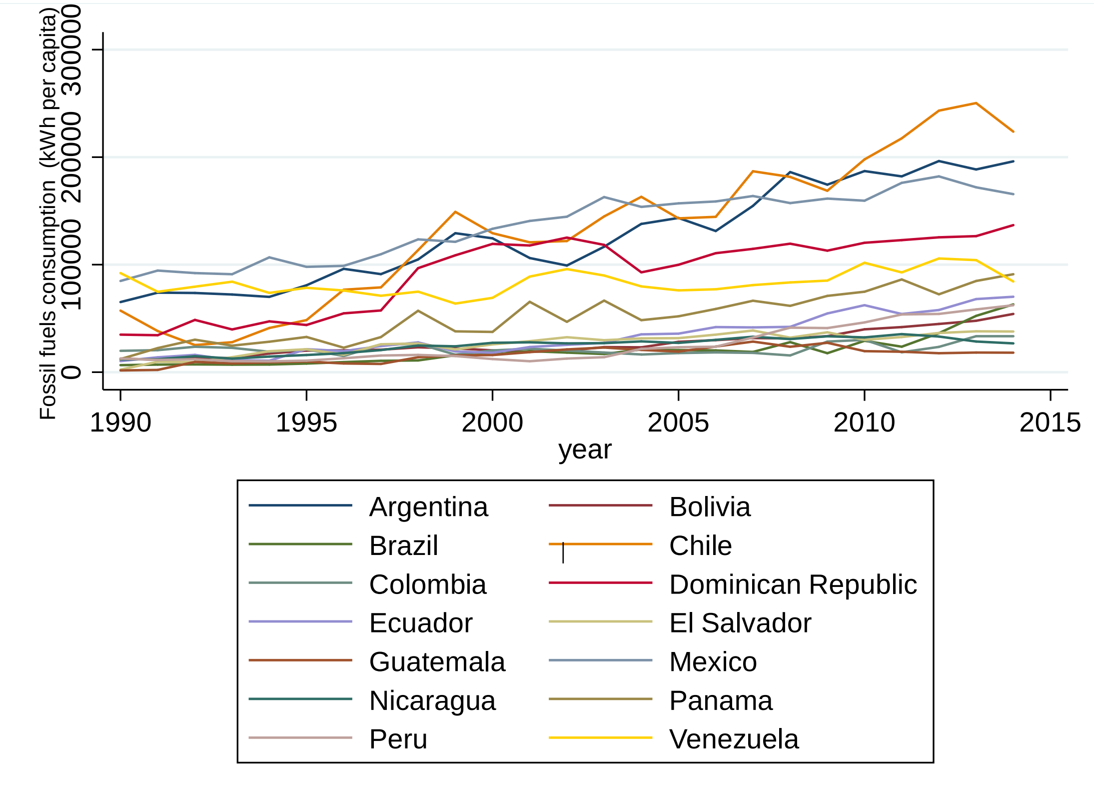

Figure 4.2 Evolution of fossil fuel consumption between (1990-2014) in LAC countries. This chart was based on the database used in this study. The *xtline* in Stata and option *overlay* were used.

As can be seen in the graph above, the consumption of fossil fuels in the LAC countries increased in all countries over twenty-four years. Indeed, this increase is also related to the rapid process of economic growth, where the GDP per capita (current US$) evolving from US$ 2319,05, and in 2014, it was US$ 10,405,48 (see **Figure 1.2A** in **Appendix A**, p. 200). It can be observed that the process of trade openness consumption of fossil fuels and economic growth follow the same growth tendency. The variables which were chosen to perform the analysis are:

- **Fossil fuel consumption (FOC)** from oil, gas and coal sources in (kWh per capita), retrieved from World Bank Open Data (2019);
- **Gross Domestic Production (Y)** in constant (2010 US$) per capita retrieved from World Bank Open Data (2019);

- **Renewable energy consumption (REC)**[(6)] from biomass, hydropower, solar, photovoltaic, wind, wave and waste in (kWh per capita), retrieved from World Bank Open Data (2019);
- **Trade openness (TR)** is an economic metric calculated as the ratio of the country's total trade – the sum of exports plus imports – to the country's gross domestic product., retrieved from World Bank Open Data (2019).

Trade expansion and technological development have increased energy demand in the last decade. Indeed, international trade and consumption of energy tend to move together. So, for this reason, it is necessary to learn more about the effect of trade openness on the consumption of energy.

The variable trade openness (**TR**) was used by several authors (e.g., Koengkan, 2018d; Nasreen and Anwar, 2014; Sebri and Ben-Salha, 2014; Sbia et al., 2014; Managi et al., 2009) and was chosen in this study because it is an essential component of economic growth and consequently increases international trade, economic activity and finally the consumption of energy (Sadorsky, 2012). Indeed, trade openness enables developing economies, which is the case of LAC countries, to import advanced technologies from developed countries. Therefore, the adoption of advanced technology lowers less energy use and produces output. Indeed, as trade openness is considered one of the potential factors that induce higher economic growth, and energy demand is expected to rise to respond to economic growth. For this reason, the variable Gross Domestic Production (**Y**) was used in this model.

Regarding the consumption of renewable (**REC**) and fossil (**FOC**) fuels, these variables were chosen in this investigation because, as mentioned in **Chapter 3** (pp.88-89), the rapid development of renewable energy technologies will consequently decrease the consumption of non-renewable. The increase of production and consumption of fossil fuels in the region encourages the use of these variables. Moreover, the energy was used in this study because the import and export of goods and services need energy. Therefore, without a suitable energy supply, trade openness will be adversely impacted. That is, energy is an essential input in trade expansion, where suitable energy consumption is crucial for expanding trade via imports and exports.

Notes (6): The renewable energy consumption (kWh) per capita is the multiplication of total energy consumption per capita in kWh by renewable energy consumption (% of total final energy consumption). Both variables were retrieved from World Bank Open Data (2019). The option to use this variable was taken because there is no data from the consumption of renewable energy in kWh.

The use of time-series from 1990 to 2014 is due to the availability of data until 2014 for the variable **REC** for all countries selected. The LAC countries were selected due to the rapid process of trade openness and consumption of fossil fuels and others. The availability of data is another motivation, as mentioned in **Chapters 2** (pp. 56-57) and **3** (pp. 87-88). A strict selection criterion was used, where only countries with a complete database were selected. While there are 32 LAC countries, only 14 countries were selected. The other 18 countries were excluded in this study due to the presence of an incomplete database (e.g., Antigua and Barbuda, Barbados, Belize, Costa Rica, Dominica, Guatemala, Grenada, Guyana, Haiti, Honduras, Jamaica, Panama, Paraguay, Saint Lucia, Saint Kitts and Nevis, Suriname, Saint Vincent and the Grenadines, Trinidad and Tobago, and the Bahamas). These countries were not used in this investigation because the method that will be used requires a strongly balanced panel data, as well as the fact that the use of this incomplete database could cause interpretation problems of estimation results.

The variables **FOC**, **Y**, and **REC** were transformed into per capita values with the total population of each cross. The per capita value allows disparities to be controlled for in population growth over time and within countries (e.g., Koengkan et al., 2018b; Koengkan, 2018c; Koengkan, 2018d). Furthermore, this investigation used the GDP in constant 2010 US$ instead of the constant LCU that was used in **Chapters 2** and **3**. The initial estimations using constant 2010 US$ presented slightly different results from when constant LCU was used. Indeed, these changes in results could be related to changes in the database source, as the old database from IEA was replaced by the World Bank database or by the exchange rates themselves.

The variable of trade openness is the result of trade and economic liberalisation that is the integration of the national economy with the rest of the world. This integration has been one of the most important developments of the last century. Indeed, this process of integration, often called “globalisation’”, has materialised remarkable growth in trade between countries. **Table 4.3** shows the summary statistics of variables.

Table 4.3. Summary statistics of variables

Variables	Descriptive Statistics				
	Obs.	**Mean**	**Std. Dev.**	**Min**	**Max**
LnFOC	350	10.576	0.9261	7.4260	12.4303
LnY	350	8.4631	0.6886	6.9659	9.5943
LnREC	350	12.0473	4.8717	8.2764	30.9759
LnTR	350	3.9433	0.4822	2.6212	5.1161

Notes: Obs. denotes the number of observations; Std. Dev. Denotes the Standard Deviation; Min. and Max. Denote Minimum and Maximum, respectively. (Ln) denotes variables in natural logarithms.

Moreover, we should stress that they are already in their natural logarithms (see prefix "Ln"). As mentioned before, in **Chapter 3**, all variables that were used in this investigation are updated every six months. Indeed, in the case of this chapter, all variables were updated in June 2019.

4.3.1 Methodology

For the realisation of this chapter, the PARDL model in the form of UECM will be used as our central model estimation, and a PNARDL model will be applied to check the robustness of results. The PARDL model in the form of UECM was developed by Granger (1981), and by Engle and Granger (1987), and later improved by Johansen and Juselius, (1980) who introduced cointegration techniques that allow the identification of a long-run relationship between non-stationary series and their parametrisation into an error correction model (UECM) (Nkoro and Uko, 2016). This model allows decomposition of the total effects of variables into their short- and long-run components (Koengkan et al., 2019).

This then raises the following questions. Why was the PARDL model used for the realisation of this investigation? As cited before in **Chapter 2** (pp. 51-52) this approach was used in this investigation because in panels with long time spans (macro panels), there is generally the presence of cointegration between the variables and then endogeneity in the model. However, if one does not use the appropriate econometric techniques to cope with the endogeneity and cointegration problem, it can lead to estimation errors and misinterpretation of results. Therefore, in order to handle the problem of endogeneity and cointegration, the literature recommends the use of PARDL models as a robust econometric estimation technique to deal with the presence of endogeneity and cointegration between the variables. Then, the PARDL in the form of a

UECM was used to cope with the endogeneity and cointegration that is expected in this investigation.

Does this model have some advantages for this investigation? According to Koengkan et al. (2019a), and Koengkan et al. (2019b), this model has many advantages, such as **(i)** this model can produce efficient parameter estimates with relatively small samples; **(ii)** it allows analysis in the presence of I(0) and I(1) variables; **(iii)** it is suitable to deal with cointegration; **(iv)** it is robust in the presence of endogeneity; and **(v)** it is a flexible technique compared with others. What are the applications of this model in the literature? This model was employed in empirical researches that have several applications in the literature. **Table 4.4** shows PARDL models applied in the literature.

Table 4.4. Applications of PARDL models in the literature

Model	Applications
PARDL model	▪ Economic growth, consumption of energy, and environmental degradation (e.g., Koengkan et al., 2018; Koengkan et al., 2019b); ▪ Financial openness, economic growth, primary energy, and environmental degradation (e.g., Koengkan et al., 2019a); ▪ Real income, inflation, foreign interest rates, and stock prices (e.g., Baharumshah et al., 2009); ▪ Visitor arrivals, real disposable incomes, relative hotel, and substitute prices (e.g., Narayan, 2004); ▪ Carbon dioxide and agriculture (e.g., Asumadu-Sarkodie and Owusu, 2016); ▪ Health care and international tourism (e.g., Lee, 2010).

The general PARDL model in the form of UECM follows the specification of **Equation (4.1)**:

$$DLnFOC_{it} = \alpha_{it} + \beta_{1i1} DLnY_{it-1} + \gamma_{1i1} + DLnREC_{it-1} + \gamma_{3i1} + DLnTR_{it-1} + \gamma_{4i1} + LnFOC_{it-1} + \gamma_{1i2} LnY_{it-1} + \gamma_{1i3} LnREC_{it-1} + \gamma_{1i4} LnTR_{it-1} + \varepsilon_{1it}. \quad \textbf{(4.1)}$$

where α_i represents the intercept, β_{ik} and γ_{ik}, with k = 1, …, 3, denote the estimated parameters and ε_{it} is the error term. The prefixes "Ln" and "DLn" denote natural logarithms and first-differences, respectively. Therefore, before the PARDL model estimation, it is mandatory to examine the characteristics of the variables, which includes the cross-section and time series, as well as to ascertain the presence of specificities which, if not considered, may produce inconsistent and incorrect results. To this end, the preliminary and specification tests will be performed before estimating the model of interest. The following tests are thus executed:

(i) Preliminary tests: **(a)** variance inflation factor (VIF) to check for the presence of multicollinearity among the variables; **(b)** cross-section dependence (CSD) test (Pesaran, 2004); **(c)** Pesaran's CADF test (Pesaran, 2003) to identify the presence of unit roots; **(d)** the Hausman test to identify heterogeneity, i.e., whether the panel has random effects (RE) or fixed effects (FE) and; **(e)** mean group (MG), fixed effects (FE), and pooled mean group (PMG) estimators.

(ii) Specification tests: (a) modified Wald test (Greene, 2002) to check for the existence of group-wise heteroscedasticity; **(b)** Wooldridge test (Wooldridge, 2002) to check the presence of serial correlation; **(c)** Pesaran (2004) test for cross-sectional independence; and **(d)** Breusch and Pagan Lagrangian multiplier test (Breusch and Pagan, 1980) for cross-sectional correlation in the fixed-effects model. The latter is used due to the large T (number of time-series observations) and the small N (number of cross-sectional observations) in the panel.

To appraise the robustness of results in the PARDL model, the PNARDL approach will be used. This model is an asymmetric extension of linear PARDL model in the form of UECM developed by Granger (1981) and by Engle and Granger (1987). Indeed, the PARDL model in the form of UECM does not consider the possibility that the positive and negative variations of the explanatory variables in the model have a different effect on the dependent variable (Rocher, 2017). Regarding PNARDL, the same author explains that this model not only allows detection of the presence of asymmetric effects that independent variables may have on the dependent variable in the model, but it also allows testing for cointegration in a single equation.

Why was the PNARDL model used as a robustness check in this study? The motivation that led us to select this model is the same as indicated in **Chapter 2** (p. 51). However, according to Rocher (2017), the PNARDL model presents some advantages that are necessary to highlight, such as their flexibility regarding the order of integration of the variables involved, the possibility of testing for hidden cointegration, avoiding omission of any causality which is not visible in a conventional linear model, with better performance in small samples and being robust in the presence of endogeneity. According to Shin et al. (2014), the PNARDL model is constructed around the following asymmetric long-run equilibrium relationship (see **Equation 4.2)**:

$$e_t = \delta^+ x^+ + \delta^- x^- + \mu_t \tag{4.2}$$

where the equilibrium relationship between e and x is divided into positive ($\delta^+ x^+$) and negative ($\delta^- x^-$) effects, plus the error term (μ_t) means the possible deviations from the long-equilibrium. As shown in **Equation (4.2)**, the effect of the variable x can be decomposed into two parts, positive and negative (see **Equation 4.3)**:

$$x_t = x_0 + x_t^+ + x_t^- \tag{4.3}$$

where x_0 represents the random initial value and $x_t^+ + x_t^-$ denote partial sum processes which accumulate positive and negative changes, respectively, and are defined as (see **Equations 4.4** and **4.5**):

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} \max\,(\Delta x_j\,, 0) \tag{4.4}$$

$$x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j=1}^{t} \min\,(\Delta x_j\,, 0) \tag{4.5}$$

Then, the general PNARDL model in the form of UECM follows the specification of **Equation (4.6)**:

$$\begin{aligned} DLnFOC_{it} = {} & \alpha_{it} + \beta_{1i1} DLnY_{it} + \gamma_{1i1} + \theta_1^+ DLnREC_{it-1}^+ + \theta_1^- DLnREC_{it-1}^- \; + \\ & \gamma_{3i1} + DLnTR_{it-1} + \gamma_{4i1} + LnFOC_{it-1} + \theta_1^+ \gamma_{1i2} LnY_{it-1}^+ \; + \\ & \theta_1^- \gamma_{1i2} LnY_{it-1}^- + \gamma_{1i3} LnREC_{it-1} + \gamma_{1i4} LnTR_{it-1} + \varepsilon_{1it}. \end{aligned} \tag{4.6}$$

where α_i represents the intercept, β_{ik} and γ_{ik}, with k = 1, …, 3, denote the estimated parameters, $DLnREC_{it-1}^+$, $DLnREC_{it-1}^-$, LnY_{it-1}^+, and LnY_{it-1}^- are the partial sums of positive and negative changes of variables **DLnREC** and **LnY**, respectively and ε_{it} is the error term. Additionally, the PNARDL model approach permits the use of a combination of variables I(0) and I(1). However, it is essential to check the integration order of variables in previous steps as the PNARDL model is not valid for variables that are I(2).

This section shows the data/variables and methodologies and their preliminary and specification tests that will be used in our analysis. The next section will show the empirical results.

4.4. Empirical Results

As previously explained, this section will present the empirical results of preliminary and specification tests as well as the results of PARDL model estimation. The first step was the computation of VIF and CSD-tests. The first test informs the presence of multicollinearity, while the second shows cross-sectional dependence. The VIF test helps us to understand the degree of multicollinearity, which may be present in our model and which can lead to problems in estimation. The null hypothesis of CSD test is the presence of CSD in all variables. Therefore, in **Table 4.5** we can see the results of VIF and CSD-tests, both in first-differences and natural logarithms.

Table 4.5. VIF and CSD tests

Variables	VIF	1/VIF	CD-test		Corr	Abs (corr)
DLnFOC	n.a.		1.91	*	0.041	0.221
DLnY	1.02	0.9834	14.96	***	0.320	0.323
DLnREC	1.01	0.9857	2.05	**	0.044	0.200
DLnTR	1.01	0.9934	12.37	***	0.265	0.282
Mean VIF	1.01					
LnFOC	n.a.		32.96	***	0.691	0.691
LnY	1.34	0.7486	41.69	***	0.874	0.874
LnREC	1.27	0.7893	28.67	***	0.601	0.610
LnTR	1.10	0.9108	19.09	***	0.400	0.502
Mean VIF	1.23					

Notes: ***, **, * denote statistically significant at 1%, 5%, and 10% level; the Stata command *estat vif* and *xtcd* were used; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively.

The information that is present in the previous table indicates that multicollinearity is not a concern in the estimation, given the low VIF and mean VIF values registered, which are lower than the usually accepted benchmarks of 10, in the case of the VIF values, and 6 in the case of the mean VIF values. Concerning the CSD-test, we see that the null hypothesis is rejected in all cases, leading us to the conclusion that there is a correlation between the series across countries.

In the presence of CSD, it is necessary to assess the order of integration of the variables. To this end, the Pesaran CADF test was computed. This test is robust in the presence of CSD, and we did not opt to use the first-generation test for the reason that it is inefficient in the presence of CSD. The null hypothesis of Pesaran's CADF is that all series are non-stationary I(0). The results of this test can be seen in **Table 4.6**.

Table 4.6. Unit root test

Variables	Pesaran's CADF test (Zt-bar)		
	Without trend		With trend
	Lags	Zt-bar	Zt-bar
DLnFOC	1	-7.923 ***	-5.558 ***
DLnY	1	-5.834 ***	-4.964 ***
DLnREC	1	-8.770 ***	-6.944 ***
DLnTR	1	-5.621 ***	-3.851 ***
LnFOC	1	-2.360 ***	-3.844 ***
LnY	1	-2.491 ***	-0.338
LnREC	1	-2.483 ***	-3.434 ***
LnTR	1	-2.337 ***	0.080

Notes: *** denotes statistically significant at 1%, level; the Stata command *pescadf* was used; The null for CADF test is: all series are non-stationary are I(1); the lag length (1) and trend were used in this test;(Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively.

The results from the Pesaran CADF test show that none of the variables seems to be I(2), although they show that some of them may be in the borderline between the I(0) and I(1) orders of integration (i.e., in the first-differences with and without trend, and all variables in natural logarithms without trend, and also **FOC** and **REC** with trend seem to be stationary).

After the realisation of the unit root test, the next step is to assess the presence of individual effects in the model. To this end, the Hausman test, confronting random (RE) and fixed effects (FE), was performed. The null hypothesis of this test is that the difference in coefficients is not systematic, (i.e., random effects are the most suitable estimator). The Hausman test indicates that the null hypothesis should be rejected (**chi2 (7) = 95.79**, statistically significant at 1% level) (see **Table 4.7C** in **Appendix C**, p. 211) and that a fixed-effects model is the most appropriate for this analysis.

To assess the presence of heterogeneity/homogeneity in the panel, the MG, PMG, and FE techniques were performed. The MG estimator that was developed by Pesaran and Smith (1995) calculates the average of coefficients of all individuals, with no restrictions regarding the homogeneity of short and long run.

However, the PMG estimator created by Pesaran et al. (1999) permits for differences in error variances, short-run coefficients, speed of adjustment and intercepts (i.e., these parameters may be country-specific), but it imposes a homogeneity restriction on the long-run coefficients (i.e., they should be equal across countries).

