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Sustainable Development in Latin America – Linking Renewable Energy, Economic Complexity and GHG Emissions

by

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Abstract This thesis analyses the interrelations of economic complexity, greenhouse gas emissions, and renewable energy in Latin America and the Caribbean (LAC), using annual data from 1998 to 2018. Economic development in the region is characterised by the exploitation of natural resources and low economic sophistication. At the same time, a dynamic renewable energy market has developed in LAC. The Environmental Kuznets Curve is tested, using economic complexity as an explanatory variable to account for the economies' structural transformation towards a knowledge-based production, directly impacting energy intensity and technological advancement. With the help of fixed effects specifications, it was found that economic complexity and renewable electricity generation have an emission reducing effect in LAC. Furthermore, economic output is associated with increasing GHG emissions and energy supply, suggesting that economic growth and environmental protection are conflicting goals in the region. The results of the thesis suggest economic complexity and renewable energy to be important factors for sustainable development in LAC, implying their relevance for national economic and energy policies.

Keywords Economic Complexity, Renewable Energy, GHG Emissions, Latin America and the Caribbean, Environmental Kuznets Curve

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List of Abbreviations

CO2	Carbon Dioxide
CPI	Consumer Price Index
ECI	Economic Complexity Index
EKC	Environmental Kuznets Curve
FE	Fixed Effects
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWh	Gigawatt hour
IEA	International Energy Agency
IMF	International Monetary Fund
IRENA	International Renewable Energy Agency
LAC	Latin America and the Caribbean
MW	Megawatt
NAFTA	North American Free Trade Agreement
OECD	Organisation for Economic Cooperation and Development
OLS	Ordinary Least Squares
PCI	Product Complexity Index
PPP	Purchasing Power Parity
RCA	Revealed Comparative Advantage
RE	Random Effects
RES	Renewable Energy Sources
R&D	Research and Development
tCO2e	Tons of Carbon Dioxide equivalent
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

1. Introduction

Global warming and the increasing environmental degradation have become the world's major threats of the past decades. Latin America's resource wealth is making the region extremely vulnerable to climate change and its economic situation particularly dependent on the state of the environment. Latin America and the Caribbean (LAC) contain between 60 and 70 percent of all forms of life on earth, 23 per cent of forest areas, and more than 30 per cent of the world's water resources (UNEP 2016). Therefore, environmental conflicts over scarce resources and social unrest due to extreme climate events are posing major risks for the region's social and economic development.

At the same time, the increasing impacts of global warming, accompanied by rising energy demand, offer LAC the opportunity to transform its energy mix. The region hosts a dynamic renewable energy sources (RES) market with one of the largest shares in renewables (Ferroukhi, Kieffer, López-Peña, Barroso, Ferreira, Muñoz & Gomelski 2016). Since the 1970s, large hydropower plants have shaped the region's energy landscape, but their importance is declining (Flavin, Gonzalez, Majano, Ochs, da Rocha & Tagwerker 2014). Although investments in biomass, wind and solar electricity generation have grown in recent years, their share remains low. National administrations recognised the importance of RES, Latin American governments have noticeably fostered regulatory frameworks and market incentives to increase the rate of RES in the energy mix (Cherni 2011).

The threat of climate change has considerably increased the attention of policy makers and researchers to the interrelations of economic growth, energy consumption and greenhouse gas (GHG) emissions. The question arises on how the Global South can reduce excessive resource dependency and carbon emissions, to achieve sustainable development, being defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN WCED 1987).

Looking at the linkages between emissions, energy, and economic output is a synthesis of the Environmental Kuznets Curve (EKC) hypothesis and the literature on the energy-growth nexus (Apergis & Payne 2009). The EKC is the most prominent theory on the relation between economic growth and environmental degradation, and the hypothesised association is termed "inverted U-shaped" (Shahbaz, Lean & Shabbir 2012). The energy-growth nexus encompasses studies on the causal relationship between economic growth and energy, with a rising interest in the impact of RES consumption in the last ten years (Adewuyi & Awodumi 2017). While the effects of RES and economic growth on environmental degradation are increasingly discussed in the literature, the results are ambiguous (Adewuyi & Awodumi 2017; Antonakakis, Chatziantoniou & Filis 2017; Apergis, Payne, Menyah & Wolde-Rufael 2010; Saidi & Omri 2020).