Then, the PMG estimator can combine the "pooling" from the FE estimator with the "averaging" from the MG estimator. However, in the presence of panel homogeneity in the long-run, this estimator is more efficient than the MG estimator. **Table 4.8** shows the outcomes for the three specifications (e.g., MG vs PMG; PMG vs FE; and MG vs FE).

Table 4.8. Hausman test

MG vs PMG	PMG vs FE	MG vs FE
Chi2(7) = 25.02***	Chi2(7) = 75.71***	Chi2(7) = -107.99

Notes: *** denotes statistically significant at 1%, level; Hausman results for H_0: difference in coefficients not systematic; the Stata commands *xtpmg*, and Hausman (with the option alleqs) were used.

The results of **Table 4.8** suggest that the panel is homogeneous and that the FE is the most appropriate estimator. Before model estimation, the following specification tests are performed: **(a)** the Modified Wald test; **(b)** the Wooldridge test; **(c)** Pesaran's test; and **(d)** the Breusch and Pagan Lagrangian multiplier test. Results are presented in **Table 4.9**.

Table 4.9. Specification tests

Statistics	Modified Wald test	Wooldridge test	Pesaran's test	Breusch and Pagan Lagrangian multiplier test
	chi2 (14) = 3147.01***	F(1,13) = 85.298***	0.125	chi2(91) = 108.217

Notes: *** denotes statistically significant at 1% level; H_0 of Modified Wald test: sigma(i)^2 = sigma^2 for all i; H_0 of Wooldridge test: no first-order autocorrelation; H_0 of Pesaran's test: residuals are not correlated; H_0 of Breusch and Pagan Lagrangian multiplier test: no dependence between the residuals.

The results of specification tests point to reject the null hypothesis of modified Wald and Wooldridge tests at the 1% level, indicating the presence of heteroscedasticity, and first-order autocorrelation. However, we cannot reject the null hypothesis of Pesaran's and Breusch and Pagan Lagrangian multiplier tests, indicating the non-presence of correlation and dependence in the residuals.

Given the specification tests results, to deal with the presence of heteroscedasticity and first-order autocorrelation, we decided to use the Driscoll and Kraay (1998), estimator. This estimator was used because it produces standard errors which are robust to the phenomena that were found in the sample errors.

During the period of analysis, the LAC countries suffered several shocks that, if not taken into account, may produce inaccurate results. The dummy and shift-dummy variables added to the regression are the following: **IDBRAZIL2009** (Brazil, year 2009); **IDCOLOMBIA1997** (Colombia, year 1997); **IDCOLOMBIA1999** (Colombia, year 1999); I**DCOLOMBIA2009** (Colombia, year 2009); **IDCOLOMBIA2011** (Colombia, year 2011); **SDCOSTA_RICA1991_1994** (Costa Rica, years between 1991 to 1994); **SDCOSTA_RICA2005_2006** (Costa Rica, years between 2005 to 2006); **SDDOMINICAN_REPUBLIC1994_1995** (Dominican Republic, years between 1994 to 1995); **IDDOMINICAN_REPUBLIC1998** (Dominican Republic, year 1998); **SDECUADOR1993_1994** (Ecuador, years between 1993 to 1994); **IDECUADOR1999** (Ecuador, year 1999); **IDEL_SALVADOR1991** (El Salvador, year 1992); **IDGUATEMALA1992** (Guatemala, year 1992); **SDGUATEMALA1996_1997** (Guatemala, years between 1996 to 1997); **IDGUATEMALA1998** (Guatemala, year 1998); and **IDPANAMA1996** (Panama, year 1996).

The outcomes from the short-run impacts, the long-run elasticities, the speed of adjustment of the model with the FE, FE robust standard errors (FE Robust), and FE Driscoll and Kraay (FE D.-K.) estimators and shocks are displayed in **Table 4.10**.

Table 4.10. PARDL Model estimation controlling by shocks

Independent variables	Dependent variable (DLnFOC)			
	FE		FE Robust	FE D.-K.
Constant	-1.0919	**	*	**
	Shocks			
IDBRAZIL2009	-0.4337	***	***	***
IDCOLOMBIA1997	0.3866	***	***	***
IDCOLOMBIA1999	-0.3657	***	***	***
IDCOLOMBIA2009	0.4424	***	***	***
IDCOLOMBIA2011	-0.4630	***	***	***
SDCOSTA_RICA1991_1994	-0.4374	***	***	***
SDCOSTA_RICA2005_2006	-0.3134	***	***	***
SDDOMINICAN_REPUBLIC1994_1995	-0.2523	***	***	***
IDDOMINICAN_REPUBLIC1998	0.6432	***	***	***
SDECUADOR1993_1994	-0.4094	***	***	***
IDECUADOR1999	-0.4020	***	***	***
IDEL_SALVADOR1991	0.8446	***	***	***
IDGUATEMALA1992	0.9872	***	***	***
SDGUATEMALA1996_1997	-0.2763	***	***	***
IDGUATEMALA1998	0.4393	***	***	***
IDPANAMA1996	-0.3851	***	***	***
	Short-run (impacts)			
DLnY	0.6255	***	***	***
DLnREC	-0.4731	***	***	***
DLnTR	0.2235	***	***	***
	Long-run (elasticities)			
LnY (-1)	2.0488	***	***	***
LnREC (-1)	-0.3508	**	**	**
LnTR (-1)	0.5912	***	*	***
	Speed of adjustment			
ECM	-0.2374	***	***	***

Notes: ***, **, * denote statistically significant at 1%, 5%, and 10% level, respectively; the ECM denotes the coefficient of the variable **LnFOC**, lagged once; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively.

Although we present the results of the model with these three estimators, we should clarify that we will base our inference on the FE Driscoll and Kraay estimator, given that it is the most robust. The inclusion of the other two estimators (i.e., FE and FE robust) was mainly linked with the possibility of seeing the differences between them, i.e., seeing the changes in the results when we control/do not control for the phenomena which were detected in the specification tests.

The results of PARDL model estimation indicated that, in the impact of variable **Y**, and elasticity of **TR** are statistically significant at the 1% levels, and thus both contribute to increasing of **FOC** in the LAC region. However, the impact and elasticity of **REC** is statistically significant at 1% and 5% levels and thus contribute to the decrease in consumption of non-renewable energy in the region. Regarding the ECM term, it is negative and statistically significant at the 1% level. In the next section, the robustness check will be shown with the realisation of PNARDL model. This verification will be made to test if the coefficients generated by PARDL are consistent with the change in methodology approach.

4.5. Robustness check

In this section, we assess the robustness of our results using a PNARDL approach. This model, as previously explained in **subsection 4.3.2**, is an asymmetric extension of a linear PARDL model in the form of UECM. This model also allows detection of the possible asymmetric nonlinearity and short- and long-run relationship.

The preliminary tests that check the characteristics of variables point to the presence of low-multicollinearity, cross-sectional dependence, unit roots in the first-differences with and without trend, and all variables in the natural logarithms without a trend. Additionally, the variables **FOC** and **REC** with the trend are stationary, while the variables **Y** and **TR** in natural logarithms and with the trend are non-stationary, the fixed effects in the model. These results can be seen in **Tables 4.4**, **4.5**, **4.6**, and **4.7C** in **Appendix C** (p. 211). Therefore, the preliminary tests in PARDL and PNARDL are the same.

The results of the heterogeneity/homogeneity test also indicate that the FE technique is the most appropriate for the fixed effects homogeneous model (see **Table 4.11C** in **Appendix C**, p. 211), and the results of specification tests indicate that the null hypothesis of Modified Wald and Wooldridge tests are rejected at 1% levels, indicating the presence of heteroscedasticity and first-order autocorrelation. Additionally, the null hypothesis of Pesaran's test cannot be rejected, indicating the non-presence of correlation. Regarding the Breusch and Pagan Lagrangian multiplier test, it could not be computed because the correlation matrix of residuals was singular. This situation occurs because the number of crosses under study is less than the number of years (see **Table 4.12C** in **Appendix C**, p. 211). Estimates for PNARDL model coefficients are shown in **Table 4.13**.

Table 4.13. PNARDL Model estimation controlling by shocks from robustness check

Independent variables	Dependent variable (DLnFOC)			
	FE		FE Robust	FE D.-K.
Constant	0.9515	***	***	***
Shocks				
IDBRAZIL2009	-0.4284	***	***	***
IDCOLOMBIA1997	0.3700	***	***	***
IDCOLOMBIA1999	-0.3601	***	***	***
IDCOLOMBIA2009	0.4347	***	***	***
IDCOLOMBIA2011	-0.4796	***	***	***
SDCOSTA_RICA1991_1994	-0.4323	***	***	***
SDCOSTA_RICA2005_2006	-0.3100	***	***	***
SDDOMINICAN_REPUBLIC1994_1995	-0.2816	***	***	***
IDDOMINICAN_REPUBLIC1998	0.6029	***	***	***
SDECUADOR1993_1994	-0.4125	***	***	***
IDECUADOR1999	-0.3966	***	***	***
IDEL_SALVADOR1991	0.8157	***	***	***
IDGUATEMALA1992	0.9655	***	***	***
SDGUATEMALA1996_1997	-0.2789	***	***	***
IDGUATEMALA1998	0.4400	***	***	***
IDPANAMA1996	-0.3813	***	***	***
Short-run (impacts)				
DLnY	0.6649	***	***	***
DLnREC_POS	-0.3755	***	**	***
DLnREC_NEG	-0.6219	***	***	***
DLnTR	0.2364	***	***	***
Long-run (elasticities)				
LnY_POS (-1)	0.5148	***	***	***
LnY_NEG (-1)	0.5490	***	***	***
LnREC (-1)	-0.0822	**	**	**
LnTR (-1)	0.1427	***	**	***
Speed of adjustment				
ECM	-0.2456	***	***	***

Notes: ***, ** denote statistically significant at 1%, and 5% level, respectively; the ECM denotes the coefficient of the variable **LnFOC**, lagged once; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively.

The PNARDL indicates that the impact of **Y** and the positive and negative asymmetry of their elasticity, and the impact of **TR** and its elasticity contribute to an increase in consumption of non-renewable energy. However, the asymmetry of the impact of **REC** and their elasticity decrease the consumption of non-renewable energy.

The results of PNARDL indicate that the impact of **REC** and the elasticity of **Y** are asymmetric nonlinearity. Indeed, only these two variables, i.e., **REC** and **Y**, were added in this estimation due to their statistical significance in the model regression. Furthermore, the coefficients of shocks and variables remain statistically significant at the 1% and 5% levels, and the ECM term remains negative and statistically significant at the 1% level. The next section will present a more thorough discussion of the results from the model estimations.

4.6. A brief debate about the results

This chapter approaches the effect of trade openness on non-renewable energy sources in fourteen countries from the LAC region. The results of the preliminary tests indicate the presence of low multicollinearity and CSD in the data (see **Table 4.4**). Indeed, the presence of CSD in all variables in the first-difference and natural logarithms is mainly the result of the interdependency that exists across the economies in the countries from our sample.

The results of Pesaran's CADF test indicate that the variables in the first-differences with and without trend, and all variables in the natural logarithms without trend, and also the variables **FOC** and **REC** with trend are stationary, while the variables **Y** and **TR** in natural logarithms and with trend are non-stationary (see **Table 4.5**).

This indication reinforces the fact that the PARDL model is the best approach for this analysis and the reason that, as was previously explained, it allows for the incorporation of variables that are I(0) and I(1) in the same estimation. Indeed, due to stationarity in the variables in first-differences and natural logarithms, it is not necessary for the realisation of the cointegration tests. The Hausman test indicates that the null hypothesis should be rejected (**chi2 (7) = 95.79**), statistically significant at 1% levels) (see in **Table 4.7C** in **Appendix C**, p. 211) and that a fixed-effects model is the most appropriate for this analysis, and the heterogeneity/homogeneity test also indicates that the FE technique is the most appropriate for the fixed effects homogeneous model (see **Table 4.8**).

The specification tests indicated the presence of heteroscedasticity and first-order autocorrelation, as well as the non-presence of correlation and dependence in the residuals (see **Table 4.9**). Therefore, the FE, FE robust standard errors (FE Robust), and FE Driscoll and Kraay (FE D.-K.) estimators were used in this study.

Moreover, the dummy and shift-dummy variables were introduced to account for shocks (peaks and breaks of significant magnitude) which occurred in some countries in the LAC region (see **subsection 4.4.**).

The PARDL estimated general model (including the dummies and shift-dummies) suggests that the impact and elasticity of **Y** have a positive impact on the consumption of non-renewable energy of 0.6255 and 2.0488, respectively. The impact and elasticity of the variable **TR** also have a positive impact on the consumption of non-renewable energy, where trade openness has an impact of 0.2235 and 0.5912, respectively.

However, as expected, the impact and elasticity of **REC** have a negative impact of -0.4731 and -0.3508, respectively. That is, the consumption of energy from renewable sources reduces the consumption of fossil fuels. Regarding the ECM term, it is negative and statistically significant at the 1% level, and also the statistical significance at the 1% level of the dummy and shift-dummy variables support the decision to include them in the model. Based on this evidence, we can approach the following questions: **(i)** Are the empirical finds of this investigation in agreement with the literature? **(ii)** What are the possible explanations for the identified impacts? **(iii)** Is the process of globalisation by trade openness of LAC countries able to help to decrease the consumption of fossil fuels? **(iv)** Do the empirical results of this investigation confirm one or more of the research hypotheses? **(v)** Are the empirical results found in **Chapters 2** and **3** able to support the results of this investigation?

The positive impact of economic growth on consumption of energy from non-renewable sources is in keeping with several authors that studied the relationship in the Latin America region (e.g., Koengkan et al., 2019b; Koengkan, 2018c; Koengkan, 2018d; Koengkan, 2017; Rodríguez-Caballero and Ventosa-Santaulària, 2017; Pablo-Romero and Jésus, 2016; Pastén et al., 2015). In **Chapter 3** (p. 104) the same positive impact on the consumption of non-renewable energy in Mercosur countries was confirmed, as economic growth in these countries exerts a positive impact of 0.1730 on the consumption of fossil fuels.

Therefore, the positive impact of economic growth on the consumption of non-renewable energy in the LAC countries is due to the region being very sensitive to changes to change in economic activity, where a rapid economic growth exerts a positive effect on the consumption of energy from non-renewable energy sources (Pablo-Romero and Jésus, 2016).

This idea is accepted by several authors, such as Koengkan et al. (2019b), and Koengkan (2018c), according to whom the Latin America region has experienced strong economic growth, and they have demanded an even more significant increase in energy use. However, Koengkan (2018d) investigated the Andean community countries in the South America region and had a different vision about this positive impact of economic growth on the consumption of non-renewable energy. According to this author, the LAC countries are dependent on the consumption of energy for growth, where an increase of 1% in the energy demand consequently increases economic activity by 0.5%.

Other authors such as Fuinhas et al. (2017) who studied the effect of renewable energy policies on environmental degradation also confirms that the countries from the Latin America region have a high economic dependence on fossil fuel energy sources, due to the fact that some countries in the region are major energy producers (e.g., Argentina, Brazil, Colombia; Mexico, Venezuela (RB), and Ecuador), and others are significant importers (e.g., Brazil, Chile, Dominican Republic, Uruguay, Paraguay).

Omri et al. (2014) have other explanation for this positive impact. According to these authors, economic capitalisation, the development of infrastructure and trade openness in LAC countries are responsible for this positive impact, where these factors have a positive effect on investment, economic activity and consequently on the consumption of energy.

The possible explanation for the negative impact of consumption of renewable energy on non-renewable in the LAC countries is due to the vast abundance of renewable energy sources i.e., solar, photovoltaic, wind, hydropower, geothermal, and waste, in these countries which stimulate investment in renewable energy technology and consequently decrease the consumption of non-renewable (Fuinhas et al., 2017).

According to Koengkan (2018c), this negative impact of renewable energy consumption on fossil fuel consumption demonstrates that the renewable energy policies in the LAC countries are effective and can encourage the development of renewable energy technologies and the consumption of energy from this kind of source. The author also claims that this results in evidence that renewable energy technologies used in these countries are effective in reducing the consumption of non-renewables and environmental degradation.

This negative impact of renewable energy consumption on non-renewable energy consumption in LAC countries was also found in **Chapter 3** (pp. 104-105), where it was identified that renewable energy sources decrease the consumption of fossil fuels by -

0.0646 in the Mercosur countries. However, this capacity of renewable energy to reduce the consumption of fossil fuels could be related to the process of globalisation via financial openness that increases capital stock and consequently reduces the cost of external financing, encouraging investment in renewable energy technologies (see **Chapter 2**, pp. 67-68).

Thus, the reduction of fossil fuel consumption by renewable energy found in this analysis and in **Chapter 3** (p. 104), confirms the process of "energy transition" in the LAC countries. According to Hauff et al. (2014), the term "energy transition" indicates a growing trend of the share of renewable energy sources to reduce the consumption of fossil fuels. Indeed, this term gives a clear objective of reducing environmental degradation.

Finally, the positive impact of trade openness on the consumption of non-renewable energy is in line with some authors that investigated this relationship (e.g., Koengkan, 2018d; Sebri and Ben-Salha, 2014; Houssain, 2011; Cole, 2006; Jena and Grote, 2008). According to Koengkan (2018d) and Houssain (2011), trade openness encourages an expansion of industrialisation and rapid economic development and consequently increases the consumption of energy from non-renewable energy sources. Cole (2006) has the same idea, pointing out that trade openness increases the per capita income by 1% approximately, and consequently increases the energy demand in the interval between 0.05% and 0.3%, approximately.

However, Sebri and Ben-Salha (2014) have a different opinion about this impact. According to these authors, trade openness brings more investment to the energy sector, principally to non-renewable energy due to the abundance of non-renewable energy sources in these countries. This investment consequently stimulates the consumption of energy. Other authors, for example, Jena and Grote (2008), point that industrialisation processes by scale effect, technique effect and comparative advantages effect brought about by trade liberalisation exert a positive impact on economic growth and consequently in the consumption of energy. That is, this result confirms **hypothesis (1)**, where trade openness exerts a positive effect on the consumption of energy, as trade liberalisation brings more industrialisation and investment that affect economic growth and consequently increase energy demand.

The confirmation of **hypothesis (1)** in this investigation was a surprise and contrary to the empirical evidence that was found in **Chapter 3** (pp. 105-106) that globalisation decreases the consumption of energy from non-renewable sources by investment and consumption of energy from renewable sources. After all, why does this variable trade openness, which is a subcomponent of globalisation as confirmed in **Chapter 3,** encourage the consumption of fossil fuels in the LAC region? A possible explanation could be either the methodology that was used or the variables not being able to capture the negative effect of trade openness on the consumption of non-renewable energy.

Moreover, could be related also with the group of countries that were approached in this study. Please note that in **Chapter 3** was approached the Mercosur countries (e.g., **Argentina**, **Brazil**, **Paraguay**, **Uruguay** and **Venezuela** (**RB**)), where as mentioned in **Chapter 3** (p. 87), these group of countries that are the most dynamic and integrated into the LAC region. This trade bloc covers 72% of the South American territory approximately; 69.5% of South American population, that is (288.5 million) and 76.2% of South America's GDP in 2016, that is ($2.79 trillion out of a total of $3.66 trillion). Together, the Mercosur is the fifth largest economy in the world, with a GDP of $2.79 trillion. Additionally, this bloc is the main recipient of foreign direct investment (FDI) in the LAC region, receiving 47.4% of all FDI flow to South America, Central America, Mexico and the Caribbean in 2016 (Mercosul, 2019). Moreover, this dynamic and integration also are visible in the recent free trade agreement between Mercosur and the European Union in June of 2019 (Ministry of Foreign Affairs of Brazil, 2019). Probably, these group of countries have more capacity to incorporate new technologies that mitigate the consumption of fossil fuels via trade openness than other countries such as Colombia, Dominican Republic, Ecuador, El Salvador, Guatemala, Nicaragua, Panama, and Peru that were included in this study. That is, probably the inclusion of countries that do not have the capacity to incorporate new technologies via trade openness in this study may have influenced in the positive impact of trade openness on the consumption of fossil fuels.However, this finding point to the necessity of an in-depth the study of the impact of trade openness on the consumption of fossil fuels in the LAC countries.

Regarding the results of PNARDL, they confirm the same results from the PARDL model. The PNARDL indicates that the impact of **REC** and the elasticity of **Y** have asymmetric nonlinearity. Additionally, the coefficients of the shocks and variables remain statistically significant at the 1% and 5% levels, and the ECM term remains negative and statistically significant at the 1% level. These achievements indicate that the model that we formulated is robust to changes in the methodologic approach (see **Table 4.13**).

In this chapter and in **Chapter 3** it was identified that the consumption of renewable energy reduces the consumption of fossil fuels and that this reduction could be related to the effectiveness of renewable energy policies or globalisation, and that consequently, this process of "energy transition" is associated with reducing environmental degradation as mentioned by Hauff et al. (2014). Therefore, in order to confirm all these affirmations, the next chapter will approach the effect of the energy transition on environmental degradation, as well as whether the renewable energy policies or globalisation are responsible for the process of the "energy transition" in the LAC countries.