Overall, the energy consumption is growing in LAC, being associated with economic expansion (Washburn & Pablo-Romero 2019). The exploitation of natural resources has been the main engine for the economic upswing around the millennium. Despite great differences within the region, LAC economies are characterised by high material and resource intensity as well as high levels of inequality (OECD 2019). This resource dependency results in high volatility of economic output and negative effects on the environment, including biodiversity loss, soil and water contamination, and hazardous waste (OECD 2019). Simultaneously, economic complexity, which is referring to the productive structure of a country, is expected to affect the structure of energy consumption and environmental degradation (Romero & Gramkow 2021; Doğan, Driha, Balsalobre Lorente & Shahzad 2021). Thereby, economic complexity potentially affects both: a countries productivity, specialisation, and competitiveness, but also its impact on the environment.

Recent literature has started to look at the relation between economic complexity and the state of the environment within the theoretical framework of the EKC, and several studies suggest that economic complexity has a significant impact on environmental pollution (Boleti, Garas, Kyriakou & Lapatinas 2021; Can & Gozgor 2017; Doğan et al. 2021; Doğan, Saboori & Can 2019; Romero & Gramkow 2021). Doğan et al. (2021) firstly looked on both the influence of economic complexity and renewable energy for a sample of OECD countries and found that both factors contribute to the reduction of emissions.

1.1 Aim and Research Question

The measurement of economic complexity is relatively new and the study of its relationship to various development factors is still in its early stages. Moreover, there is a lack of research on the energy-growth-emissions nexus for LAC, a region that has made substantial improvements of RES penetration other than large hydro in the past twenty years. The purpose of this thesis is to investigate the interrelations of RES, economic complexity, and GHG emissions in LAC. Thereby, to the author's best knowledge, a first attempt is made to take into account the dynamics of the three variables for a developing region.

This thesis aims to contribute to the discussion by combining the research on RES and economic complexity for the under researched region LAC. A better understanding of the link between renewables energy transitions, economic complexity, and environmental pollution is central for policymaking, especially for countries that rely on the extraction of non-renewable resources and that want to diversify. Economic complexity is considered to be a key determinant for long-term sustained economic growth, as it is crucial to decrease vulnerability to external shocks and increases resilience to economic shrinking (Andersson 2018; OECD & WTO 2019). At the same time, many green and renewable energy products are characterised through high product complexity (Mealy & Teytelboym 2020), which makes it challenging for countries that are less technologically advanced to achieve the Sustainable Development Goal of affordable and sustainable energy for all. For effective climate change mitigation policies, more knowledge is needed on the linkages between the far-reaching transformations to sustainable industrial systems and energy structures.

This thesis therefore aims to contribute to the research in energy and environmental economics by answering the following research question:

How have renewable energy sources and economic complexity affected sustainable development in Latin America and the Caribbean from 1998 to 2018?

The research question will be answered with the help of the following two sub-questions:

1) *How are renewable energy generation, GHG emissions, and economic complexity associated with each other from 1998 to 2018 in Latin America and the Caribbean?*
2) *How does economic complexity affect greenhouse gas emissions and energy supply from 1998 to 2018 in Latin America and the Caribbean?*

1.2 Outline of the Thesis

The research question will be answered with the help of cross-sectional panel, containing data of 20 countries. The study is conducted including the countries for which the Economic Complexity Index (ECI) is available: Costa Rica, Cuba, Dominican Republic, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, El Salvador, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Peru, Paraguay, Uruguay, Venezuela. In addition, the availability of ECI data defines the time period from 1998 to 2018. The focus on this period is also significant given the fact that since then, the share of RES other than large hydropower plants has been increasing in LAC. The data will be compiled from different datasets and taken from publicly available sources.

General connections between the variables of interest are analysed in a descriptive way to examine the development in LAC over the years and the differences between countries. To investigate the relation between economic complexity and GHG emissions, an econometric analysis will be conducted, using panel fixed effects estimations. Examining panel data allows for a larger data set that includes cross-sectional data over time to obtain robust results of the associations. In addition, the theoretical framework of the energy-growth nexus and the EKC is applied.

After this introduction, a chapter on the contextualisation of the renewable energy transition, environmental performance, and economic development in LAC follows. Chapter 3 develops the theoretical framework for this thesis, including the energy-growth nexus, the EKC, and economic complexity. Afterwards, the most important previous studies of the energy-growth-emissions nexus are discussed in Chapter 4, focusing on RES and economic complexity. Chapter 5 provides the data and methodology for this analysis, introducing the data sources as well as the limitations of data and method. Afterwards, the empirical results are presented in Chapter 6, which includes a descriptive and an econometric analysis. The results are discussed and brought together with the literature in Chapter 7, followed by a conclusion.

2 Contextualisation: Sustainable Economic Development in Latin America

This section provides a brief overview to set the regional context of the study, focusing on different aspects. Firstly, the context of economic development in LAC is analysed, followed by a section on about environmental degradation and the state of nature over time. The last subchapter describes the transition to RES in LAC. This contextualisation part intends to facilitate the understanding of the results and dynamics of the quantitative analysis.

2.1 Economic Outline

Around the turn of the 21st century, Latin-American economic development was characterised by economic recovery and strong growth rates, that began to stagnate in 2011 (OECD 2019). Economic development and growth obstacles are varying across countries and subregions of LAC. However, the economic outlook of OECD (2019) describes income inequality, violence, and informality as persistent and slowly improving development outcomes.

After two decades of sharply rising Gini coefficients, income concentration began to fall from 1998 onwards, accompanied by a decline in poverty (see Figure 1 & 2). In the first decade of the millennium, approximately 70 million people could be lifted out of poverty in LAC, expanding the middle class to one third of the population (Freire, Schwartz Orellana, Zumaeta Aurazo, Costa, Lundvall, Viveros Mendoza, Lucchetti, Moreno & Sousa 2015).

Nonetheless, LAC remains one of the world's most unequal regions, with the middle class being particularly vulnerable to fall back into poverty, which is caused by a vicious circle of low-quality jobs, lack of social protection, and volatile income (OECD 2019). Additionally, inequality in LAC goes beyond income. Education is one area of concern: despite significant progress in school enrolment, there are vast disparities in the quality of education, depending on the socio-economic backgrounds of the children (Meléndez 2021). A further issue is the lack of political participation and high economic vulnerability of ethnic minorities. Indigenous and black people represent close to 25 percent of the total population of LAC and are facing exclusion and disadvantages in access to public services and educational attainment (Meléndez 2021).

Overall, the reductions in income inequality and poverty through labour market developments and fiscal transfers from 2000 to 2014 coincided with the commodity super cycle (Balakrishnan, Lizarazo, Santoro, Toscani & Vargas 2021). Countries where commodities account for more than ten per cent of trade, such as Bolivia, Chile, and Peru, particularly profited and experienced income growth for low-skilled workers as well as increases in government transfers

(Balakrishnan et al. 2021). In addition, the dependency on resource-intensive activities of Latin American economies further increased during that time (Gorenstein & Ortiz 2018). Consequently, a large part of the region is highly exposed to global price fluctuations.

Latin America has always been rich in natural resources, including 61% of the world's lithium reserves and 39% of copper, but also renewable resources, as LAC exports 23% of the world's agricultural commodities (Bárcena 2018; OECD & FAO 2019)

Figure 1 Poverty headcount ratio per region 3.20$/day, 2011 PPP

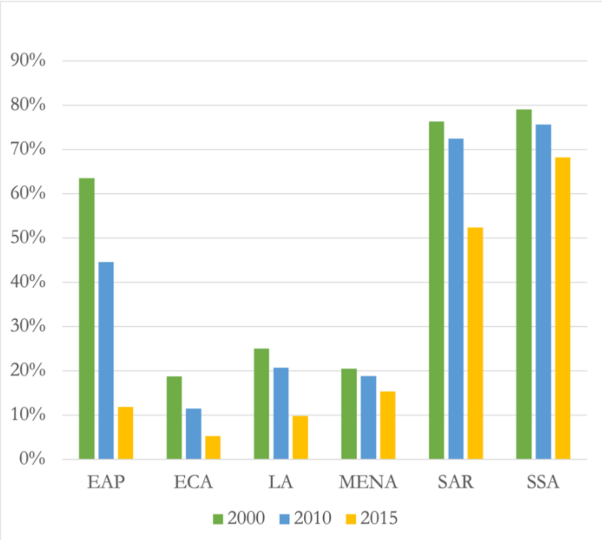
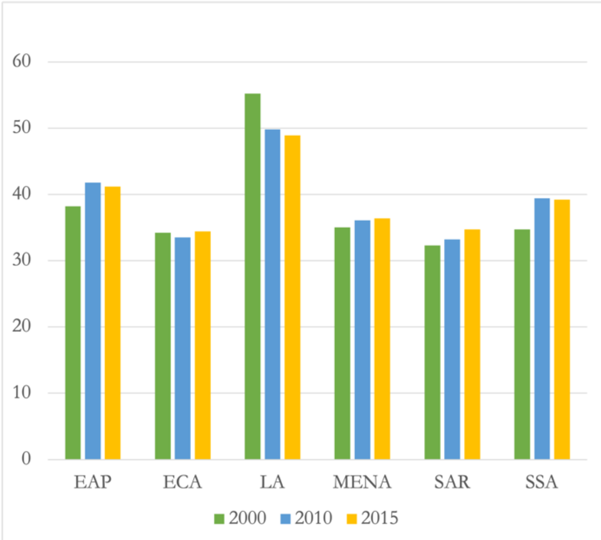