4.7. Conclusions and policy implications

The main aim of this chapter is to analyse the impact of the trade openness on the consumption of energy from non-renewable sources. Fourteen LAC countries were selected in a period 1990 to 2014. This chapter opted to use PARDL as the methodology in the form of a UECM and to check the robustness of the main model PNARDL was used.

The preliminary tests of this study indicated that the variables used have characteristics such as low-multicollinearity, cross-sectional dependence in the variables in logarithms and first-differences, and in almost all cases, I(0)/I(1) for all variables, and also the presence of fixed effects. Additionally, the specification tests indicated the presence of heteroscedasticity and first-order autocorrelation, as well as the non-presence of correlation and dependence in the residuals. The results of these tests are essential to identify the characteristics of countries that are under study as well as possible methodologies that will be applied.

The results of the PARDL model indicated that in the short and long run, the impact and the elasticity of variable economic growth and trade openness are statistically significant at the 1% level, and thus both contribute to the consumption of energy from non-renewable sources. Nevertheless, the impact and the elasticity of the variable consumption of renewable energy is statistically significant at the 1% and 5% levels and thus contribute to a decrease in the consumption of fossil fuels in the LAC region. The PNARDL that verifies the robustness of the PARDL model indicates the same results. Additionally, PNARDL also points towards the impact of the variable renewable energy consumption and the elasticity of economic growth having asymmetric nonlinearity. That is, the results of PARDL and PNARDL confirmed hypothesis (1), that trade openness increases the consumption of non-renewable energy.

Therefore, the positive impact of trade openness on the consumption of fossil fuels reveals that the process of globalisation by trade liberalisation in LAC countries is not sufficient to bring more investment, which encourages the R&D in energy efficiency technologies, and equipment that reduces the consumption of energy from non-renewable energy sources by households and firms.

Therefore, to reverse this situation in LAC countries, policymakers must take advantage of the process of globalisation via trade liberalisation to reduce the costs of renewable energy technology. Indeed, the reduction of these costs is possible with the creation of tariff and non-tariff barriers on products and technologies that improve energy efficiency during the process of trade liberalisation. Indeed, energy-efficiency product standards and labelling are an important policy mechanism to reduce the consumption of fossil fuels and CO2 emissions.

Moreover, this chapter makes a significant contribution to the literature for several reasons. First, it sheds light on how economic growth and trade openness increases the consumption of fossil fuels in the LAC. Second, it shows how the consumption of renewable energy decreases the consumption of fossil fuels. Third, the empirical results of this chapter have critical consequences for governments and policymakers with respect to the current model of trade openness, where LAC countries do not take advantage of liberalisation to bring more investment that encourages the R&D in energy efficiency technologies, and equipment that reduces the consumption of energy. Moreover, this investigation is an opportunity for policymakers and governments to reflect on the current mechanisms that are used in trade liberalisation and which are not beneficial for the environment. Fourth, this study can open a new field of research about the effects of trade openness on technological progress in the energy sector, in order to identify whether the process of trade liberalisation brings energy efficiency and encourages the process of the energy transition.

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Chapter 5

The Asymmetric Impact of the Energy Paradigm Transition on Environmental Degradation of Latin America & the Caribbean Countries

Abstract

The asymmetric impact of the energy paradigm transition on environmental degradation of eighteen LAC countries in the period from 1990 to 2014 was analysed. A panel non-linear autoregressive distributed lag approach in the form of an unrestricted error correction model was used. The empirical results indicate that the economic growth in both the short (impacts) and long run (elasticities) have a positive impact of 0.5475 and 0.2186 respectively; the variable public capital stock in the short run has a positive impact of 0.4763 on carbon dioxide emissions. However, the positive and the negative asymmetry of the ratio of renewable energy on fossil energy in the short and long run has a negative impact of -0.0601 on positive variations, and -0.0792 on negative variations in the short run, and -0.0281 on positive variations and -0.0339 on negative variations, in the long-run. The capacity of the ratio of renewable/fossil energy consumption to reduce environmental degradation is compatible with the renewable energy technological efficiency that produces more clean energy and fewer emissions. That was also in line with the increasing participation of renewable energy sources on the energy matrix in the LAC countries.

JEL Codes: F62; Q43; Q50.

Keywords: Energy transition; Globalisation; Latin America & the Caribbean; Macro panel; Asymmetric non-linear.

5.1. Introduction

CO_2 emissions are a significant contributor to global warming. Therefore, these emissions are the most significant potential cause of climate change, along with one of the most significant challenges that human society currently faces. Given this, policymakers and scholars have discussed and developed strategies for reducing these emissions and, consequently, their impacts on global warming.

Indeed, many international initiatives, such as Eco-1992, Kyoto Protocol in 1997 and COP 21 in 2015 have been made. In these commitments, several nations committed themselves to a decrease in their greenhouse gas emissions. In order for these countries to be able to accomplish this goal, it then becomes crucial to identify the primary determinant of CO_2 emissions, as well as creating policies that reduce them.

In the LAC countries, emissions of CO_2 have grown almost ten-fold since the 1970s (see **Figure 5.1D** in **Appendix D**, p. 213). Indeed, only two countries, Brazil and Mexico, are in the top 20 highest emissions countries of the region. Brazil and Mexico account together for 52.6% of emissions in the region. Other countries from the LAC region are emitting more than 10 million kilotons of carbon annually, such as Argentina 52.4, Venezuela (RB) 46.2, Chile 19.9, Colombia 18.5, Trinidad and Tobago 13.6, and Peru 11.1 as mentioned by Marland et al. (2011).

According to Hollanda et al. (2016), the energy sector is the most significant contributor to the increase of CO_2 emissions in the LAC countries, where this sector accounted for approximately 35% of total emissions in 2010. A sustainable energy transition to low carbon will play an essential role in reducing environmental degradation and promoting changes in the global climate scenario.

Energy transition implies a radical transformation of the energy sector towards a low carbon energy system, where renewable energy, energy efficiency technology and CCS will play an essential role in energy transition in order to reduce the consumption of fossil fuels and consequently the environmental degradation, as cited by Tavares (2017). The term “energy transition” does not have a precise or widely accepted meaning. However, this term is often used to describe changes in the composition of the energy matrix. Indeed, this change takes place gradually from an established energy system to a new one, as mentioned by Smil (2010) in **Chapter 1** (p. 23).

The term "energy transition", according to Hauff et al. (2014) in **Chapter 1** (p. 23), is as a structural change in the energy sector of a country. According to the authors, this term indicates the growing trend of the share of renewable energy combined with the promotion of energy efficiency to reduce the consumption of fossil fuels.

This process of energy transition in the LAC countries was initiated after the oil shocks of the 1970s, when the region began to focus on the development of renewable energy technology. This process started in Brazil with hydropower plants in 1973 and biofuels in 1975; in Uruguay and Paraguay with hydropower plants also in 1973, followed by Argentina with biomass, biogas, hydropower plants, geothermal, wind, waves, and photovoltaic plants in 1998, and Venezuela (RB) with hydropower plants in 2001, as cited before by IRENA (2016) in **Chapter 2** (p. 46). In Latin America, the consumption of energy from renewable sources represented 35% of the total energy consumption in 2013 (Koengkan, 2018a). The energy mix of the LAC region relies less on fossil fuels than the global average.

According to Hollanda et al. (2016) the LAC region is ahead in the energy transition to a low carbon economy due to a high participation of hydropower and the recent increase in the share of "new renewables" (e.g., photovoltaic, solar, wind, wave, biomass). Moreover, the authors add that this process was accomplished due to the region having enormous availability and diverse natural resources, including large hydropower, wind and solar potential, as well as suitable weather conditions.

Based on this information, the central questions of this chapter are as follows. What is the effect on energy transition on CO2 emissions in the LAC countries? How does energy transition decrease environmental degradation? The primary objective of this chapter is to study the impact of the energy transition on environmental degradation of eighteen LAC countries, over a period ranging from 1990 to 2014. A PNARDL approach in the form of UECM was used to decompose the positive and negative variations of the independent variables into their short-run impacts and long-run elasticities. However, another objective of this chapter is to extend and confirm some results from the analysis developed in **Chapters 2**, **3** and **4**, where it was identified that globalisation increases investment and consumption of renewable energy and consequently reduces the consumption of fossil fuels. Indeed, it is expected that this process of energy transition can decrease environmental degradation.

In the literature, the impact of the energy transition on the environment has not been explored in the literature, which is especially scarce on the LAC countries. Due to the shortage of studies on the impact of the energy transition on environmental degradation, this chapter will opt to use literature-based studies that investigated similar issues as well the use of this structure of the investigation, in this case, chapters that explored the impact of renewable energy consumption on CO2 emissions (e.g., Koengkan et al., 2018; Fuinhas et al., 2017; Koengkan and Fuinhas, 2017; Bilgili et al., 2016; Shafiei and Salim, 2014; Apergis and Payne, 2014; Sadorsky, 2009; Akella et al., 2009). This literature was reviewed bearing in mind that it is the closest to the topic under discussion.

Although several studies have used different variables, countries, time-span, and methodologies to clarify the impact of the energy transition on environmental degradation, the best approach to achieve it remains without a clear solution. What conclusions have been reached by the literature about the impact of renewable energy consumption on environmental degradation? The literature that approaches this relationship has evolved in two divergent ways. The first argues that renewable energy consumption reduces ecological degradation (e.g., Fuinhas et al., 2017; Koengkan and Fuinhas, 2017; Bilgili et al., 2016; Shafiei and Salim, 2014; Akella et al., 2009). Regarding the negative impact of renewable energy consumption on CO2 emissions, some authors have stressed some key features.

For instance, Koengkan and Fuinhas (2017) investigated the impact of renewable energy consumption on CO2 emissions in ten South American countries in the period from 1980 to 2012. PARDL in the form of UECM was used. The authors found that renewable energy consumption has a negative impact of -0.0420 in the short run. Indeed, this negative impact is related to the globalisation process that exerts a positive effect on economic growth and consequently on the consumption of renewable energy and new investment in green technology and therefore, on CO2 emissions.

Fuinhas et al. (2017) investigated the impact of renewable energy policies on carbon dioxide emissions, for which a panel of ten Latin American countries was analysed, for the period from 1991 to 2012 and a PNARDL model was used as the method. The authors have a different opinion about this impact and confirm that this decrease is related to the efficiency of renewable energy policies that encourage the introduction of alternative energy sources in the energy mix. Other authors share this vision (e.g., Bilgili et al., 2016; Shafiei and Salim, 2014; Akella et al., 2009).

The second approach in the literature suggests that the consumption of renewable energy causes an increase in emissions (e.g., Koengkan et al., 2018; Apergis and Payne, 2014; Sadorsky, 2009). Therefore, some authors have stressed some key features. For example, Koengkan et al. (2018) studied the impact of hydroelectricity consumption on environmental degradation in seven South American countries from 1966 to 2014. The authors found that the use of this kind of energy increases emissions by 0.0593 in the long run. Indeed, this effect occurs in the first few years after a reservoir is created, when the trees that have died in the process of flooding release CO2 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.

However, Apergis and Payne (2014) examined the determinants of renewable energy consumption for a panel of seven Central American countries from 1980 to 2010. The authors used the FMOLS model as the methodology. The authors found that the positive impact of renewable energy consumption on environmental degradation is due to several legal and institutional barriers that do not encourage the expansion of renewable energy, as well as the increase in the use of renewable energy sources. Sadorsky (2009) has a different opinion, where, according to this author, the positive impact of renewable energy on CO2 emissions is due to the lack of financial incentives that do not encourage the development of renewable energy technologies and consequently the consumption of alternative energy sources.

This chapter is organised as follows: **Section 5.2** describes the data and methodology that will be used in this chapter; **Section 5.3** describes the empirical results and discussion; **Section 5.4** describes the robustness check, and finally, **Section 5.5** concludes and debates policy implications.

5.2. Data and methodology

This section is divided into two parts. The first one presents the data and variables that will be used, and the second describes the adopted methodological strategy that will be applied in this chapter.

5.2.1 Data

To explore the asymmetric impact of ratio of renewable energy that is a proxy of energy transition on environmental degradation, eighteen LAC countries, i.e. Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, and Venezuela (RB), were carefully chosen in a period from 1990 to 2014. The use of time-series between 1990 to 2014 is due to the availability of data until 2014 for the variable renewable energy consumption in kWh per capita that compose the variable ratio of renewable energy in all countries selected.

Therefore, this group of countries was selected due to several reasons: **(a)** they have registered rapid growth in the consumption of renewable and non-renewable energy; **(b)** they have experimented a rapid process of economic growth; **(c)** in the last three decades, the CO2 emissions from the LAC countries have more than doubled, and **(d)** the existence of a complete database was the main criteria for choosing the countries from the LAC region, as mentioned in **Chapters 2**, **3** and **4**.

Additionally, the variables which were chosen to perform the analysis are:

- **Carbon dioxide emissions (CO2)**(7) in kilotons (Kt) per capita from the burning of fossil fuels and the manufacture of cement. These include carbon dioxide produced during the consumption of solid, liquid and gas fuels and gas flaring retrieved from World Bank Open Data (2019);
- **Gross domestic product (Y)** in constant (2010 US$) per capita retrieved from World Bank Open Data (2019);
- **Ratio of renewable energy (RE)**, which is the ratio of renewable energy consumption(8) from biomass, hydropower, solar, photovoltaic, wind, wave, and waste in (kWh) per capita divided by the fossil fuel consumption from oil, gas and coal sources in (kWh) per capita. The use of renewable energy was created with data retrieved from World Bank Open Data (2019), and the consumption of fossil energy source was retrieved from the same place;

Notes (7): According to World Bank Open Data (2019), the CO2 emissions of these emissions come largely from energy production and use, which accounts for the largest share of greenhouse gases, associated with global warming. Moreover, anthropogenic CO2 emissions result primarily from the consumption of fossil fuels and cement manufacturing. Therefore, in combustion different, fossil fuels release different amounts of carbon dioxide for the same level of energy use, where oil releases about 50% more carbon dioxide than natural gas, and coal releases about twice as much. Moreover, cement manufacturing releases about half a metric ton of carbon dioxide for each metric ton of cement produced. The data for CO2 emissions includes gases from the burning of fossil fuels and cement manufacture but excludes emissions from land use such as deforestation.

Notes (8): The renewable energy consumption (kWh) per capita is the multiplication of total energy consumption per capita in kWh by renewable energy consumption (% of total final energy consumption). Both variables were retrieved from World Bank Open Data (2019). The option to use this variable was taken because there is no data from the consumption of renewable energy in kWh.

- **Public capital stock (PUBK),** which measures the general government capital stock in billions of constant (2010 US$) per capita retrieved from (IFM) Investment and Capital Stock Dataset (2019).

The increased effect of greenhouse gas (GHG) concentrations on global temperatures and the earth's climate have consequences for ecosystems, human settlements, agriculture and other socio-economic activities (UNEP, 2001). GHG emissions have increased due to the fact that CO2 emissions are still growing in many countries, despite some progress achieved in decoupling CO2 emissions from GDP growth (OECD Environment Directorate, 2008). In the LAC countries it is no different, with emissions of CO2 growing almost ten-fold since the 1970s reaching 1,912,531.50 million kilotons in 2014 (see **Figure 5.1D** in **Appendix D**, p. 213). Therefore, CO2 emissions are a better indicator of environmental performance because, they are the major contributor to the greenhouse effect (OECD Environment Directorate, 2008). The consumption of energy is the main contributor to CO2 emissions, where in the LAC countries the energy sector accounts for approximately 35% of total emissions in 2010, as cited by Hollanda et al. (2016).This is the justification for our study using **CO2** as the dependent variable.

As mentioned before, a relationship exists between CO2 emissions and GDP growth and this relationship is due to economic growth raising standards of living in most countries; it was also responsible for the increase in CO2 emissions and reductions in natural resources (Mardani et al., 2019). In the Latin American countries, the GDP per capita has registered average annual growth rates of approximately 3.0%, (see **Figure 1.1A** in **Appendix A**, p. 200). As a consequence of this growth in the Latin American countries, electric power consumption (kWh per capita) in the region has followed a similar path (see **Figure 1.3A** in **Appendix A**, p. 201), where the use of energy grew by approximately 5.4%, as stated before by Balza et al. (2016) in **Chapter 2** (p. 47). For this reason, this investigation opted to use **Y** as an independent variable.

Indeed, economic growth, financial and trade liberalisation as well as the capital stock accumulation resulting from several economic reforms and political transitions in the last forty years are responsible for the increased investment in and consumption of energy in the Latin American region. Indeed, the use of renewable energy represented 35% of the total energy consumption in 2013, and investment in renewable energy grew by 13% between 2000 and 2013, as cited before by Koengkan (2018a) and Koengkan et al., (2019) in **Chapter 2** (p. 46). This increase in the consumption of renewable energy is an indicator of the energy transition process, as mentioned by Hauff et al. (2014). Therefore, to identify the effect of the energy transition on environmental degradation, we opted to use the ratio of renewable energy consumption to fossil fuel consumption. This ratio is obtained by dividing the consumption of renewable energy by the consumption of fossil fuels. This ratio captures the progression of the consumption of renewable energy to the consumption of fossil fuels over time. Moreover, this method for capturing this progression was used before by Fuinhas et al., (2019) to capture the progress of the weight of oil production to consumption of oil consumption over time. For this reason, **RE** is used as an independent variable in this investigation.

Then, as cited before, the increase of capital stock accumulation is responsible for the rise in investment in and consumption of energy in the Latin American region. The abundance of capital as cited by Lee and Chien (2010) and Lee et al. (2008) reduces its price and makes the capital cheaper and encourages new investment and economic activity and consequently the consumption of fossil fuels and environmental degradation. This explanation justifies the use of **PUBK** as the independent variable.

Table 5.1 shows the summary statistics of variables. Moreover, it should be stressed that they are already in their natural logarithms and their first-differences (see prefix “Ln” and “DLn”).

Table 5.1. Summary statistics of variables

Variables	Descriptive Statistics				
	Obs.	**Mean**	**Std. Dev.**	**Min**	**Max**
LnCO2	450	-6.7708	1.3936	-11.7542	-4.8785
LnY	450	8.4056	0.7719	6.4956	9.5943
LnRE	450	1.9695	4.5903	-2.5181	18.6579
LnPUBK	450	-12.3765	0.8855	-15.0981	-10.4755
DLnCO2	432	0.0203	0.1198	-0.8107	1.0799
DLnY	432	0.0203	0.0349	-0.1462	0.1503
DLnRE	432	-0.0337	0.5760	-5.1653	3.5362
DLnPUBK	432	0.0174	0.0326	-0.0441	0.1813

Notes: Obs. denotes the number of observations; Std. Dev. Denotes the Standard Deviation; Min. and Max. Denote Minimum and Maximum, respectively; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

The variables **CO2**, **Y**, **RE** and **PUBK** were transformed into per capita values with the total population of each cross. This allows controlling for disparities in population growth over time and within countries (Koengkan, 2018b). The ratio of renewable energy was used as a proxy of the energy transition in this chapter because this variable can capture the effect of energy transition from fossil to renewable on CO2 emissions in the LAC countries. The data source of each variable is open access that allows download and reapplication. As cited in **Chapter 4** (p. 128), this investigation opted for the use of GDP in constant (2010 US$) instead of constant (LCU) used in **Chapters 2** and **3** because, in initial studies, the use of constant (2010 US$) presented results slightly different than when constant LCU was used. Indeed, these results could be related to the change of the database source, where the old database from IEA was replaced by the World Bank database.

Additionally, as mentioned before in **Chapter 4** (p. 129), all variables that were used in this investigation are updated every six months. Indeed, in the case of this chapter, all variables were updated in June of 2019.

5.2.2 Methodology

A PNARDL approach in the form of UECM will be used with the purpose of the realisation of this chapter. This methodology is an asymmetric extension of linear PARDL model in the form of UECM, which was created by Granger (1981) and Engle and Granger (1987).

The difference between the two models is that the PNARDL allows the positive and negative variations of the independent variables in the model, which has a different effect on the dependent variable (Rocher, 2017). The same author also adds that the PNARDL allows the detection of the presence of asymmetric effects that the independent variables may have on the dependent variable, as well as testing the existence of cointegration in a single equation.

Indeed, the PNARDL methodology approach was used in this investigation because, in panels with long time spans (macro panels), there is generally the presence of cointegration between the variables and then endogeneity in the model. However, if one does not use the appropriate econometric techniques to cope with the endogeneity and cointegration problem, it can lead to estimation errors and misinterpretation of results. Therefore, to handle the problem of endogeneity and cointegration, the literature recommends the use of PNARDL models as an econometric estimation technique which is robust enough to deal with the presence of endogeneity and cointegration between the variables. Then, the PNARDL in the form of a UECM was used to cope with endogeneity and cointegration that is expected in this investigation.