Figure 2 Gini coefficient per region, population weighted average



Source: Balakrishnan et al. (2021); World Bank (2022a), EAP = East Asia Pacific, ECA = Europe and Central Asia, LA = Latin America, MENA = Middle East and North Africa, SAR = South Asia, SSA = Sub-Saharan Africa; PPP=Purchasing Power Parity

Furthermore, the economic structure of most Latin American countries is characterised by the fact that the manufacturing sector has peaked in terms of both employment and value added and a transition to the service sector is taking place. There are large income disparities at the tipping point of decline in the importance of manufacturing compared to other late industrialisers such as Korea or Japan, indicating a premature deindustrialisation taking place in LAC (Stiglitz, Dosi, Mazzucato, Pianta & Iütkenhorst 2018). The differences in structural transformation can largely be explained by low labour productivity growth and inefficient resource allocation (Stiglitz et al. 2018). Furthermore, the cyclical patterns of exchange rates due to commodity prices are associated with the shrinking share of the manufacturing sector (Ocampo 2017).

Despite large regional disparities, the region is caught in a middle-income trap, and due to stagnating labour productivity, countries in LAC are classified as middle-income for 65 years on average (OECD 2019). The total factor productivity of LAC is about 37% of that of the United

States, and according to OECD (2019) the low productivity is mainly due to the region's export structure based on primary goods with low levels of sophistication. Pérez (2010) assesses that LAC is too far behind technologically to develop high-tech sectors and that, at the same time, wages are too high for low-skilled manufacturing, impeding industrialisation.

The COVID-19 pandemic hit hard in LAC in a period of social unrest, intensifying social and economic difficulties. In 2021, the region rebounded with an estimated growth rate of 6.8 per cent, driven by fast-rising commodity prices (Goldfajn, Ivanova & Roldos 2022).

2.2 The State of the Environment and Greenhouse Gas Emissions

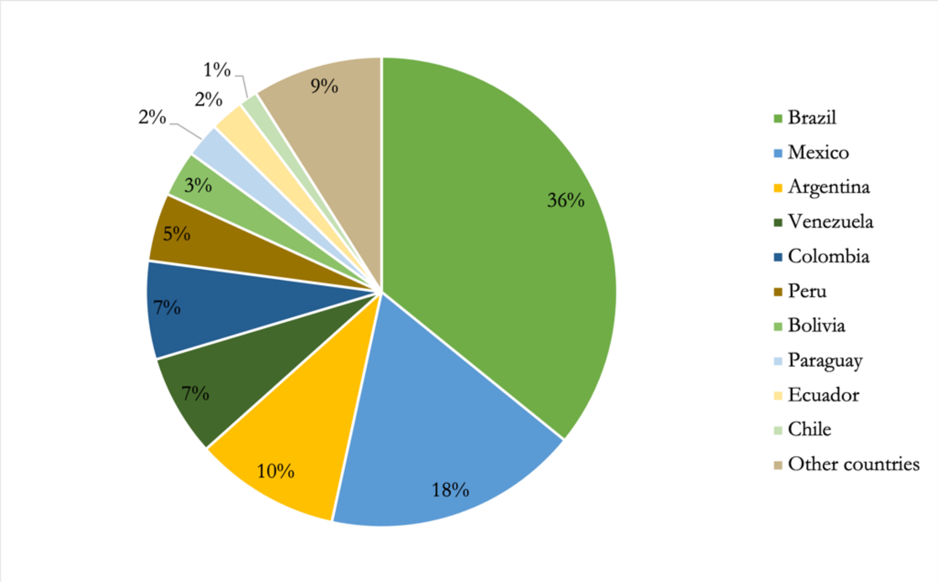
LAC has always played a rather small role in the worldwide emissions of GHG. GHG emissions are defined as "atmospheric gases responsible for causing global warming and climatic change" (UNEP 2021). The per capita carbon dioxide (CO2) emissions in LAC are similar to the world average and at around one third of the per capita emissions of Europe and the United States (Bárcena, Prado, Samaniego & Malchik 2010). Nevertheless, the total CO2 emissions in the LAC region have almost doubled from 1990 to 2018 (CEPALSTAT 2021), mainly due to increased demands by the transport and industry sector.

The region accounts for less than 10 per cent of worldwide CO2 emissions but is confronted with an extreme vulnerability to climate change. The impacts of climate change include water stress, loss of biodiversity, and increasing risk of extreme weather events. Out of the pressuring vulnerability to climate change and the high reliance of the economies on ecosystem services, there has been considerable institutional progress in putting climate change and the Sustainable Development Goals high on the political agenda and to strengthen governmental efforts (Cherni 2011).

As can be seen in Figure 3, a few countries in LAC account for mayor parts of emissions in the region, which is caused by high deforestation rates and energy-intensive industries, while other countries are small contributors. In that context, Brazil stands out as a GHG emitter with high land use emissions, which, however, have been considerably reduced since 2011 (Vergara, Rios, Paliza, Gutman, Isbell, Suding & Samaniego 2013).

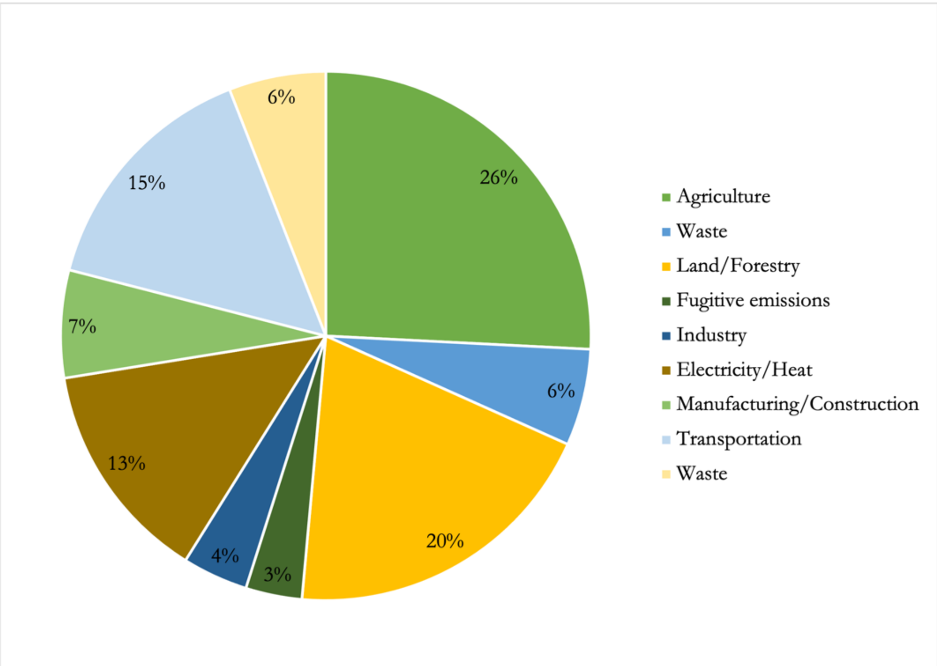
In contrast to other regions of the world, almost half of GHG emissions in LAC are generated from agriculture, land-use change and forestry. Even though the share of land use in emissions is decreasing, competing land uses such as cattle ranching, bioenergy production, and agriculture is stressing the environment and deforestation in most countries in the region is remaining above average. Comparably low levels of energy emissions are due to low per capita energy demands and the dominance of hydropower (Vergara et al. 2013).

Figure 3 LAC country contributions of total GHG emissions in %, 2018



Source: Climate Watch (2021)

Figure 4 Sector composition of total GHG emissions in % for LAC, 2018



Source: Climate Watch (2021)

LAC is highly diverse in its climate, ecosystem, cultural diversity, and population density, indicating varying challenges of contamination. Economic growth in South America has largely been based on natural resources exploitation, involving problems of intensive land and water usage as well as pollution. In addition, especially communities in the Caribbean are highly vulnerable to environmental disasters and affected by rising sea levels (UNEP 2016).

Besides, due to high inequalities, the most vulnerable population groups face large disparities in access to water, housing and infrastructure and, as a result, are strongly exposed to the impacts of climate change (Magrin & Marengo 2014).