Moreover, the modelling itself should be considered in the research approach. Does this model have some advantages for this investigation? According to Rocher (2017), this model has several advantages, namely: **(a)** flexibility regarding the order of integration of the variables in the model; **(b)** the possibility of testing for hidden cointegration; **(c)** better performance in small samples; and **(d)** it permits the use of a combination of variables I(0) and I(1). There are other justifications for opting to apply this methodology in this chapter, one of them being **(e)** the capacity to identify the effect of independent variables on the dependent variable in the short and long run. Indeed, as the LAC countries suffered several economic, political and social shocks, this methodology is the best approach; and finally **(f)** it presents better estimations when compared to other methods.

Therefore, the PNARDL model is constructed around the following asymmetric long-run equilibrium relationship (see **Equation (5.1)**):

$$e_t = \alpha^+\gamma^+ + \alpha^-\gamma^- + \mu_t \tag{5.1}$$

where the equilibrium relationship between e and γ is divided into positive ($\alpha^+\gamma^+$) and negative ($\alpha^-\gamma^-$) effects, plus the error term (μ_t) means possible deviations from the long-run equilibrium. As shown in **Equation (5.1)**, the impact of the variable γ can be decomposed into two parts, positive and negative (see **Equation (5.2)**):

$$\gamma_t = \gamma_0 + \gamma_t^+ + \gamma_t^- \tag{5.2}$$

where γ_0 represents the random initial value and $\gamma_t^+ + \gamma_t^-$ denote partial sum processes which accumulate positive and negative changes, respectively, and are defined as (see **Equation (5.3)** and **(5.4)**):

$$\gamma_t^+ = \sum_{j=1}^{t} \Delta\gamma_j^+ = \sum_{j=1}^{t} \max(\Delta\gamma_j\, , 0) \tag{5.3}$$

$$\gamma_t^- = \sum_{j=1}^{t} \Delta\gamma_j^- = \sum_{j=1}^{t} \min(\Delta\gamma_j, 0) \tag{5.4}$$

Then, the general and main PNARDL model in the form of UECM follows the specification of **Equation (5.5)**:

$$\begin{aligned} DLnCO2_{it} = \ & \alpha_{it} + \theta_1^+ \beta_{1i1} DLnY_{it-1}^+ + \theta_1^- DLnY_{it-1}^- + \theta_2^+ \beta_{2i1} DLnRE_{it-1}^+ + \\ & \theta_2^- DLnRE_{it-1}^- + \beta_{3i1} DLnPUBK_{it-1}^+ + \\ & \theta_3^- DLnPUBK_{it-1}^- + LnCO2_{it-1} + \theta_1^+ \gamma_{1i2} LnY_{it-1}^+ + \theta_1^- \gamma_{1i2} LnY_{it-1}^- + \\ & \theta_2^+ \gamma_{2i2} LnRE_{it-1}^+ + \theta_1^- \gamma_{2i2} LnRE_{it-1}^- + \theta_1^+ \gamma_{3i2} LnPUBK_{it-1}^+ + \\ & \theta_1^- \gamma_{3i2} LnPUBK_{it-1}^- + \varepsilon_{1it} \end{aligned} \tag{5.5}$$

where α_i represents the intercept, β_{ik} and γ_{ik}, with k = 1, …, 4, denote the estimated parameters, $DLnY_{it-1}^+$, $DLnY_{it-1}^-$, $DLnRE_{it-1}^+$, $DLnRE_{it-1}^-$, $DLnPUBK_{it-1}^+$, $DLnPUBK_{it-1}^-$, LnY_{it-1}^+, LnY_{it-1}^-, $LnRE_{it-1}^+$, $LnRE_{it-1}^-$, and $LnPUBK_{it-1}^+$, $LnPUBK_{it-1}^-$ are the partial sums of positive and negative changes of variables **DLnY**, **DLnRE**, **DLnPUBK**, **LnY**, **LnRE**, and **LnPUBK**, respectively and ε_{it} is the error term.

Consequently, before the realisation of PNARDL estimation, it is necessary to verify the proprieties of the variables that will be used in this chapter, which includes checking the cross-section and time series, in addition to the existence of specificities that, when not considered in the initial verification, may produce inconsistent results and interpretation. Therefore, the first tests that need to be applied before the estimation of the model are **(a) preliminary**; and **(b) specification tests**.

(a) **Preliminary tests**: **(i)** Correlation matrix; **(ii)** Variance inflation factor (VIF) test; **(iii)** Cross-sectional dependence (CSD) test (Pesaran, 2004 and Pesaran, 2015); **(iv)** Levin–Lin–Chu panel unit root test (LLC) (2002) and 2nd generation unit root test (CIPS-test) (Pesaran, 2007); **(v)** Hausman test; and **(vi)** MG (Pesaran and Smith, 1995), FE, and PMG (Pesaran et al., 1999) estimators;

(b) **Specification tests:** **(i)** Modified Wald test (Greene, 2002); **(ii)** Wooldridge test (Wooldridge, 2002); **(ii)** Pesaran (2004); and **(iii)** Breusch and Pagan Lagrangian multiplier test (Breusch and Pagan, 1980).

This section shows the variables and methodologies and their preliminary and specification tests that will be used in our analysis. The next section will show the empirical results and discussion.

5.3 Empirical results and discussion

This section will show the empirical results of preliminary and specification tests as well as the outcomes of PNARDL estimators and the debate as previously explained. Therefore, the first step that was made was the realisation of the correlation matrix test to inquire about the presence of collinearity between the variables. **Table 5.2** gives the results of the correlation matrix of variables, both in natural logarithms and first-differences.

Table 5.2. Correlation matrix

Variables	LnCO2		LnY		LnRE		LnPUBK
LnCO2	1.0000						
LnY	0.5330	***	1.0000				
LnRE	0.2337	***	0.2763	***	1.0000		
LnPUBK	0.5360	***	0.7348	***	-0.0868	*	1.0000
	DLnCO2		**DLnY**		**DLnRE**		**DLnPUBK**
DLnCO2	1.0000						
DLnY	0.2266	***	1.0000				
DLnRE	-0.3776	***	-0.0921	**	1.0000		
DLnPUBK	-0.0189		0.0448		0.0105		1.0000

Notes: ***, **, and * denote statistically significant at 1%, 5%, and 10% level, respectively; the Stata command *pwcorr* was used; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

The results from **Table 5.2** indicate that the collinearity between the variables is not a concern in the estimation, and there is only one "high" correlation value: between the variables **LnPUBK** and **LnY**.

The second step in this analysis was the realisation of the VIF test that informs the presence of multicollinearity between the variables, and the CSD test for the existence of cross-sectional dependence. The null hypothesis is either strict cross-sectional independence (Pesaran, 2004) or weak cross-sectional dependence (Pesaran, 2015). **Table 5.3** gives the results of VIF and CSD-tests, both in first-differences and natural logarithms.

Table 5.3. VIF and CSD tests

Variables	VIF	1/VIF	CD-test		Average joint T	mean ρ	mean abs(ρ)
LnCO2	n.a.		33.232	***	25.00	0.54	0.58
LnY	2.91	0.3435	43.417	***	25.00	0.70	0.84
LnRE	2.71	0.3691	6.8782	***	25.00	0.11	0.34
LnPUBK	1.35	0.7410	12.591	***	25.00	0.20	0.68
Mean VIF	2.32						
DLnCO2	n.a.		0.262		24.00	0.00	0.17
DLnY	1.01	0.9894	17.702	***	24.00	0.29	0.32
DLnRE	1.01	0.9913	1.621		24.00	0.03	0.22
DLnPUBK	1.00	0.9977	18.235	***	24.00	0.30	0.42
Mean VIF	1.01						

Notes: The Stata commands *estat vif* and *xtcdf* were used; *** denotes statistically significant at the 1% level; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

The results from the above table indicate that multicollinearity is also not a concern in the estimation, given the existence of low VIF and mean VIF values, where the results are lower than the usually accepted benchmarks of 10 in the case of the VIF values, and 6 in the case of the mean VIF values. Regarding the CSD-test, we see that the null hypothesis is rejected in all variables in natural logarithms and some variables in first-differences such as **DLnY**, and **DLnPUBK**, leading us to the conclusion that there is a correlation between the series across countries in these variables.

Then, in the presence of CSD, it is advised to assess the order of integration of the variables of our model. To this end, the LLC and CIPS tests were computed. Indeed, these both tests are robust in the presence of CSD, and the option was not taken to use the 1^{st} generation test due to the reaction that it is inefficient in the presence of CSD. Moreover, the null hypothesis of LLC-test is that all series contains a unit root I(1), and the null hypothesis of CIPS-test is that all series are non-stationary I(0). The results of these tests can be seen in **Table 5.4**.

Table 5.4. Unit root test

Variables	Panel-data unit-root test								
	Levin-Lin-Chu (2002) Panel Unit Root test (LLC) (Adjusted t)					Pesaran (2007) Panel Unit Root test (CIPS) (Zt-bar)			
	Without trend			With trend		Without trend		With trend	
	Lags	Adjusted t		Adjusted t		Zt-bar		Zt-bar	
LnCO2	1	-1.7795	**	-0.9099		-1.719	**	-0.193	
LnY	1	-2.4779	***	-3.0526	***	-2.369	***	-1.561	*
LnRE	1	-0.6844		-1.3416	*	-2.297	**	-0.742	
LnPUBK	1	1.8370		2.8653		2.417		-2.308	**
DLnCO2	1	-9.7455	***	-7.8242	***	-9.155	***	-8.314	***
DLnY	1	-8.3567	***	-6.6535	***	-6.566	***	-5.218	***
DLnRE	1	-10.4247	***	8.2803	***	-10.036	***	-8.323	***
DLnPUBK	1	0.5114		-3.0009	***	-2.754	***	-1.852	**

Notes: The Stata commands *xtunitroot* and *multipurt* were used; The null for LLC test is that all series are I(1), and in CIPS test is: series are I(0); the lag length (1) and trend were used in these tests;***, **,* denote statistically significant at the 1%, 5%, and 10% levels respectively; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

The results from **Table 5.4** show that none of the variables tested seems to be I(2), while they show that some of them may be in the borderline between the I(0) and I(1) orders of integration, such as the LLC indicating the variables **CO2, Y** without trend, **Y** and **RE** with trend in natural logarithms, and the variables **CO2**, **Y**, **RE** without trend in first-differences, and that all variables with trend are stationary. Moreover, the CIPS test presents the same results, where the variables **CO2**, **Y**, **RE** are without trend and **Y** and **PUBK** with trend in logarithms and all variables in first-differences without and with trend are stationary too.

After assessing the order of integration of the variables, it is necessary to verify the presence of individual effects in the model. To this end, the Hausman test, which compares the random (RE) and fixed effects (FE), was calculated. The null hypothesis of the Hausman test is that the difference in the coefficients is not systematic, where the RE effects are the most suitable estimator of the model. Therefore, this test indicates that the null hypotheses should be rejected (**chi2 (8) = 80.07**, statistically significant at 1% level) (see in **Table 5.5D** in **Appendix D**, p. 214) and that a fixed-effects model is the most appropriate for this analysis.

So, to verify the presence of heterogeneity or homogeneity in our panel data, the MG PMG and FE estimators were performed. The MG estimator calculates the average of coefficients of all individuals, with no restrictions regarding the homogeneity of short and long run. The PMG allows for differences in error variances in short-run coefficients, speed of adjustment, and intercepts, but it imposes a homogeneity restriction on the long-run coefficients.

Moreover, the PMG estimator can combine the "pooling" from the FE estimator with the "averaging" from the MG estimator. Nevertheless, in the presence of panel homogeneity in the long run, the PMG estimator is more efficient if compared with MG. **Table 5.6** shows the outcomes from the estimations of the three specifications (e.g., MG, PMG, and FE).

Table 5.6. Heterogeneous estimators

Independent variables	Dependent variable (DLnCO2)					
	MG		PMG		FE	
Constant	-9.7595	***	-6.2612	***	-4.3525	***
			Short-run (impacts)			
DLnY	0.7750	***	0.8867	***	0.6396	***
DLnRE_POS	-0.0709		-0.0732	*	-0.0623	***
DLnRE_NEG	-0.1211	***	-0.1248	***	-0.0809	***
DLnPUBK	0.2892		0.0478		0.6864	***
			Long-run (elasticities)			
LnY (-1)	1.6284		0.0576		0.3823	***
LnRE_POS (-1)	0.6080		-0.0570	***	-0.0769	***
LnRE_NEG (-1)	0.3086		-0.2416	***	-0.0958	***
			Speed of adjustment			
ECM	-0.7530	***	-0.3995	***	-0.3876	***

Notes: ***, **, * denote statistically significant at the 1%, 5%, and 10% levels, respectively; the ECM denotes the coefficient of the variable LnCO2, lagged once; the long-run parameters are computed elasticities; the Stata command *xtpmg* was used; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

A note should be addressed to the results for the PMG estimation when confronted with the MG and FE estimations. However, the inconsistency of the MG model could raise doubts about the soundness of research. It is most likely that the algorithm used in MG estimator failed the starting conditions.

Table 5.7 shows the results from the Hausman tests between the following specifications: MG vs PMG; PMG vs FE; MG vs FE. From the information that is present in this table, we can conclude that there is evidence that the panel is homogeneous, with the results indicating that the FE estimator is the most appropriate. Moreover, the results also indicate that the LAC countries in this chapter return to equilibrium as quickly as expected.

Table 5.7. Hausman test

MG vs PMG	PMG vs FE	MG vs FE
Chi2(8) = 325.90***	Chi2(8) = 167.23***	Chi2(8) = 52.81***

Notes: *** denotes statistically significant at 1% level; Hausman results for H_0: difference in coefficients not systematic; the Stata commands *xtpmg*, and Hausman (with the options, alleqs constant) were used.

Before the realisation of model estimation, a battery of specification tests must be conducted, such as **(a)** Modified Wald test to assesses the panel groupwise heteroskedasticity in the residuals of FE estimation; **(b)** Wooldridge test for autocorrelation in panel data; **(c)** Pesaran's test for cross-sectional independence; and **(d)** Breusch and Pagan Lagrangian multiplier test of independence for contemporaneous correlation. The results from all these tests are presented in **Table 5.8**.

Table 5.8. Specification tests

Statistics	**(a) Modified Wald test**	**(b) Wooldridge test**	**(c) Pesaran's test**	**(d) Breusch and Pagan Lagrangian multiplier test**
	chi2 (18) =6019.71 ***	F(1, 17) = 53.346***	1.123	n.a.

Notes: *** denotes statistically significant at 1% level; H_0 of Modified Wald test: sigma(i)^2 = sigma^2 for all i; H_0 of Wooldridge test: no first-order autocorrelation; H_0 of Pesaran's test: residuals are not correlated; H_0 of Breusch and Pagan Lagrangian multiplier test: no dependence between the residuals; (n.a) denotes not available.

The results of the specification test indicate rejection of the null hypothesis of modified Wald and Wooldridge tests at the 1% level, indicating the presence of heteroscedasticity and first-order autocorrelation.

Moreover, it cannot reject the null hypothesis of Pesaran's test, indicating the non-presence of correlation. Regarding the Breusch and Pagan Lagrangian multiplier test, it could not compute it because the correlation matrix of residuals was singular. This situation occurs because the number of crosses under study is less than the number of years.

Moreover, it is worth remembering that the Hausman test, MG, PMG and DFE estimators and the specification tests that were specified in subsection **5.2.2** were applied in the parsimonious model. That is, insignificant variables were removed (e.g., **DLnY_POS**, **DLnY_NEG**, **DLnPUBK_POS**, **DLnPUBK_NEG**, **LnY_POS**, **LnY_NEG**, **LnPUBK_POS**, and **LnPUBK_NEG**) in previous regressions from our general model (see **Equation 5.5**). The positive and negative asymmetry of these variables was not revealed as expected in the model.

After the realisation of preliminary and specification tests, the model regression can be made. Therefore, three estimations were computed in this model, the FE, FE robust standard errors (FE Robust), and FE Driscoll and Kraay (FE D.-K.). Indeed, the FE D.-

K. was used due to the specification tests results, to deal with the presence of heteroscedasticity and first-order autocorrelation. This estimator can produce standard errors robust to the phenomena that were found in the sample errors. Moreover, regression dummy and shift-dummy variables were included in the model.

These dummies variables were added to the model because during the period of analysis, the LAC countries suffered several shocks that, if not considered, could have produced inaccurate results that could lead to misinterpretations.

Additionally, all these dummies and shift-dummies variables following triple criterion were thus used to include: **(a)** significant disturbances in the estimated residuals; **(b)** the occurrence of international events known to have disturbed the LAC region; and **(c)** the potential relevance of recorded economic, social, and political events at the country level. Thus, the dummy and shift-dummy variables that were added to the regression are the following: **IDBOLIVIA_2001** (Bolivia, year 2001); **IDECUADOR_1994** (Ecuador, year 1994); **IDGUATEMALA_2014** (Guatemala, year 2014); **SDHAITI_1993_1995** (Haiti, years between 1993 to 1995); **IDPANAMA_1995** (Panama, year 1995); **SDPANAMA_1996_1997** (Panama, years between 1996 to 1997).

- **IDBOLIVIA_2001**: Represents a break in the GDP of Bolivia in 2001. This break can be justified by a decrease in economic activity, where the GDP of Bolivia grew just 1.7% in 2001 (Weisbrot et al., 2009);
- **IDECUADOR_1994**: Represents a break in the GDP of Ecuador in 1994. This break can be justified by low economic growth between 1993 and 1995 (Jácome, 2004);
- **IDGUATEMALA_2014**: Represents a peak in the GDP of Guatemala in 2014. This peak can be justified by the acceleration of the country's economic activity in 2014, where the GDP of the country grew 4.2% (World Bank Open Data, 2019);
- **SDHAITI_1993_1994**: Represents two breaks in the GDP of Haiti between 1993 and 2014. These breaks can be justified by Operation Uphold Democracy that was a military intervention designed to remove the military regime installed by the 1991 *Haitian coup d'état* that overthrew the elected President Jean-Bertrand Aristide. The operation was effectively authorised in 1994 (The Carter Center, 1994);

- **IDPANAMA_1995:** Represents a break in the GDP of Panama in 1995. This break can be justified by a decrease in economic activity, where the GDP of Panama grew just 1.8% in 1995 (World Bank Open Data, 2019);

- **SDPANAMA_1996_1997**: Represents two peaks in the GDP of Panama between 1996 to 1997. These peaks can be justified by an increase in economic activity, where the GDP of Panama in 1996 grew 4.1%, and in 1997, 6.5% (World Bank Open Data, 2019).

Therefore, these peaks and breaks impacted the consumption of energy and consequently, the emissions of CO2 in these countries. **Table 5.9** displays the short-run impacts, the model speed of adjustment, and the computed long-run elasticities.

Table 5.9. Elasticities, short-run impacts, elasticities, and adjustment speed (controlling for shocks)

Independent variables	Dependent variable (DLnCO2)			
	FE		FE Robust	FE D.-K.
Constant	-5.2612	***	***	***
		Shocks		
IDBOLIVIA_2001	-0.2468	***	***	***
IDECUADOR_1994	-0.5198	***	***	***
IDGUATEMALA_2014	0.3023	***	***	***
SDHAITI_1993_1995	-0.3676	***	***	
IDPANAMA_1995	-0.3857	***	***	***
SDPANAMA_1996_1997	0.2165	***	***	***
		Short-run (impacts)		
DLnY	0.5475	***		**
DLnRE_POS	-0.0601	***	***	***
DLnRE_NEG	-0.0792	***	***	***
DLnPUBK	0.4763	***		*
		Long-run (elasticities)		
LnY (-1)	0.2186	***	***	***
LnRE_POS (-1)	-0.0281	***	***	***
LnRE_NEG (-1)	-0.0339	***	***	***
		Speed of adjustment		
ECM	-0.4452	***	***	***

Notes: ***, ** denote statistically significant at the 1%, 5%, and 10% levels, respectively; the ECM denotes the coefficient of the variable **LnCO2**, lagged once; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

In summary, the results from **Table 5.9** indicate that the variable Y in the short and long run, have a positive impact of 0.5475 and 0.2186, respectively and the variable **PUBK** in the short run has a positive impact of 0.4763 on **CO2** emissions. However, the positive and negative asymmetry of variable **RE** in the short and long run has a negative impact of -0.0601 **(POS)** -0.0792 **(NEG)** in the short run and -0.0281 **(POS)** and -0.0339 **(NEG)** in the long run.

Moreover, the results of positive and negative asymmetry are consistent because both the results are negative. Concerning the ECM term, it is negative and statistically significant at the 1% level, and the statistical significance at the 1% level of the dummy and shift-dummy variables supports the decision to include them in the model.