2.3 Renewable Energy Development

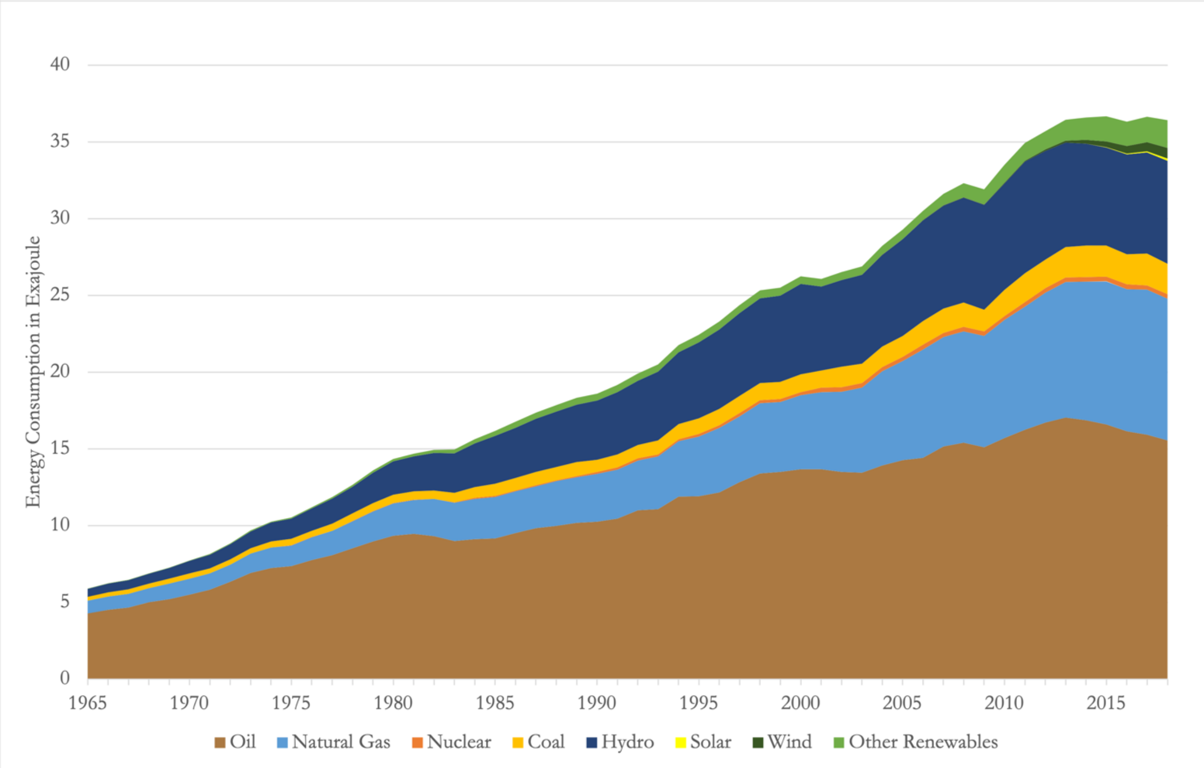
The energy sector is a key component in the transition to a low-carbon economy, and the emergence of renewable energy technology is rather unevenly distributed in the world economy. Historically, LAC is an important oil and gas producer, and the energy sector is a key pillar of the region's economic activity (Ferroukhi et al. 2016). As depicted in Figure 5, the role as an oil and gas exporter has resulted in significant shares of both resources in the region's energy mix. At the same time, LAC is endowed with large untapped renewable and non-renewable energy abundance, including high wind potential and large availability of geothermal energy (UNEP 2016).

Due to population and economic growth, the total primary energy supply in LAC doubled in the past 20 years (see Figure 5). Along with growing energy consumption, most countries followed the global trend of power market liberalisation and deregulation reforms in the 1990s (Cherni 2011). The opening of energy markets varies greatly from country to country, but liberalised markets have paved the way for international investment in RES (Flavin et al. 2014). In addition, the residential electrification rate significantly improved since the 1970s, with Brazil, Mexico, and the Southern Cone being close to universal access (Flavin et al. 2014). Although it is estimated that 97 percent of the population in Latin America has access to electricity, around 10 percent of the population still lives in energy poverty (Hernández Téllez 2020).

The importance of electricity consumption in the total energy consumption is increasing in LAC, and the power generation in Latin America quadrupled between 1980 and 2013 (Ferroukhi et al. 2016). Along with economic development in the 1990s and 2000s, electricity production has starkly increased in the region. This correlation of economic growth and electricity consumption is a common characteristic of developing regions, as they face overall lower energy efficiency, electrification rates, and rapidly growing use of energy (Flavin et al. 2014).

Within electricity generation, the predominance of large hydropower plants is a distinctive feature of the LAC electricity market. However, its share in the electricity mix is declining, which can be especially observed for Argentina, Chile, and Brazil (Flavin et al. 2014). The capacity expansion of hydroelectricity came to halt, pushed by increasing social and environmental concerns surrounding displacement of local communities, the deforestation and flooding of large areas of land involved in the construction of dams (Ferroukhi et al. 2016).

Figure 5 Total primary energy consumption in Exajoule for LAC 1965 - 2018

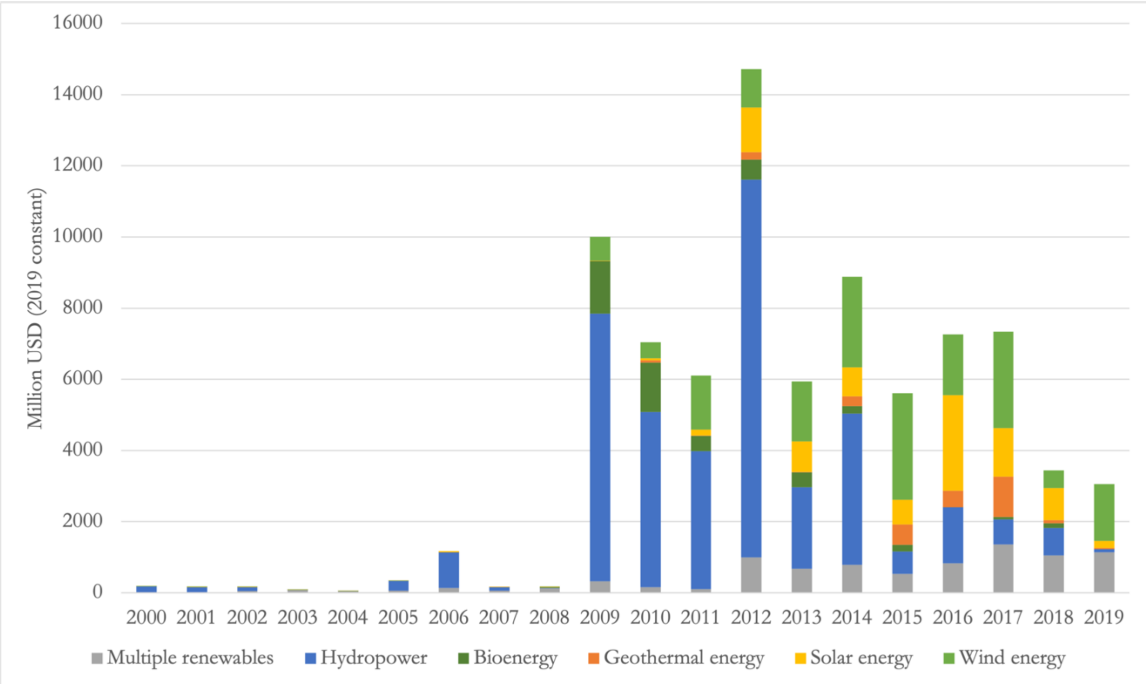


Source: BP (2021), countries included: Argentina, Bolivia, Brazil, Chile, Colombia, Cuba, Curacao, Ecuador, Netherlands Antilles, Mexico, Peru, Trinidad & Tobago, Venezuela

Worldwide renewable energy consumption has increased significantly in the past years and LAC has led the way in some aspects of the expansion (Griffith-Jones, Spratt, Andrade & Griffith-Jones 2017). With large untapped RES, decreasing technology costs and supportive policies in clean energy, LAC developed to a renewable energy hub. Investments in RES are strongly growing, with 16,400 million USD invested in 2015, of which Brazil was the largest recipient with around 40 per cent (Lucas, Leidreiter & Muñoz 2017). Also in Figure 6, the strong growth in RE investments becomes visible, with public investments in solar and wind energy accounting for a large share since 2013. With the installation of 3,000 megawatt (MW) RES in LAC, the renewable energy capacity increased by 270 per cent between 2006 and 2013 (Currás 2014).

The exploitation of RES is strongly depending on the country. In 2016, Brazil was the country with the third largest renewable energy capacity, and Costa Rica and Uruguay have almost a 100 per cent electricity generation coming from renewables (Lucas et al. 2017).

Figure 6 Public investment in renewable energies in LAC, 2000 - 2019



Source: IRENA (2022)

Nonetheless, RES other than hydro still comprises a fraction of overall electricity generation, contributing to 11 per cent of energy consumption in 2018 (CEPALSTAT 2021). The overall energy matrix remains highly dependent on fossil fuels, in particular for the intensive usage in transport and industry (Martínez Salgado & Castellanos 2019). In addition, the increased capacity of renewables also has negative impacts, such as increased environmental damage due to lithium and cobalt mining in Chile and Cuba for renewable energy technologies (Hernández Téllez 2020).