Therefore, the possible explanation for the positive impact of economic growth on environmental degradation is due to fossil fuel sources being the primary inputs for agriculture and industry, which influence both economic growth and environmental degradation in the LAC countries (Mirza and Kanwal, 2017). Another possible clarification for this impact is that an increase in economic growth will lead to an increase in environmental degradation (CO2) at high levels of income due to the increase in manufacturing industries.

In other words, in the early stages of development of LAC countries, environmental degradation would decrease but increase later after the economic growth exceeds the threshold parameter. Therefore, in the period of economic boom, the households and firms will have more income and consequently will increase the consumption of energy from electric devices, transportation, appliances among others that will contribute to the increase of CO2 emissions (Aye and Edoja, 2017). These possible explanations about the impact of economic growth on the consumption of fossil fuels were confirmed in **Chapters 3** and **4**, where it was confirmed that in the Mercosur countries, economic growth increases the consumption of fossil fuels by 0.1730 and that there exists a bi-directional causality between the variables (see **Table 3.6** in **Chapter 3**, p.98). Moreover, it also was confirmed that in the LAC countries the impact and elasticity of economic growth have a positive impact of 0.6255 and 2.0488, respectively, on the consumption of fossil fuels (see **Table 4.10** in **Chapter 4**, p. 137).

The capacity of the ratio of renewable energy that is a proxy of the energy transition to reduce environmental degradation is probably related to the renewable energy technological efficiency that produces more clean energy and fewer emissions, as well as the increasing participation of renewable energy sources in the energy matrix (Koengkan et al., 2019). Indeed, these factors, according to Koengkan and Fuinhas (2017), are related to the globalisation process in LAC countries that exerts a positive impact on the factor of productivity and economic growth and consequently on the consumption of renewable energy and new investment in green technology. Indeed, this evidence was confirmed in **Chapters 2** and **3,** where financial openness, which is a subcomponent of globalisation, increases investment in installed capacity of renewable energy by 0.6371 (see **Table 2.10** in **Chapter 2**, p. 63). This explanation also was confirmed in **Chapter 3**, where the consumption of renewable energy and globalisation process increases economic growth, while the consumption of fossil fuels reduces it. Economic growth, consumption of fossil fuels and globalisation increase the consumption of renewable energy. Economic growth increases the consumption of fossil fuels, while the consumption of renewable energy and globalisation reduce the consumption of energy from fossil sources. Furthermore, the consumption of energy from renewable and fossil sources increases the process of globalisation, while economic growth reduces it (see **Table 3.6**, p. 98 and **Figure 3.2**, p. 100 in **Chapter 3**).

Shahbaz et al. (2015) add that the openness and competition brought by the globalisation process increase the environmental regulation standards regarding investment in cleaner technology. Shahbaz et al. (2016) confirm that globalisation is a way of improving economic growth and welfare by reduction of cross border restrictions on trade and investment with other countries. Therefore, this reduction in border restrictions encourages foreign firms to set up new businesses or expand their existing ones using newer and more advanced technologies that reduce the consumption of non-renewable energy and thereby lower their overall costs. This is likely to influence the existing firms in the host country to adopt new methods of production, reducing the consumption of fossil fuels and consequently the emissions of CO2. This idea is shared by Leitão (2014), who confirms that the process of globalisation by trade liberalisation encourages developing countries to access efficient technologies from developed countries that consequently reduce the consumption of non-renewable energy sources and environmental degradation. This explanation was mentioned in **Chapter 4** (pp. 119-120) where the technique effect reduces energy consumption as an improvement in technology. Indeed, this improvement is due to the technology transfer that improves energy efficiency.

Therefore, as mentioned before by Shahbaz et al. (2014) in **Chapter 4** (pp. 118-119), the technique effect is possible through trade liberalisation, which allows developing countries to import advanced technologies from developed countries. Moreover, the process of trade liberalisation, as mentioned before by Zahonogo (2016) in **Chapter 4** (p. 119) encourages the transfer of new technologies helping the technological progress and productivity improvement. Henry et al. (2009) in **Chapter 4** (p. 119) also add that this technology transfer consisting in intermediated manufactured products, capital equipment, and new material that are commercialised in the international markets.

Moreover, another possible explanation for this negative impact is related to the efficiency of renewable energy policies that encourage the introduction of alternative energy sources in the energy mix. For example, in the LAC countries, the most effective policies are national renewable energy targets, which provide a clear indication about the intended level of development of alternative energy sources and the timeline envisioned by governments (Fuinhas et al., 2017).

Finally, there is an indirect effect of public capital stock on environmental degradation. According to Lee and Chien (2010) and Lee et al. (2008), the abundance of capital reduces the price and makes capital cheaper and consequently encourages new investment and economic activity and subsequently the consumption of non-renewable energy and environmental degradation. Moreover, Lee (2005) also adds that that capital stock can positively affect investment and industrial production, which in consequence, leads to an increase in energy demand/consumption.

However, one doubt in the explanations about the impact of the energy transition on environmental degradation arise: can globalisation and renewable energy policies encourage the energy transition in the LAC countries as mentioned in the literature? In the next section robustness checks will be carried out to verify if the energy transition in LAC countries is influenced by the globalisation process and renewable energy policies as mentioned before. This verification is essential to confirm if the results are in line with the literature.

5.4 Robustness check

To verify if the globalisation process influences the energy transition in LAC countries and renewable energy policies, the following variables were utilised.

- **Globalisation index (GLB)**, retrieved from the KOF Globalisation index *De Facto* (KOF, 2018). This variable measures the economic, social and political dimensions of globalisation on a scale from 1 to 100. Therefore, economic globalisation measures trade and financial globalisation. Trade globalisation is determined based on trade in goods and services, and financial globalisation includes foreign investment in various categories. Social globalisation measures interpersonal contact, flows of information and cultural proximity. Interpersonal contact is measured within the de facto segment concerning international telephone connections, tourist numbers, and migration. The flows of information are determined within the de facto segment concerning international patent applications, international students and trade in high-technology goods. Cultural proximity is measured in the de facto segment from trade in cultural goods, international trademark registrations and the number of McDonald's restaurants and IKEA stores. Finally, political globalisation measures the numbers of embassies and international non-governmental organisations (NGOs), along with participation in United Nations (UN) peacekeeping missions;

- **Renewable energy policies (REP)**, retrieved from the International Renewable Energy Agency (IRENA, 2019). This variable includes all policies defined by the International Energy Agency (IRENA), namely: **(a)** Economic Instruments; **(b)** Information and Education; **(c)** Policy Support; **(d)** Regulatory Instruments; **(e)** Research, Development and Deployment (RD&D). This variable was built in accumulated form, where each policy that was created is represented by (1) accumulated over other policies throughout its useful life or end (e.g. 1, 1, 2, 2, 2, 3,3).

The motivation that led us to include these variables was mentioned in **Section 5.3**. The variable **GLB** retrieved from the KOF Globalisation index (KOF, 2018) as discussed before in **Chapter 3**, was used because it can present more satisfactory results than the use of other subcomponents of globalisation (e.g., capital mobility, economic integration, financial liberalisation, FDI, trade flow openness, trade openness and trade liberalisation), when fixed-effect techniques are used (e.g., Koengkan et al., 2019; Koengkan, 2017b; Dogan and Deger, 2016). Additionally, as cited before by Iheanacho (2018) in **Chapter 3** (p. 91) the globalisation process is considered one of the potential facts that encourages higher economic growth and that consequently increases the demand and investment of energy to respond to economic growth. Koengkan et al. (2019) in **Chapter 3** (p. 91), confirmed that this process allows countries to improve their trade and total factor productivity and raises standards of living, which consequently enhances economic growth. Therefore, this variable was also used in this robustness check for the reason that the LAC countries are in a process of rapid globalisation (see **Figure 1.8A** in **Appendix A**, p. 203). Therefore, for this reason, the inclusion of this variable is essential and indispensable for this investigation because it will evidence the influence of globalisation on the process of energy transition.

Moreover, the variable **REP**, retrieved from the International Renewable Energy Agency (IRENA, 2019) as mentioned before. This variable was built in the accumulated form to identify its effect on energy transition. The first authors that utilised this variable were Fuinhas et al., (2017) to identify the impact of renewable energy policies on environmental degradation in the Latin American countries. However, according to Fuinhas et al., (2017), this indicator has the shortcoming of not capturing the strength of policies, as it only registers their deployment. Zhao et al., (2013) said that this problem is due to the fact that a precise measurement of the intensity of policies is nearly impossible because of both the unavailability of data and the diverse particularities of countries. Then, this problem was not a severe constraint given that the objective of the use of this variable, as mentioned before, is to assess the possible effectiveness of public policies on the process of energy transition as suggested by the literature.

The variables **RE** and **CO2** are the same as used in the previous model (see in subsection **5.2.1**). **Table 5.10D** in (**Appendix D**, p. 214), shows the summary statistics of variables that were used in this robustness check. Indeed, the PNARDL model was used to carry out this check. The general PNARDL model in the form of UECM follows the specification of **Equation (5.6)**:

$$
\begin{gathered}
DLnRE_{it} = \alpha_{it} + \theta_1^{+}\beta_{1i1}DLnGLB_{it-1}^{+} + \\
\theta_1^{-}DLnGLB_{it-1}^{-} \quad + \theta_2^{+}\beta_{2i1}DLnREP_{it-1}^{+} + \\
\theta_2^{-}DLnREP_{it-1}^{-} \quad + \beta_{3i1}DLnCO2_{it-1}^{+} + \\
\theta_3^{-}DLnCO2_{it-1}^{-} \quad + LnRE_{it-1} + \theta_1^{+}\gamma_{1i2}LnGLB_{it-1}^{+} \quad + \theta_1^{-}\gamma_{1i2}LnGLB_{it-1}^{-} + \\
\theta_2^{+}\gamma_{2i2}LnREP_{it-1}^{+} \quad + \theta_1^{-}\gamma_{2i2}LnREP_{it-1}^{-} + \theta_1^{+}\gamma_{3i2}LnCO2_{it-1}^{+} \quad + \\
\theta_1^{-}\gamma_{3i2}LnCO2_{it-1}^{-} + + \varepsilon_{1it}
\end{gathered}
\tag{5.6}
$$

where α_i represents the intercept, β_{ik} and γ_{ik}, with k = 1, …, 4, denote the estimated parameters, $DLnGLB_{it-1}^{+}$, $DLnGLB_{it-1}^{-}$, $DLnREP_{it-1}^{+}$, $DLnREP_{it-1}^{-}$, $DLnCO2_{it-1}^{+}$, $DLnCO2_{it-1}^{-}$, $LnGLB_{it-1}^{+}$, $LnGLB_{it-1}^{-}$, $LnREP_{it-1}^{+}$, $LnREP_{it-1}^{-}$, and $LnCO2_{it-1}^{+}$, $LnCO2_{it-1}^{-}$ are the partial sums of positive and negative changes of variables **DLnGLB**, **DLnREP**, **DLnCO2**, **LnGLB**, **LnREP**, and **LnCO2**, respectively and ε_{it} is the error term.

The parsimonious model was used to carry out the robustness check. That is, insignificant variables were removed (e.g., **DLnGLP_POS**, **DLnGLB_NEG**, **DLnREP_POS**, **DLnREP_NEG**, **DLnCO2_POS**, **DLnCO2_NEG**, **LnREP_POS**, **LnREP_NEG**, **LnCO2_POS**, **LnCO2_NEG**) in previous regressions from our general model (see **Equation 5.6**). The positive and negative asymmetry of these variables was not revealed as expected in this chapter. Moreover, it is worth remembering that the Hausman test, MG, PMG and DFE estimators and the specification tests that were specified in Subsection **5.2.2** were applied in the parsimonious model.

The results of preliminary tests point to the existence of low collinearity between the variables, low-multicollinearity, cross-sectional dependence in all variables in the natural logarithms and the variable **GLB** in the first-differences. Moreover, it also identified unit roots in the variables in the first-differences with and without trend, and in the variables **GLB**, **REP** and **CO2** in natural logarithms without trend, and **RE**, **GLB**, **REP** with trend, as well as the presence of fixed effects in the model. These results can be seen in **Tables 5.11D**, **5.12D**, **5.13D**, and **5.14D** in **Appendix D** (pp. 215-216).

However, the heterogeneity/homogeneity test cannot be applied due to the MG and PMG estimators requiring a considerable number of variables, where this model has only two variables in the short run in the parsimonious model. The results of specification tests indicate rejection of the null hypothesis of modified Wald and Wooldridge tests at the 1% level, indicating the presence of heteroscedasticity and first-order autocorrelation. Additionally, we cannot reject the null hypothesis of Pesaran's and Breusch and Pagan Lagrangian multiplier tests, indicating the non-presence of correlation and dependence in the residuals (see **Table 5.15D** in **Appendix D**, p. 216).

Moreover, dummy and shift-dummy variables were included in the model regression. The dummy and shift-dummy variables added to the regression are the following: **IDPARAGUAY_1995** (Paraguay, year 1995); **IDPARAGUAY_2000** (Paraguay, year 2000); and **SDURUGUAY_2001_2004** (Uruguay, years between 2001 to 2004).

- **IDPARAGUAY_1995**: Represents a break in the consumption of renewable energy in 1995. This break can be justified by a decrease in economic activity, where the GDP of Paraguay grew just 6.8% in 1995 (World Bank Open Data, 2019);

- **IDPARAGUAY_2000**: Represents a peak in the consumption of renewable energy in 2000, where Paraguay had 100% of renewable energy in their energy matrix (e.g., hydropower) in 2000 (World Bank Open Data, 2019);
- **SDURUGUAY_2001_2004**: Represents several peaks in the consumption of renewable energy between 2001 to 2004, where between 2001 and 2003 the renewable energy sources represented 99% of Uruguay's energy matrix, and 81% in 2004 (World Bank Open Data, 2019).

Table 5.16 displays the short-run impacts, the model speed of adjustment, and the computed long-run elasticities.

Table 5.16. Elasticities, short-run impacts, elasticities, and adjustment speed (controlling for shocks) from robustness check

Independent variables	**Dependent variable (DLnRE)**			
	FE		**FE Robust**	**FE D.-K.**
Constant	-10.2464	***	***	***
		Shocks		
IDPARAGUAY_1995	-2.7902	***	***	***
IDPARAGUAY_2000	2.2685	***	***	***
SDURUGUAY_2001_2004	0.9755	***	**	
		Short-run (impacts)		
DLnC02	-2.0582	***	**	***
		Long-run (elasticities)		
LnGLB_POS (-1)	1.4870	***	***	***
LnGLB_NEG (-1)	1.8678	***	**	***
LnREP (-1)	-0.0847	**	*	***
LnCO2 (-1)	-1.0577	**	*	**
		Speed of adjustment		
ECM	-0.4612	***	***	***

Notes: ***, ** denote statistically significant at the 1%, 5%, and 10% levels, respectively; the ECM denotes the coefficient of the variable **LnRE**, lagged once; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

The results from **Table 5.16** indicate that the variable **CO2** reduces the process of energy transition in the LAC countries in the short and long run. Moreover, the positive and negative asymmetries of variable globalisation index has a positive effect on the proxy of energy transition in the long run. This result confirms the explanations of, for example, Koengkan (2017), Shahbaz et al. (2016), Shahbaz et al. (2015) and Leitão (2014) that the process of globalisation in the LAC countries influences the process of energy transition. Therefore, the capacity of globalisation to increase the renewable energy transition is related to technology transfer that improves energy efficiency and encourages the use of green technologies via investment and imports, as mentioned in **Chapter 4** (p. 144). Indeed, these technology transfers are possible through trade and financial liberalisation that allows the developing countries to import advanced and green technologies from developed countries, as well as encouraging investment in and development of these technologies, as cited in **Chapters 2** and **4**. All this helps technological progress and the improvement of productivity and subsequently an increase in economic activity and the consumption of energy from this kind of source. Koengkan et al. (2019) investigated the impact of globalisation on development of renewable energy in the Latin American countries, and the authors confirm this explanation, where the globalisation process encourages investment in installed capacity of renewable energy and that these new investments exert a positive impact on economic growth and subsequently on energy consumption. Moreover, these authors summarise the effect of globalisation on the development of renewable energy (see **Figure 5.2**) below.

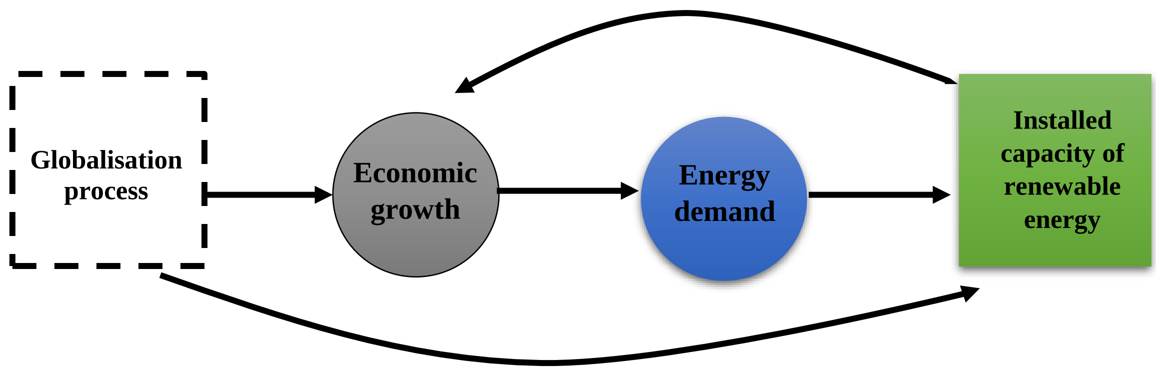

Figure 5.2. Summary of the impact of globalisation on the development of renewable energy (adapted from Koengkan et al., 2019, p. 9).

Moreover, the same authors also add that globalisation can allow households and firms to purchase renewable energy technology more cheaply, increasing the consumption of green energy.

However, the negative effect of renewable energy policies on energy transition is a surprise for this chapter, because this result was not expected. Indeed, the possible explanation for this impact can be related to the possible inefficiency of these policies in that it encourages the development of green energy in LAC countries or the methodology or the construction of variable **REP** are not able to reveal the real effect of this variable on energy transition. Moreover, concerning the ECM term, it is negative and statistically significant at the 1% level, and the statistical significance at the 1% level of the dummy and shift-dummy variables supports the decision to include them in the model.

After identifying that the globalisation process influences energy transition, other doubts arose in the explanations about the effect of globalisation on energy transition in the LAC countries, namely: can globalisation encourage imports of advanced technology in the LAC countries? Do imports of advanced technology increase the process of energy transition? To answer these questions, it is necessary to make a "complementary robustness check" to identify and to confirm if the results are in line with the literature. Regarding the effect of globalisation on investment in renewable energy, it was established in **Chapter 2**, with the use of a proxy of globalisation, i.e., financial openness.

Therefore, to carry out this check, the following variables were used, such as the **ratio of renewable energy (RE)**, **globalisation index (GLB) –** the same used in **Sections 5.2** and **5.4** – and the experimental variable **imports of ICT goods imports (ICT_IMPORTS)** in (current US$).(9) Therefore, we opted to use this experimental variable as a proxy of technological progress because globalisation via imports of manufactured products, capital equipment, technological goods, electronic equipment, and new materials that are commercialised in the international markets, as mentioned by Henry et al., (2009) in **Chapter 4**, causes technological progress and consequently encourages energy transition due to the availability of technologies. In the literature, some studies have used a similar variable (e.g., Yan et al., 2018; Mattern et al., 2010; Hilty et al., 2009; Holmgren and Thorslund, 2009). The variables **RE** and **ICT_IMPORTS** are in per capita values.

Then, a time span between 2000 to 2014, as well as, a group of seventeen countries from the LAC region i.e., Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, and Venezuela (RB), were used to carry out this "complementary check". Indeed, this period and these countries were selected due to the availability of data for the variable **ICT_IMPORTS**.

Notes (9): This variable is the multiplication of goods imports (BoP, current US$) that refers to all movable goods (including non-monetary gold) involved in a change of ownership from non-residents to residents by ICT goods imports (% total goods imports), that is information and communication technology goods imports including computers and peripheral equipment, communication equipment, consumer electronic equipment, electronic components, and other information and technology goods (miscellaneous). Both variables were retrieved from World Bank Open Data (2019).

Moreover, **Table 5.17D** in **Appendix D** (p. 220), shows the summary statistics of variables that were used. The PVAR model estimation was used. Indeed, this methodology and the preliminary and specification tests, such as panel VAR lag-order selection; Granger causality Wald test; eigenvalue stability condition; forecast-error variance decomposition (FEVD); and impulse-response functions (IRF) are the same as those used in **Chapters 2** and **3**.

The results of preliminary tests that check the characteristics of variables point to the presence of low collinearity and multicollinearity, with cross-sectional dependence in the variables **GLB** and **ICT_IMPORTS** in the first-difference and natural logarithms. The presence of unit roots was also identified in the variables in first-differences with and without trend, except the variable **GLB** with trend, and in the variables **RE**, **GLB**, and **ICT_IMPORTS** without and with trend in natural logarithms, as well as the presence of random effects in the model. Moreover, the results of PVAR lag order selection point to the need to use the lag length (1) in the PVAR regression. These results can be seen in **Tables 5.18D**, **5.19D**, **5.20D**, **5.21D** and **5.22D** in **Appendix D** (pp. 217-218).

The PVAR model indicates that globalisation increases the process of energy transition, and the import of technological goods. Moreover, was identified that the imports of technology encourage the process of energy transition. The results of the PVAR model can be seen in **Table 5.23D** in **Appendix D** (p. 218). Indeed, this result confirms the possible explanation that the process of globalisation increases the technological efficiency of renewable energy by imports of technological goods and consequently increases renewable energy production.

Moreover, other authors such as Shirazi (2008) confirm that technological progress consists of learning about new technologies and materials, production processes or organisational methods. Indeed, the indirect benefits of this process derive from the imports of goods and services that have been developed by trade partners. Additionally, developing countries that successfully absorbed FDI inflow, particularly in the production of ICT and services (e.g., China, India, and Malaysia), have seen a variety of benefits. Regarding the impact of imports of technological goods on the energy sector, this effect is confirmed by Yan et al., (2018); according to these authors, ICT development can stimulate economic growth with a less-than-proportionate increase of energy use, i.e., energy productivity improvement. This explication is in consonance with Mattern et al., (2010), which confirms that ICT reduces consumption of resources and energy in other economic sections and consequently mitigates environmental degradation. The authors also add that ICT improves energy efficiency by the established process (i.e., increasing the ratio of a relevant target variable such as productivity or convenience to energy consumption), or by the development of new concepts to generate, allocate, distribute, share and use energy in a resource-efficient and environmentally-friendly way.

The results of specification tests point out that the PVAR model is stable. One period after the shock, the variables themselves explained almost all the forecast error variance, and the impulse – response functions are such that all variables converge to equilibrium, supporting that the variables of the model are I(1) (see **Tables 5.24D**, **5.25D**, and **Figure 5.3D** in **Appendix D**, pp. 218-219).

Moreover, it is worth remembering that this complementary robustness check which was made is experimental in character and was used out of curiosity to discover the possible effect of globalisation on technological efficiency. Indeed, it is necessary to develop this issue further using other variables and methodology to discover the real impact. However, this verification is a kick-off to study this relationship.

5.5 Conclusions and policy implications

The main aim of this chapter was to assess the asymmetric impact of energy transition on environmental degradation. Eighteen LAC countries were considered, and a period from 1990 to 2014 proved to be the most appropriate. Moreover, this chapter opted to use PNARDL in the form of a UECM as the methodology.

The preliminary tests of this chapter indicated that the variables used have the following characteristics, such as low-multicollinearity, cross-sectional dependence in all variables in natural logarithms and some variables in first-differences, such as Y and PUBK, I(0)/I(1) for all variables, and the presence of fixed effects. Moreover, the specification test indicated the presence of heteroscedasticity, first-order autocorrelation, and non-presence of cross-sectional independence. The results of these tests are essential to identify the characteristics of countries that are under study as well as the possible methodologies that need to be applied.

The results of the PNARDL model estimation suggest that economic growth in the short and long run, as well as the public capital stock in the short run, have a positive effect on environmental degradation. Nevertheless, the positive and negative asymmetry of the variable ratio of renewable energy, which is a proxy of energy transition, hurts the environment in the short and long run.

The capacity for the proxy of energy transition to reduce environmental degradation is probably related to the effect of globalisation on renewable energy technological efficiency that consequently produces more clean energy with fewer emissions of CO2, as well as being due to the increasing participation of renewable energy sources in the energy matrix of these countries due to the new investment and the energy demand caused by the effect of the globalisation process on economic growth. Another possible explanation for this negative impact is related to the efficiency of renewable energy policies that encourage the introduction of alternative energy sources in the energy mix.

Indeed, to confirm these possible explanations the robustness check was made, and it was identified that the positive and negative asymmetries of the variable globalisation index in the long run has a positive effect on the proxy of energy transition. However, the negative impact of renewable energy policies on the proxy of energy transition is a surprise of this chapter. The possible explanation for this impact can be related to the possible inefficiency of these policies, or that the methodology/construction of variable renewable energy policies are not able to reveal the real effect of this variable on energy transition.

Thus, based on these findings, it is recommended that the LAC region put more effort into the development of policies for more efficient renewable energy that contribute to increasing growth, investment and consumption of green energy and inversely reduce the consumption of energy from non-renewable sources by households and industries. Regarding the public capital stock, local governments should encourage public banks to support investment in renewable energy technologies or purchase technologies with higher energy efficiency that reduce the consumption of non-renewable energy with lower interest and credit rates. Moreover, given the mistakes that were committed in the past, policymakers from the LAC region should also think about the possibility of integrating measures linked with the regulation of CO2 emissions in their growth strategies.

This chapter has a significant contribution to the literature for several reasons. First, it sheds light on how the process of energy transition affects environmental degradation. Second, the results of this chapter have critical consequences for local government appraisal of the relationship between economic growth, public capital stock, and environmental degradation. Finally, this study will help policymakers develop renewable energy policies more efficiently to reduce fossil fuel consumption and boost the development, investment, and use of renewable energy sources in developing countries to mitigate environmental degradation.

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Chapter 6

Conclusions and policy implications

This thesis has as the main objective to identify the effect of globalisation on renewable energy transition in LAC countries. The focus in the LAC countries is related to the process of globalisation that has grown in the last thirty years. This process of integration with the rest of the world is a potential factor the influences a higher economic activity and consequently, the energy demand and environmental degradation. However, the LAC countries have been adopting mechanisms, such as renewable energy transition in order to meet the energy demand at the same time that mitigates the consumption of fossil fuels and CO2 emissions caused by globalisation. For this reason, it is necessary to understand how this same globalisation process interacts with this energy transition and if its net impact is positive or negative.

In order to answer the central question of this thesis and contribute to the construction of the big picture that emerges from this puzzle. The analysis of the impact of globalisation on renewable energy transition was organised as a compilation of four essays that were based on four specific questions created from three spheres or aspects related to the renewable energy transition. Each one of them produced individual and overall results that are relevant to literature, policymakers, financial agents, governments, environmentalists as well as to societies and organisations directly relevant and that are related to this investigation.

The first essay of this thesis had as objective to assess the positive effect of financial openness on renewable energy investment in Latin American countries. The PARDL model, in the form of a UECM, as well as the PVAR model and the Panel Granger causality Wald test as a robustness check, were computed. The results of PARDL model indicated that the variable financial openness has a positive impact on renewable energy investment in the long-run. Additionally, the investment of this kind of source is also encouraged positively by economic growth in the short-run and by the general government’s capital stock in the long-run. The PVAR model was used in order to assess the robustness and the same indicated that the financial openness, economic growth, and general government's capital stock stimulate the investment in renewable energy. The results of the Granger causality Wald test analysis indicated the presence of bidirectional Granger causal links exist between (i) the installed capacity of renewable energy and economic growth; (ii) financial openness and the installed capacity; (iii) financial openness and economic growth; (iv) the installed capacity of renewable energy and general government capital stock; and (v) general government capital stock and economic growth.

The objective of the second essay was to assess the positive interactions between consumption of renewable energy and economic growth, as well as the positive effect of globalisation on renewable energy, and the negative effect of globalisation and renewable energy on the consumption of fossil fuels in five Mercosur countries. The PVAR model and Granger causality Wald test were used. The results of the PVAR model indicated that the consumption of renewable and globalisation increase economic growth, while the consumption of fossil fuels reduces it. The economic growth, consumption of fossil fuels and globalisation increase the consumption of renewable energy. Economic growth increases the consumption of fossil fuels, while the consumption of renewable energy and globalisation reduce the consumption of fossil fuels. Moreover, the consumption of renewable and fossil increases the process of globalisation, while economic growth decreases this process. The Panel Granger causality Wald test pointed out to the existence of bidirectional causality links between all variables. Then, these results suggest that the assessed countries' economic growth is dependent on fossil fuels as well as the presence of substitutability in the consumption of energy from renewable and fossil sources in periods of drought and that the process of globalisation has a positive indirect influence on the Mercosur countries' consumption of renewable energy.

The third essay aimed to assess the positive reaction of the consumption of fossil fuels to trade openness and negative reaction from renewable energy consumption for a panel of fourteen LAC countries as well as extend the previous analysis. The PARDL model in the form of UECM was estimated as well as the PNARDL model as a robustness check. The results of PARDL model indicated that the economic growth in short-run and trade openness in long-run increase the consumption of fossil fuels. However, consumption of renewable energy in short- and long-run contributes to decreasing the consumption of fossil fuels. Regarding the results of robustness check, the PNARDL pointed out that the economic growth in the short-run and the positive and negative asymmetry in the long-run, and the trade openness in the short-run and long-run contribute to increasing of consumption of fossil fuels. Nevertheless, the positive and negative asymmetry of consumption of renewable energy in the short-run and the variable in the long-run decrease the consumption of fossil fuels.

The objective of the fourth essay was to assess the negative effect of the renewable energy transition on environmental degradation in the LAC countries, as well as extend the analysis of the first, second, and third essay. A panel non-linear autoregressive distributed lag approach in the form of unrestricted error correction model was used. The empirical results indicate that the economic growth in both short- (impacts) and long-run (elasticities), and the variable public capital stock in the short-run has increased the carbon dioxide emissions. However, the positive and the negative asymmetry of the ratio of renewable energy on fossil energy in the short- and long-run decrease the emissions of carbon dioxide. The capacity of the ratio of renewable/fossil energy consumption to reduce environmental degradation is compatible with the renewable energy technological efficiency that produces more clean energy and fewer emissions.

These essays answered each specific questions that arose in the introduction. Therefore, the answer to the question **(a)** is that the globalisation via financial openness encourages the investment in renewable energy in Latin American countries, and the explanation of this is that financial openness decreases the financing costs it causes. Less expensive credit increases the consumption of goods and services, thus enhancing economic activity and energy consumption, which in turn boosts investment in investment in renewable energy technologies in order to attend the energy demand and mitigate the environmental degradation. The answer to the question **(b)** is that globalisation increases the consumption of renewable energy, and globalisation and renewable energy consumption decrease the consumption of fossil fuels in Mercosur countries. This could be the result from the globalisation that has a positive impact on factor productivity and economic growth, and consequently exerts a positive impact on renewable energy consumption, and also in new investment in renewable technology that consequently increases the efficiency technology due to the access of new green technologies via imports and financial openness and consequently decrease the consumption of fossil fuels.

The answer to the question **(c)** is that the renewable energy consumption decreases the consumption of fossil fuels in LAC and Mercosur countries. This reduction is related to the process of globalisation that increases capital stock and consequently reduces the cost of external financing, encouraging investment in renewable energy technologies. The answer to the question **(d)** is that the process of renewable energy transition mitigates environmental degradation (CO2 emissions) in LAC countries. This mitigation is related to the capacity of globalisation encourage the renewable energy technological efficiency by new investments and imports of manufactured products, capital equipment, technological goods, electronic equipment, and new material with high technological efficiency in energy consumption or production and that are commercialised in the international markets. Consequently, this reduces the consumption of energy from non-renewable energy sources and produces more clean energy with fewer emissions. Therefore, based on these responses from four essays, one can conclude that the globalisation contributes positively to the process of the renewable energy transition in the LAC countries.

This thesis is not free of limitations during the process of investigation. In the first essay, the data time was limited due to the availability of data for the variable installed capacity of renewable energy between 1980 to 2014 for all selected countries. Moreover, this variable can not be updated because the IEA site no longer provides open access data. Another limitation in this essay was of the 32 countries in the LAC region, and only 10 had a complete database that can be used. In the second essay had limitations in data time due to the availability of data for the variable consumption of renewable energy and fossil fuels between 1980 to 2014 for all selected countries. These variables can not be updated because the IEA site no longer provides open access data. In the third essay, also had limitations in data time due to availability of data for the variable consumption of renewable energy between 1990 to 2014. Another limitation in this essay was of the 32 countries in the LAC region, and only 14 had a complete database that can be used. In the fourth essay,had also the same limitations in data time due to availability of data for the variable consumption of renewable energy, where the consumption of this kind of sources compose the variable ratio of renewable energy between 1990 to 2014 for all countries selected in the primary model, as well as in the complementary robustness check due to availability of data for the variable imports of ICT goods imports between 2000 to 2014 for all countries selected. Another limitation in this essay was of the 32 countries in the

LAC region, and only 18 had a complete database that can be used in the primary model and in the complementary robustness check only 17 had a complete database. All these limitations lead to conduct further investigations about this topic of study.

Despite the limitations about the availability of data, the findings and results obtained from this thesis may have some important policy implications. First, it is necessary that the financial institutions in the LAC region should take advantage of the increase in the stock of public capital promoted by financial openness and stimulate investment in research and development activities related to renewable energy sources. This could lead to an increase in the connection of domestic financial institutions in environmentally relevant activities. Moreover, in the LAC countries should implement policies to encouraging the participation of financial institutions in the funding of small and micro firms dedicated to low environmental impact projects, as well as to increasing households' preferences towards sustainable consumption.

Second, in order to attract more investment in renewable energy and increase the consumption of this kind of source, it is necessary to create more public policies and incentives. Should be advanced policies that encourage households and firms to purchase appliances with a high energy efficiency standard in order to reduce energy consumption. However, this is only possible with the participation of financial institutions that disponibility cheap credit by the increase of capital stock caused by financial liberalisation to purchase these appliances with high energy efficiency.

Moreover, it reduces the bureaucracy that discourages the renewable energy foreign investment should be reduced, as should the political lobby between governments and large producers of fossil fuels. These policies need to be implanted to reduce the dependency on fossil fuels, as well as to mitigate environmental degradation by increasing the consumption of renewable energy. Also, it is advisable to promote economic growth and take advantage of the enormous abundance of renewable energy sources.

Third, the policymakers from LAC countries must take advantage of the process of globalisation via trade and financial liberalisation to reduce the costs of renewable energy technology. The reduction of these costs is possible with the creation of tariff and non-tariff barriers of products and technologies that improve the energy efficiency during the process of trade liberalisation, as well as policies of financial liberalisation that opening the capital account and removing "financial repression" policies and restriction to foreign ownership and that consequently decrease the cost of capital and makes the alternative energy sources more feasible. All these are essential policy mechanisms to increase the participation of renewable energy in the energy mix and reduce the consumption of fossil fuels and CO2 emissions.

The impact of globalisation on the process of the energy transition sure will be a topic under discussion in the forthcoming years. This discussion began to be discussed in several international forums such as (G20 Buenos Aires summit 2018, and the World Economic Forum Annual Meeting 2018 in Davos). Indeed, in recent years has been growing a great concern about globalisation impacts on the economy, society, energy and the environment, as well as has grown a significant protectionist and anti-globalisation movement. Then, for this reason, this research about the impact of the globalisation process on renewable energy transition is not complete, and it is necessary more research about this topic. Consequently, some topics for future researches about the impact of globalisation on renewable energy transition are recommended. For example; (a) it is necessary to expand knowledge about the globalisation process impact on renewable energy transition in other countries and regions on the globe, mainly developed and developing countries; (b) it is vital to focus on economic blocs (e.g., Andean, Mercosur, European Union, North American Free Trade Agreement (NAFTA), and others(c) expand the study of the impact of the globalisation on renewable energy transition using other variables, such as desegregate globalisation index (e.g., economic, social, and political globalisation), urbanisation index, rents of natural resources, and energy efficiency; and, (d) in the availability of more data for LAC countries, it is necessary confronted with the new results from an expanded database, for the reason that the present countries that were approached in this thesis were used with restricted of data.

Appendix A

Chapter 1

Appendix A – Chapter 1

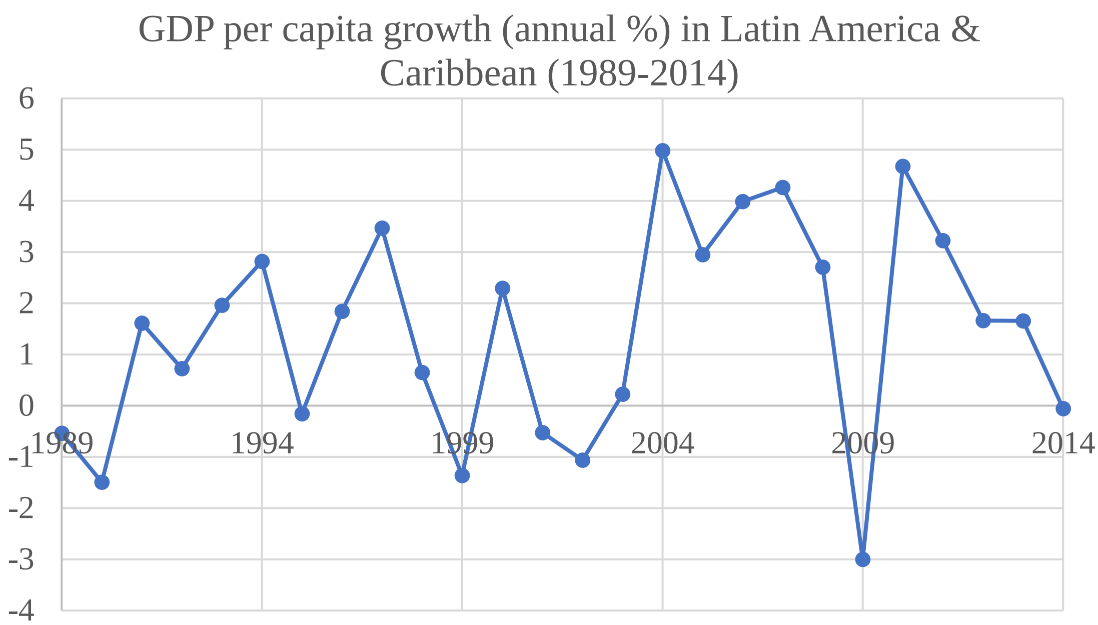


Figure 1.1A Evolution of GDP per capita growth (annual %) in Latin America & Caribbean (1989-2014). This graph was created with the database from the World Bank Open Data, (2019). URL: http://www.worldbank.org/.

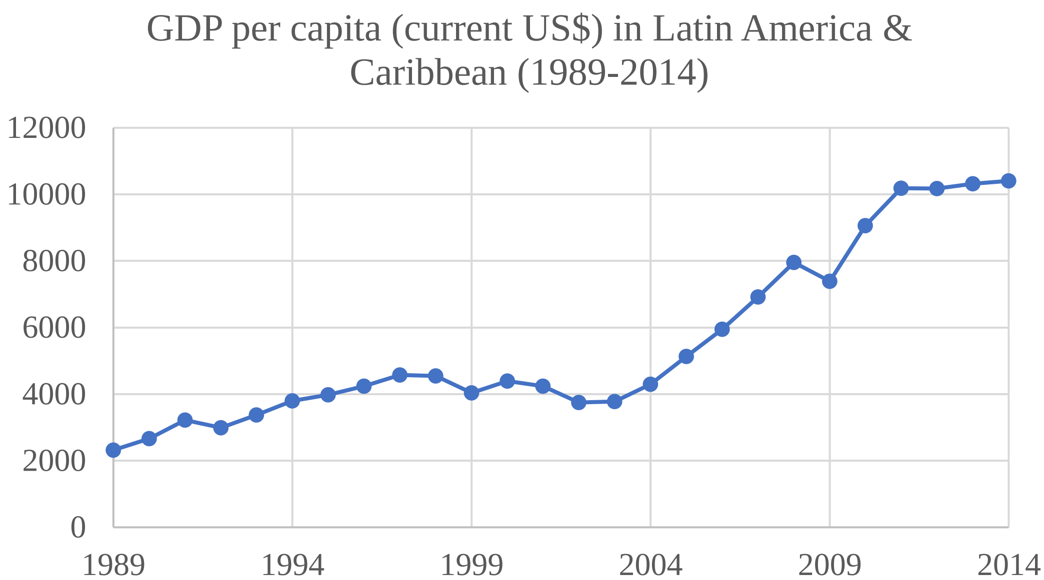


Figure 1.2A Evolution of GDP per capita (current US$) in Latin America & Caribbean (1989-2014). This graph was created with the database from the World Bank Open Data, (2019). URL: http://www.worldbank.org/.

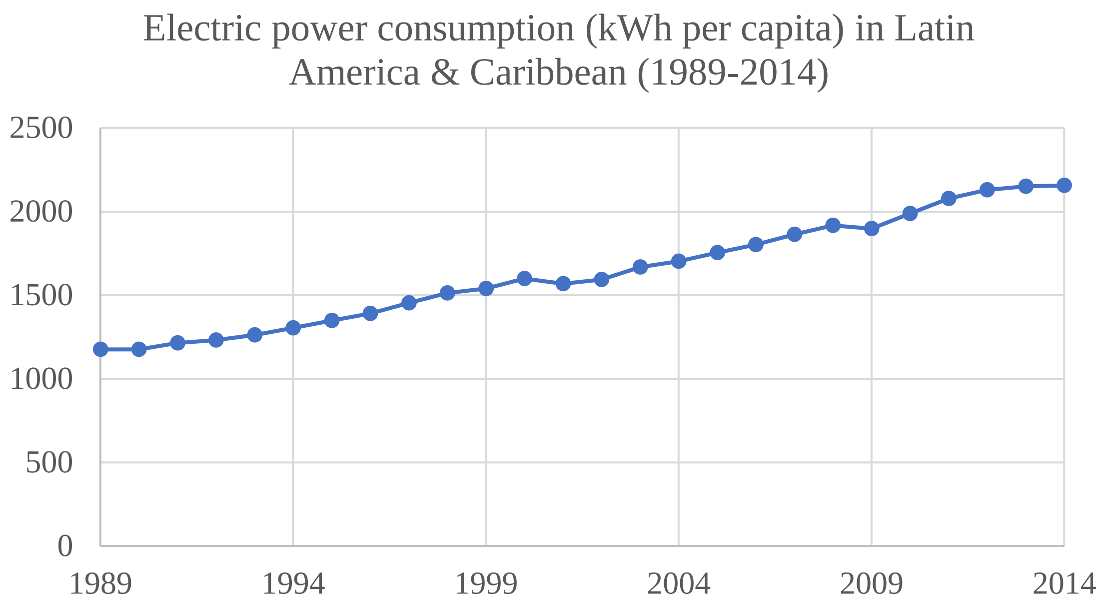


Figure 1.3A Evolution of Electric power consumption (kWh per capita) in Latin America & Caribbean (1989-2014). This graph was created with the database from the World Bank Open Data, (2019).URL: http://www.worldbank.org/.

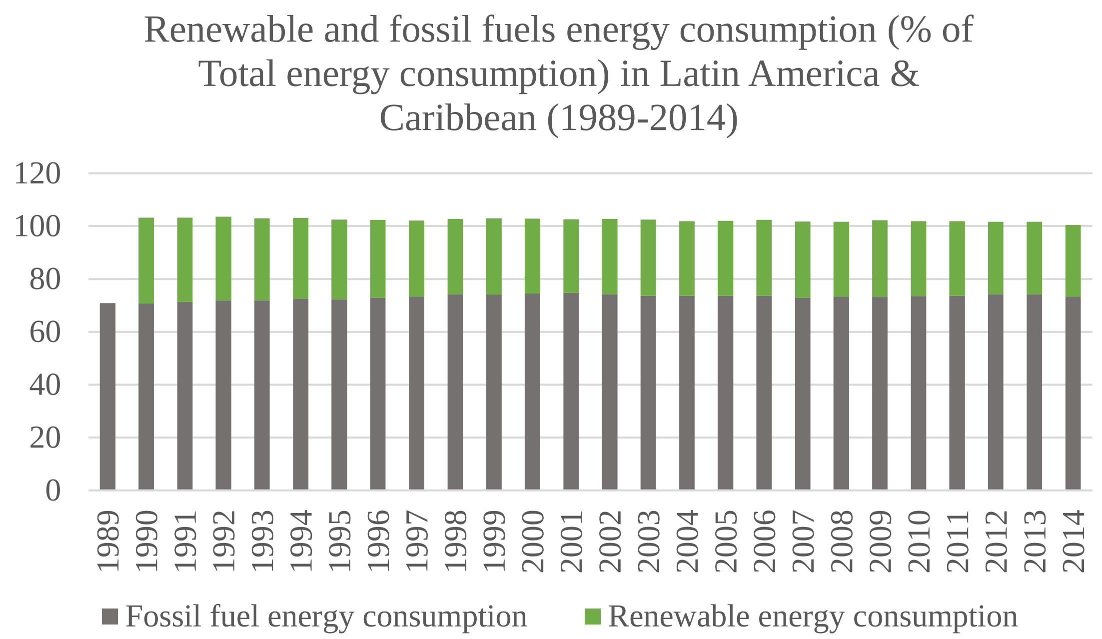


Figure 1.4A Evolution of Renewable and fossil fuels energy consumption (% of total energy consumption) in Latin America & Caribbean (1989-2014). This graph was created with the database from the World Bank Open Data, (2019). URL: http://www.worldbank.org/.

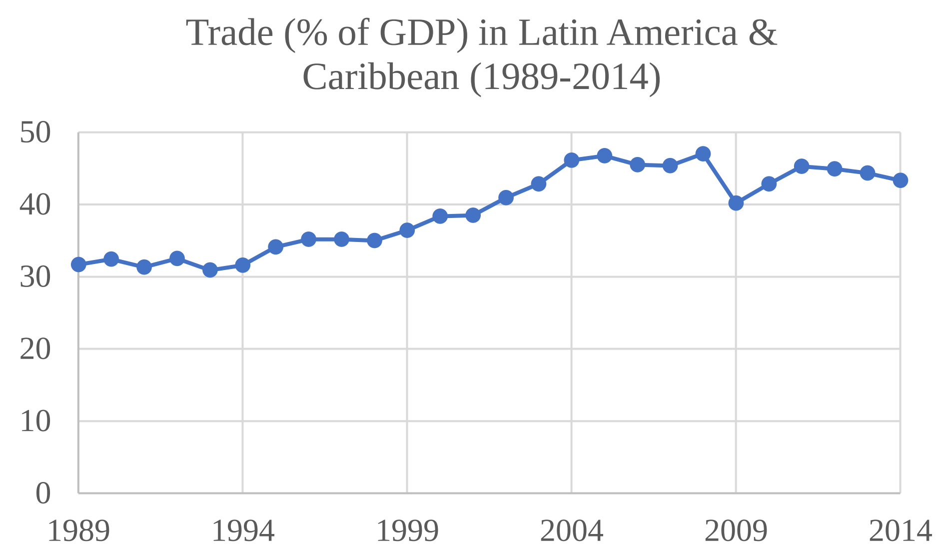


Figure 1.5A Evolution of Trade (% of GDP) in Latin America & Caribbean (1989-2014). This graph was created with the database from the World Bank Open Data, (2019). URL: http://www.worldbank.org/.

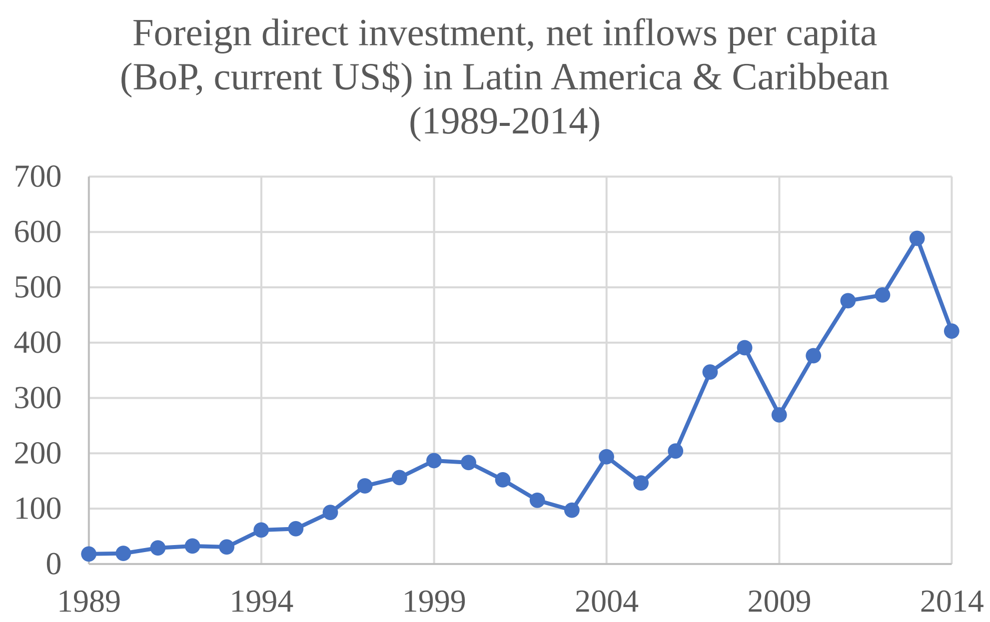


Figure 1.6A Evolution of foreign direct investment (FDI), net inflows per capita (BoP, current US$) in Latin America & Caribbean between (1989-2014). This graph was created with the database from the World Bank Open Data, (2019). URL: http://www.worldbank.org/.

Figure 1.7A Evolution of Exports and Imports of goods and services per capita (BoP, current US$) in Latin America & Caribbean between (1989-2014). This graph was created with the database from the World Bank Open Data, (2019).URL: http://www.worldbank.org/.

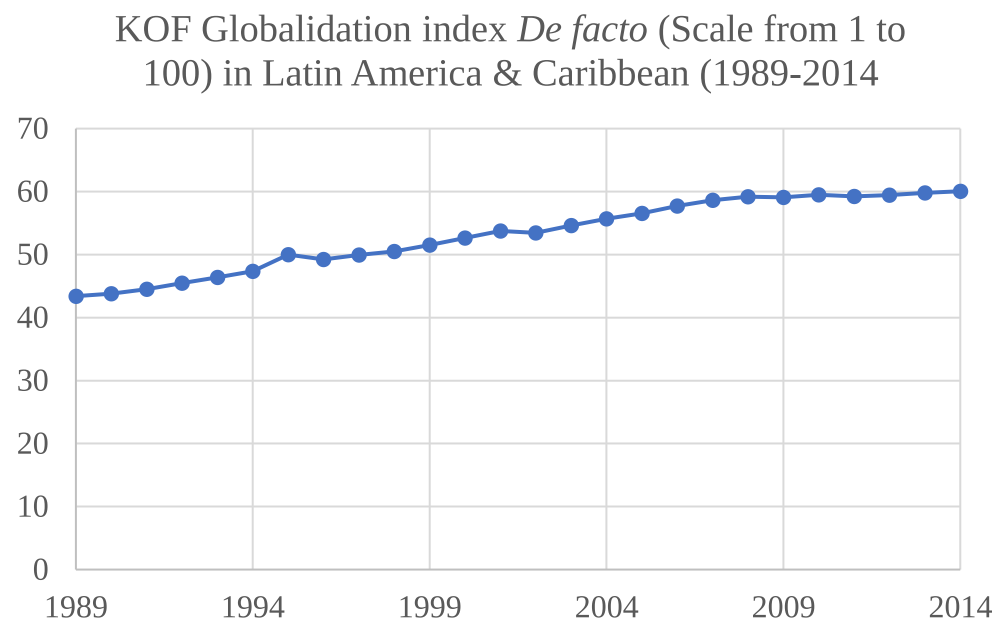


Figure 1.8A Evolution of KOF Globalisation index *De Facto* (Scale from 1 to 100) in Latin America & Caribbean between (1989-2014). This graph was created with the database from the KOF Globalizatin Index, (2019).URL:https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html.

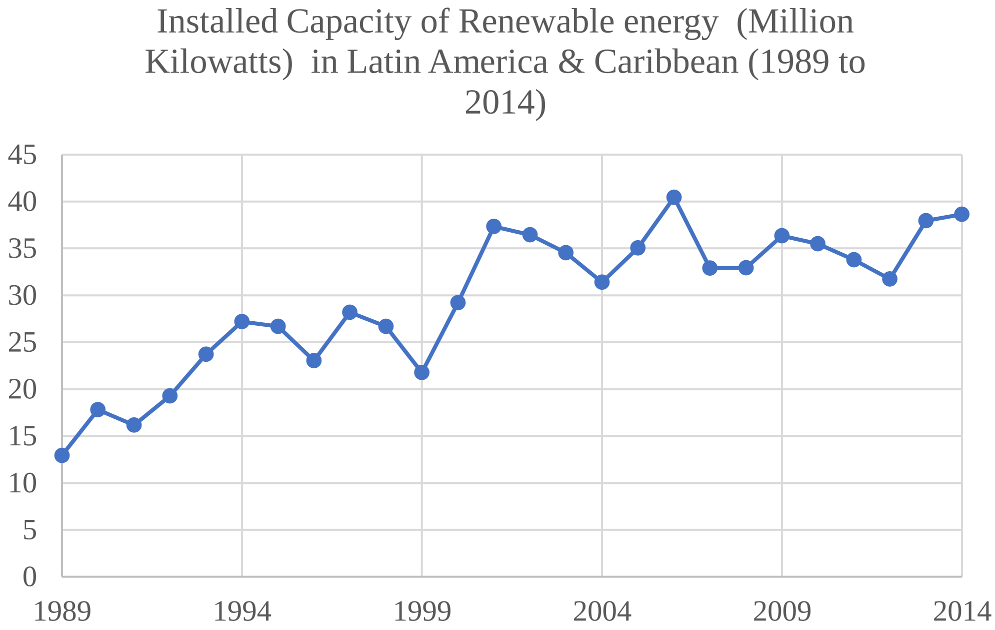


Figure 1.9A Evolution of Installed capacity of Renewable energy (Million Kilowatts) from biomass, hydropower, solar, photovoltaic, wind, wave, and waste in Latin America & Caribbean between (1989-2014). This graph was created with the database from the IEA, (2018). URL: https://www.iea.org/energyaccess/database/.

Appendix B

Chapter 2

Appendix B – Chapter 2

Table 2.1B Variables' description statistics

Variables	Descriptive Statistics				
	Obs.	**Mean**	**Std. Dev.**	**Min**	**Max**
LnIREC	350	2.4854	1.6384	-1.0526	6.1291
LnGDP	350	10.7417	2.6517	7.6628	16.1937
LnFOPI	350	0.3646	0.2443	0.000	0.6931
LnKPUBLIC	350	-12.1820	0.6760	-13.2325	-10.9931

Notes: Obs. denotes the number of observations; Std. Dev. is the Standard Deviation; Min. and Max. are the minimum, and maximum values, respectively; and (Ln) denotes variables in natural logarithms.

Table 2.4B Westerlund cointegration test between **LnGDP** and **LnKPUBLIC**

Westerlund test (with constant)		
Statistics	**Value**	**P-value robust**
Gt	-0.754	1.000
Ga	-1.562	0.999
Pt	-1.119	1.000
Pt	-1.216	0.984

Notes: H_0: No cointegration; H_1 Gt and Ga test the cointegration for each country individually and Pt and Pa test the cointegration of the panel as a whole; the Stata command *xtwest* was used.

Table 2.5B Hausman test

Variables	(b) Fixed	(B) Random	(b-B) Difference	Sqrt(diag(V_b-V-B)) S.E.
DLnGDP	0.2868	0.0237	0.2630	0.0000
LnIREC	-0.2208	-0.0101	-0.2107	0.0276
LnFOPI	0.1388	-0.0378	0.1766	0.0256
DLnKPUBLIC	0.1566	0.0128	0.1437	0.0566
Chi2 (4)	58.33***			

Notes: *** denotes statistically significant at 1% level; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively; The Stata command *Hausman* (with the options, sigmamore alleqs constant) was used.

Table 2.6B Heterogeneous estimators

Independent variables	Dependent variable (DLnIREC) MG		PMG		FE	
Constant	0.2003		3.2983	***	2.4368	***
LnFOPI (-1)	0.5284		0.7099	***	0.6284	***
LnKPUBLIC (-1)	0.0603		0.7965	***	0.7094	***
ECM	-0.3370	***	-0.2796	***	-0.2209	***
DLnGDP	0.3317	*	0.3472	**	0.2868	

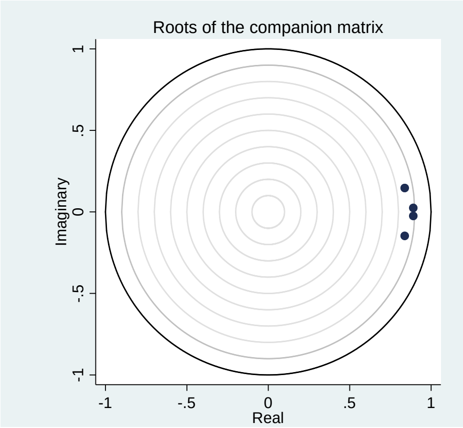
Notes: ***, **, * denote statistically significant at 1%, 5%, and 10% level, respectively; The ECM denotes the coefficient of the variable **LnIREC**, lagged once; the long-run parameters are computed elasticities. The Stata command *xtpmg* was used; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

Table 2.11B PVAR lag-order selection from robustness check

Lags	CD	J	Jp-value	MBIC	MAIC	MQIC
1	0.9999	172.427	0.5620*	-768.663	-179.572	-417.720
2	0.9999	154.192	0.6145	-701.345	-165.808	-382.305
3	0.9996	136.983	0.6483	-633.000	-151.016	-345.864

Notes: The Stata command *pvarsoc* was used.

Table 2.14B Eigenvalue stability condition from robustness check

Eigenvalue Real	Imaginary	Modulus	Graph
0.8906	-0.0245	0.8909	
0.8906	0.0245	0.8909	
0.8378	0.1468	0.8506	
0.8378	-0.1468	0.8506	

Notes: The Stata command *pvarstable* was used.

Table 2.15B Forecast-error variance decomposition from robustness check

Response variable and Forecast Impulse Variable Horizon	Impulse variables			
	LnIREC	**DLnGDP**	**LnFOPI**	**DLnKPUBLIC**
LnIREC				
0	0	0	0	0
1	1	0	0	0
5	0.8072	0.1312	0.0392	0.0222
10	0.5696	0.3365	0.0612	0.0325
15	0.4999	0.4086	0.0609	0.0304
DLnGDP				
0	0	0	0	0
1	0.0312	0.9687	0	0
5	0.0348	0.9276	0.0177	0.0197
10	0.0328	0.8792	0.0393	0.0485
15	0.0343	0.8741	0.0396	0.0518
LnFOPI				
0	0	0	0	0
1	0.0035	0.0282	0.9682	0
5	0.0403	0.0918	0.8663	0.0014
10	0.1540	0.0774	0.7469	0.0215
15	0.2360	0.1379	0.5798	0.0461
DLnKPUBLIC				
0	0	0	0	0
1	0.0034	0.0001	0.0037	0.9926
5	0.1060	0.4641	0.0016	0.4281
10	0.1553	0.6129	0.0015	0.2302
15	0.1811	0.6341	0.0034	0.1813

Notes: The Stata command *pvarfevd* was used; (DLn) denotes variables in the first-differences of logarithms.

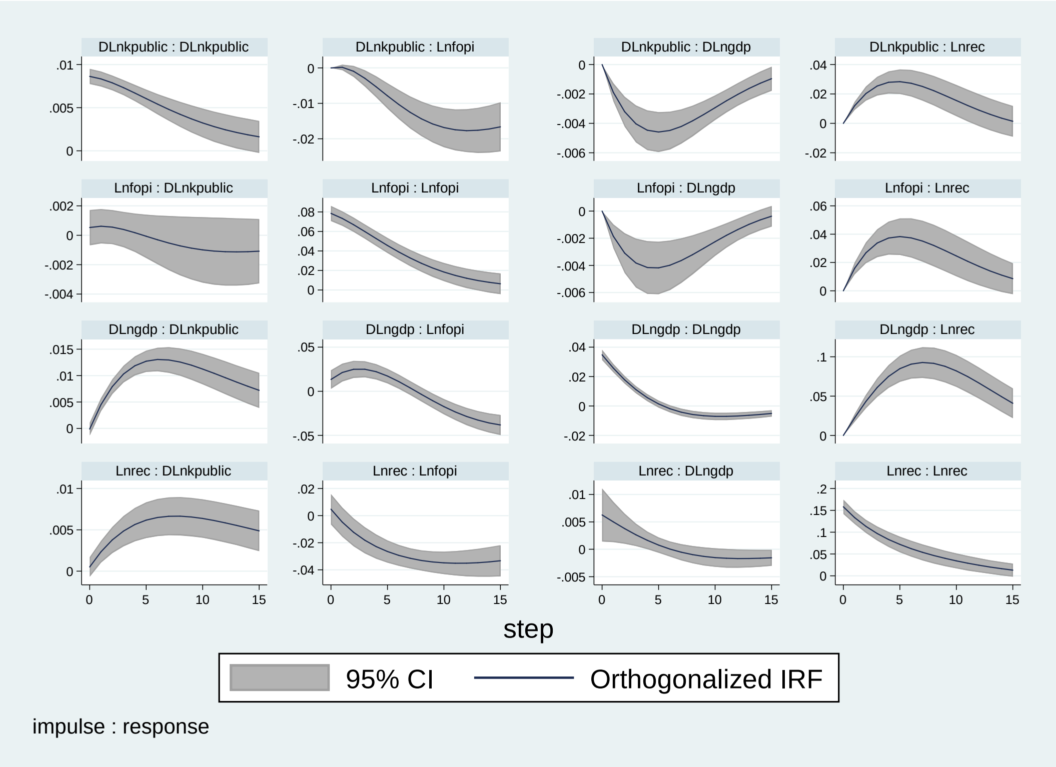


Figure 2.2B Impulse – response functions from robustness check; The Stata command *pvarirf* was used.

Appendix C

Chapter 4

Appendix C– Chapter 4

Table 4.7C Hausman test

Variables	(b) Fixed	(B) Random	(b-B) Difference	Sqrt(diag(V_b-V-B)) S.E.
DLnY	0.6973	0.8162	-0.1188	0.0822
DLnREC	-0.4224	-0.4611	0.0387	0.0226
DLnTR	0.2946	0.1886	0.1059	0.0272
LnFOC	-0.3619	-0.0786	-0.2833	0.0306
LnY	0.7441	0.0477	0.6963	0.1080
LnREC	-0.0426	0.0032	-0.0458	0.0430
LnTR	0.1652	0.0420	0.1232	0.0538
Chi2 (7)	95.79***			

Notes: *** denotes statistically significant at 1% level; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively; The Stata command *Hausman* (with the options, sigmamore alleqs constant) was used.

Table 4.11C Hausman test from robustness check

MG vs PMG	PMG vs FE	MG vs FE
Chi2(21) = -36.37	Chi2(25) = -374.58	Chi2(25) = -275.03

Notes: *** denotes statistically significant at 1%, level; Hausman results for H_0: difference in coefficients not systematic; the Stata commands *xtpmg*, and Hausman (with the option alleqs) was used.

Table 4.12C Specification tests from robustness check

Statistics	Modified Wald test	Wooldridge test	Pesaran's test	Breusch and Pagan Lagrangian Multiplier test
	chi2 (14) =421.28***	F(1,13) =17.470***	-1.166	n.a

Notes: *** denotes statistically significant at 1% level; H_0 of Modified Wald test: sigma(i)^2 = sigma^2 for all i; H_0 of Wooldridge test: no first-order autocorrelation; H_0 of Pesaran's test: residuals are not correlated; H_0 of Breusch and Pagan Lagrangian Multiplier test: no dependence between the residuals; (n.a) denotes not available.

Appendix D

Chapter 5

Appendix D– Chapter 5

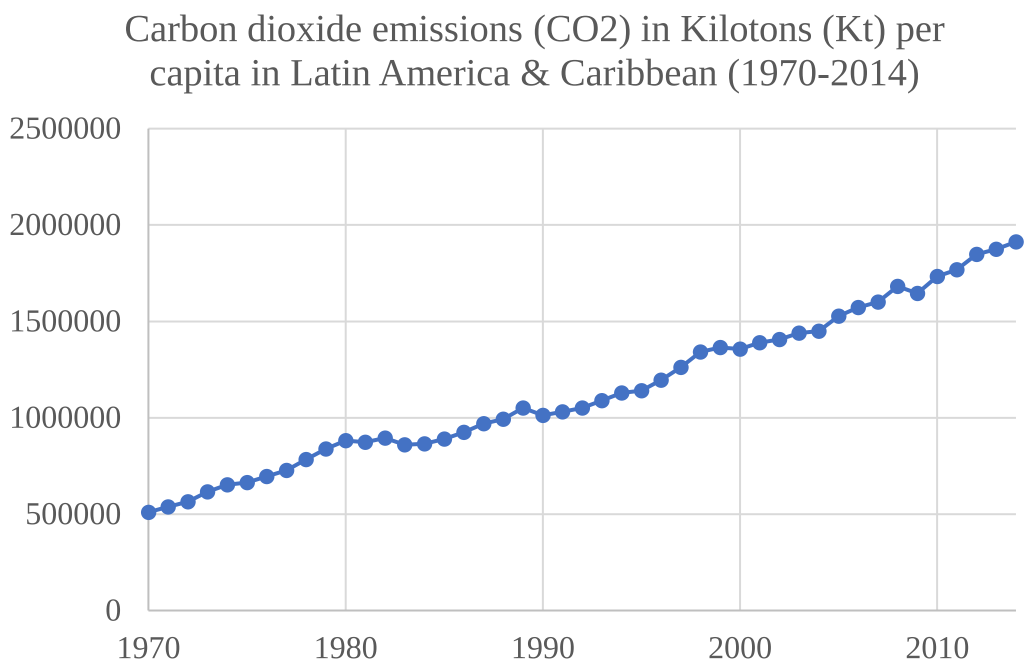


Figure 5.1D Evolution of Carbon dioxide emissions (CO_2) in Kilotons (Kt) per capita in Latin America & Caribbean (1989-2014). This graph was created with the database from the World Bank Open Data, (2019). URL: http://www.worldbank.org/.

Table 5.5D Hausman test

Variables	(b) Fixed	(B) Random	(b-B) Difference	Sqrt(diag(V_b-V-B)) S.E.
DLnY	0.6396	0.6769	-0.0373	0.0609
DLnRE_POS	-0.0623	-0.0585	-0.0038	0.0092
DLnRE_NEG	-0.0809	-0.0881	0.0071	0.0078
DLnPUBK	0.6864	-0.1505	0.8369	0.1929
LnCO2	-0.3875	-0.0041	-0.3834	0.0436
LnY	0.1481	-0.0051	0.1533	0.0481
LnRE_POS	-0.0297	-0.0025	-0.0272	0.0080
LnRE_NEG	-0.0371	-0.0018	-0.0353	0.0088
Chi2 (8)	80.07***			

Notes: *** denotes statistically significant at 1% level; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively; The Stata command *Hausman* (with the options, sigmamore alleqs constant) was used.

Table 5.10D Summary statistics of variables from robustness check

Variables	Descriptive Statistics				
	Obs.	**Mean**	**Std. Dev.**	**Min**	**Max**
LnRE	450	1.9695	4.5903	-2.5181	18.6579
LnGLB	450	4.0277	0.1704	3.4324	4.3283
LnREP	400	1.3278	1.0312	0.0000	3.8712
LnCO2	450	-6.7708	1.3936	-11.7542	-4.8785
DLnRE	432	-0.0337	0.5760	-5.1653	3.5362
DLnGLB	432	0.0139	0.0266	-0.0704	0.1128
DLnREP	384	0.1002	0.2266	-0.4054	1.3862
DLnCO2	432	0.0203	0.1198	-0.8107	1.0799

Notes: Obs. denotes the number of observations; Std. Dev. Denotes the Standard Deviation; Min. and Max. Denote Minimum and Maximum, respectively; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

Table 5.11D Correlation matrix from robustness check

Variables	LnRE		LnCO2		LnGLB		LnREP
LnRE	1.0000						
LnCO2	0.2337	***	1.0000				
LnGLB	0.2076	***	0.4651	***	1.0000		
LnREP	-0.0165		0.2059	***	0.4603	***	1.0000
	DLnRE		**DLnCO2**		**DLnGLB**		**DLnREP**
DLnRE	1.0000						
DLnCO2	-0.3776	***	1.0000				
DLnGLB	-0.0233		0.0366		1.0000		
DLnREP	0.0051		-0.0180		-0.0065		1.0000

Notes: ***, denotes statistically significant at 1% levels respectively; the Stata command *pwcorr* was used; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

Table 5.12D VIF and CSD tests from robustness check

Variables	VIF	1/VIF	CD-test		Average joint T	mean ρ	mean abs(ρ)
LnRE	n.a.		6.872	***	25.00	0.11	0.34
LnGLB	1.40	0.7156	49.113	***	25.00	0.79	0.83
LnREP	1.27	0.7861	47.232	***	25.00	0.68	0.68
LnCO2	1.15	0.8695	33.232	***	25.00	0.54	0.58
Mean VIF	1.27						
DLnRE	n.a.		1.621		24.00	0.03	0.22
DLnGLB	1.00	0.9996	9.252	***	24.00	0.15	0.21
DLnREP	1.00	0.9996	0.234		24.00	0.00	0.12
DLnCO2	1.00	0.9998	0.262		24.00	0.00	0.17
Mean VIF	1.00						

Notes: The Stata command *estat vif* and *xtcdf* were used; ***denotes statistically significant at 1% level; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively.

Table 5.13D Unit root test from robustness check

Variables	Panel-data unit-root test								
	Levin-Lin-Chu (2002) Panel Unit Root test (LLC) (Adjusted t)					Pesaran (2007) Panel Unit Root test (CIPS) (Zt-bar)			
	Without trend			With trend		Without trend		With trend	
	Lags	Adjusted t		Adjusted t		Zt-bar		Zt-bar	
LnRE	1	-0.6844		-1.3416	*	-0.704		-0.074	
LnGLB	1	-0.7850		-2.3462	***	-2.785	***	-1.418	*
LnREP	1	-1.6610	**	-1.9724	**	-1.490	*	-3.076	***
LnCO2	1	-1.7795	**	-0.9099		-2.148	**	0.148	
DLnRE	1	-10.4247	***	-8.2803	***	-9.872	***	-8.463	***
DLnGLB	1	-9.6220	***	-7.9294	***	-7.797	***	-5.905	***
DLnREP	1	-8.3106	***	-6.5823	***	-7.359	***	-5.313	***
DLnCO2	1	-9.7455	***	-7.8242	***	-8.394	***	-7.501	***

Notes: The Stata command *xtunitroot* and *multipurt* were used; The null for LLC test is that all series are I(1), and in CIPS test is: series are I(0); the lag length (1) and trend were used in these tests;***, **,* denote statistically significant at 1%,5%, and 10% level respectively;(Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

Table 5.14D Hausman test from robustness check

Variables	(b) Fixed	(B) Random	(b-B) Difference	Sqrt(diag(V_b-V-B)) S.E.
DLnCO2	-2.3429	-2.1260	-0.2168	0.1383
LnRE	-0.4095	-0.0012	-0.4082	0.0452
LnGLB_POS	1.6357	0.0656	1.5701	0.4306
LnGLB_NEG	1.7704	0.3301	1.4402	0.8504
LnREP	-0.0980	0.0005	-0.0985	0.0451
LnCO2	-1.1074	-0.0047	-1.1026	0.2953
Chi2 (6)	**81.90*** **			

Notes: *** denotes statistically significant at 1% level; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively; The Stata command *Hausman* (with the options, sigmamore alleqs constant) was used.

Table 5.15D Specification tests from robustness check

Statistics	(a)Modified Wald test	(b) Wooldridge test	(c) Pesaran's test	(d) Breusch and Pagan Lagrangian Multiplier test
	chi2 (16)=3145.98	F(1,15) = 224.341 ***	0.371	chi2(120) = 136.911

Notes: *** denotes statistically significant at 1% level; H_0 of Modified Wald test: sigma(i)^2 = sigma^2 for all i; H_0 of Wooldridge test: no first-order autocorrelation; H_0 of Pesaran's test: residuals are not correlated; H_0 of Breusch and Pagan Lagrangian Multiplier test: no dependence between the residuals.

Table 5.17D Summary statistics of variables from complementary robustness check

Variables	Descriptive Statistics				
	Obs.	**Mean**	**Std. Dev.**	**Min**	**Max**
LnRE	255	2.0635	4.8624	-2.5181	18.6579
LnGLB	255	4.1280	0.0899	3.8387	4.3283
LnICT_IMPORTS	255	13891.22	14854.78	563.6581	66637.91
DLnRE	238	-0.0275	0.5424	-5.1653	3.5362
DLnGLB	238	0.0082	0.0227	-0.0605	0.1128
DLnICT_IMPORTS	238	823.2538	4215.752	-20611.12	17623.34

Notes: Obs. denotes the number of observations; Std. Dev. Denotes the Standard Deviation; Min. and Max. Denote Minimum and Maximum, respectively; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

Table 5.18D Correlation matrix from complementary robustness check

Variables	LnRE		LnGLB		LnICT_IMPORTS
LnRE	1.0000				
LnGLB	0.3715	***	1.0000		
LnICT_IMPORTS	0.1521	*	0.4303	***	1.0000
	DLnRE		**DLnGLB**		**DLnICT_IMPORTS**
DLnRE	1.0000				
DLnGLB	-0.0355		1.0000		
DLnICT_IMPORTS	-0.0823		0.0226		1.0000

Notes: ***, denotes statistically significant at 1% levels respectively; the Stata command *pwcorr* was used; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

Table 5.19D VIF and CSD tests from complementary robustness check

Variables	VIF	1/VIF	CD-test		Average joint T	mean ρ	mean abs(ρ)
LnRE	n.a.		-0.202		15.00	0.00	0.44
LnGLB	1.00	0.9994	23.501	***	15.00	0.52	0.84
LnICT_IMPORTS	1.00	0.9994	35.669	***	15.00	0.79	0.79
Mean VIF	1.00						
DLnRE	n.a.		-1.266		14.00	-0.03	0.29
DLnGLB	1.23	0.8148	11.202	***	14.00	0.26	0.31
DLnICT_IMPORTS	1.23	0.8148	17.073	***	14.00	0.39	0.41
Mean VIF	1.23						

Notes: The Stata command *estat vif* and *xtcdf* were used; ***denotes statistically significant at 1% level; (Ln and DLn) denote variables in natural logarithms and first-differences of logarithms respectively.

Table 5.20D Unit root test from complementary robustness check

Variables	Panel-data unit-root test								
	Levin-Lin-Chu (2002) Panel Unit Root test (LLC) (Adjusted t)					Pesaran (2007) Panel Unit Root test (CIPS) (Zt-bar)			
	Without trend			With trend		Without trend		With trend	
	Lags	Adjusted t		Adjusted t		Zt-bar		Zt-bar	
LnRE	1	-2.3463	***	-1.8206	**	-1.701	**	-3.311	***
LnGLB	1	-2.7825	***	-1.4280	*	-0.458		0.078	
LnICT_IMPORTS	1	-1.2938	*	-0.7751		0.003		1.543	
DLnRE	1	-5.9102	***	-6.4032	***	-6.758	***	-4.720	***
DLnGLB	1	-8.7236	***	-10.4653	***	-3.353	***	-1.174	
DLnICT_IMPORTS	1	-3.7520	***	-3.1838	***	-2.090	***	-2.386	***

Notes: The Stata command *xtunitroot* and *multipurt* were used; The null for LLC test is that all series are I(1), and in CIPS test is: series are I(0); the lag length (1) and trend were used in these tests;***, **,* denote statistically significant at 1%,5%, and 10% level respectively;(Ln and DLn) denote variables in natural logarithms and first-differences of logarithms, respectively.

Table 5.21D Hausman test from complementary robustness check

Variables	(b) Fixed	(B) Random	(b-B) Difference	Sqrt(diag(V_b-V-B)) S.E.
DLnGLB	-1.1305	-0.8029	-0.3276	0.6378
DLnICT_IMPORTS	-9.85e-0	-0.0000	6.41e-0	2.35e-0
Chi2 (1)	**0.26**			

Notes: (DLn) denote variables in first-differences of logarithms respectively; The Stata command *Hausman* (with the options, sigmamore alleqs constant) was used.

Table 5.22D PVAR lag-order selection from complementary robustness check

Lags	CD	J	Jp-value	MBIC	MAIC	MQIC
1	0.5261	55.6071	0.4140*	-194.1414	-52.3928	-109.7917
2	-6.7212	46.8109	0.3980	-161.3128	-43.1890	-91.0213
3	-2.9161	25.7337	0.8976	-140.7653	-46.2662	-84.5321

Notes: The Stata command *pvarsoc* was used.

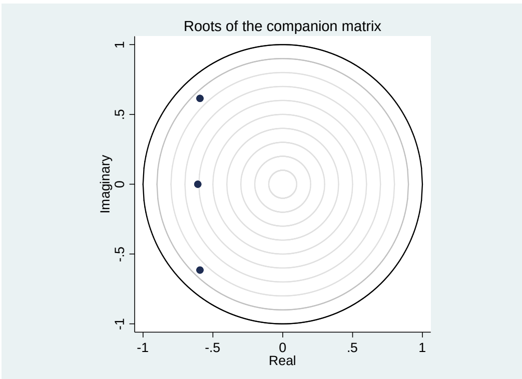
Table 5.23D PVAR model outcomes from complementary robustness check

Response of	Response to					
	$\mathbf{DLnRE^{(t)}}$		$\mathbf{DLnGLB^{(t)}}$		$\mathbf{DLnICT\_IMPORTS^{(t)}}$	
$\mathbf{DLnRE_{(t-1)}}$	-0.3972	***	-0.0444	***	5813.394	***
$\mathbf{DLnGLB_{(t-1)}}$	8.9389	***	-0.8952	***	327692.4	***
$\mathbf{DLnICT\_IMPORTS_{(t-1)}}$	3.07e-0	*	-2.05e-0		-0.5007	***
***N.* obs**			**102**			
***N.* panels**			**17**			

Notes: *** denotes statistical significance level of 1% level; (DLn) denotes variables in the first-differences of logarithms; The Stata command *pvar* with one lag was used. Instruments: l (1/7).

Table 5.24D Eigenvalue stability condition from complementary robustness check

Eigenvalue			Graph
Real	**Imaginary**	**Modulus**	
-0.5925	-0.6147	0.8538	
-0.5925	0.6147	0.8538	
-0.6080	0.0000	0.6080	



Notes: The Stata command *pvarstable* was used.

Table 5.25D Forecast-error variance decomposition from complementary robustness check

Response variable and Forecast Impulse Variable Horizon		Impulse variables		
		DLnRE	DLnGLB	DLnICT_IMPORTS
DLnRE				
	0	0	0	0
	1	1	0	0
	5	0.6294	0.3670	0.0035
	10	0.5860	0.4105	0.0034
	15	0.5793	0.4171	0.0034
DLnGLB				
	0	0	0	0
	1	0.0130	0.2399	0.7469
	5	0.3512	0.5725	0.0761
	10	0.3620	0.6361	0.0018
	15	0.3700	0.6280	0.0018
DLnICT_IMPORTS				
	0	0	0	0
	1	0.0130	0.2399	0.7469
	5	0.3512	0.5725	0.0761
	10	0.3639	0.5710	0.0650
	15	0.3646	0.5726	0.0627

Notes: The Stata command *pvarfevd* was used; (DLn) denotes variables in the first-differences of logarithms.

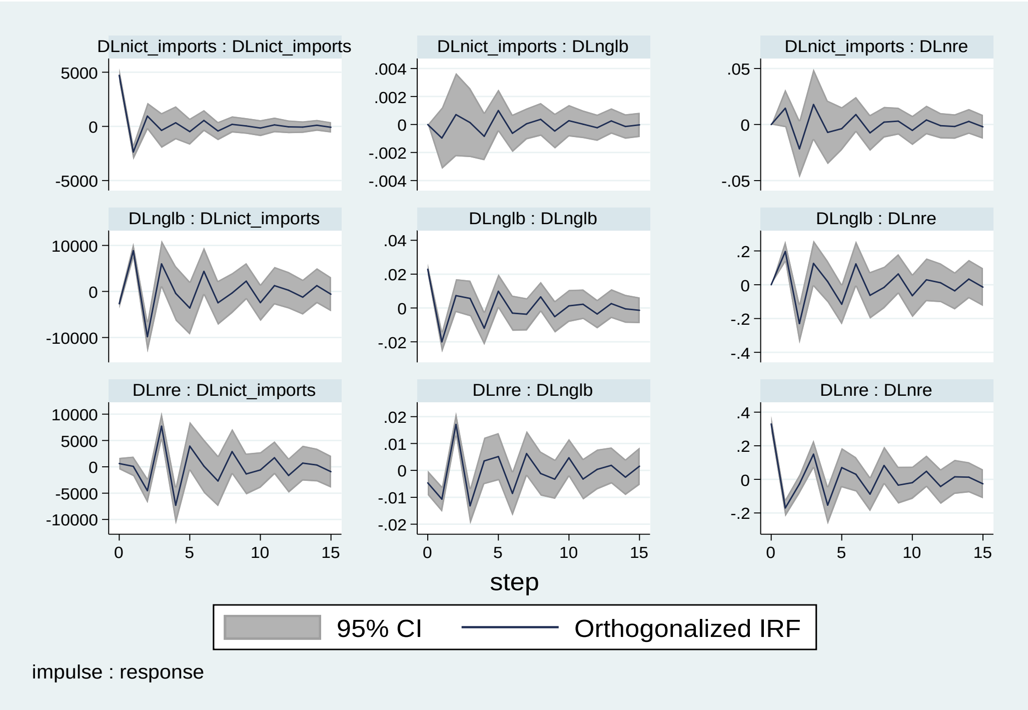


Figure 5.3D Impulse – response functions from complementary robustness check; The Stata command *pvarirf* was used.

Globalisation and the paradigm of renewable energy transition in the Latin American and the Caribbean (LAC) countries

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