3 Theoretical Framework

This section discusses relevant theories on the interrelations of energy, economic growth, and environmental pollution. The theoretical framework is then used as a basis to examine the specific case of renewable and non-renewable energy, economic complexity, and GHG emissions in LAC.

3.1 The Energy-Growth Nexus

Although conventional economic growth models do not consider energy as a growth determining factor (Stern & Kander 2012), research about the relation of economic growth and energy consumption is far from new, and was initiated by Kraft and Kraft (1978). The literature on the energy-growth nexus can be divided into four testable hypotheses: 1) the growth hypothesis, 2) the conservation hypothesis, 3) the feedback hypothesis, and 4) the neutrality hypothesis.

1) $Growth: Energy\ Consumption \rightarrow Economic\ Growth$

The growth hypothesis suggests a unidirectional causality running from energy consumption to economic growth. In terms of RES, this would mean that an increase in renewable energy production promotes economic development (Singh, Nyuur & Richmond 2019). Thereby, energy consumption contributes directly to the process of economic growth and indirectly as a complement to labour and capital inputs (Antonakakis et al. 2017)

2) $Conservation: Economic\ Development \rightarrow Energy\ Growth$

The conservation hypothesis is met if there is a unidirectional causality from economic growth to energy consumption. Thus, the penetration of RES would increase as a result of economic growth. In contrast to the growth hypothesis, energy conversation policies aiming to reduce energy consumption may not have adverse effects on economic growth, as energy consumption is only seen as an outcome and not as a driver of development (Apergis & Payne 2010).

3) $Feedback: Economic\ Development \leftrightarrow Energy\ Growth$

The feedback hypothesis postulates a bidirectional causality between energy consumption and economic growth. In the context of RES, renewables and economic growth are interrelated and complement each other (Singh et al. 2019). The presence of the feedback hypotheses would emphasise the interdependencies between the two variables, indicating that energy policies could harm the economy and should be carefully implemented (Antonakakis et al. 2017).

4) $Neutrality: Economic\ Development\ \neq Energy\ Growth$

The fourth hypothesis proposes the absence of a causal relationship between energy or renewable energy consumption and economic growth. Implications for energy-efficiency policies to reduce environmental pollution would have similar effect like in the case of the growth hypothesis, suggesting little or no effect on economic growth. According to the neutrality hypothesis, energy does not play a major role in the overall economic output (Apergis & Payne 2010).

3.2 The Environmental Kuznets Curve

The EKC is presumably the most tested hypothesis describing the causal link between various indicators of economic growth and environmental degradation. The EKC hypothesis considers the long-term relationship between income and environmental pollution to follow an inverted-U pattern and is named after Simon Kuznets, as it follows the same shape as the relationship between inequality and national income famously proposed by Kuznets (Perkins, Radelet, Lindauer & Block 2013). The concept of an inverted U-shaped relationship between economic output and environmental pollution has been firstly established by Grossman and Krueger (1991) and gained momentum with the World's Bank's World Development Report 1992, noting that greater economic activity not necessarily harms the environment (World Bank 1992). The term EKC was coined by Panayotou (1993), who found a U-shaped relationship for deforestation and air pollution.

There are various explanations in the literature aiming to explain the dynamics behind the EKC. Grossman and Krueger (1991) point out a scale, composition, and technique effect, shaping the relationship between economic growth and environmental pollution. The scale effect is referring to the pure expansion of an economy, which leads to a proportional increase in environmental pollution and is not considering other factors of development (Stern 2017). When only considering the scale effect and no changes in the economy and society, economic growth and environmental sustainability are conflicting goals. Contrary, the composition and technique effects refer to the changing structure of an economy during the development process. Environmental degradation starts to increase when countries move from a rural agricultural society to an energy-intensive industrialisation and declines again when countries transform to a knowledge-based service economy (Dinda 2004). This transformation is strongly linked to the technique effect. With technological advancement, the production structure of an economy gets more sophisticated and lead to more efficient energy and material use (Panayotou 1993). Additionally, the choice of technology is influenced by policies and regulatory frameworks.

Besides these initial considerations by Grossman and Krueger (1991), income elasticities regarding environmental degradation are discussed in the literature. Thereby, the question arises whether environmental quality is a normal good, as suggested by Kristrom and Riera (1996), or a luxury good as found by Pearce and Palmer (2001). If environmental quality is a normal good, there is more income available for spending on environmental protection at higher levels of development. At the same time, wealthier societies can put more pressure on governments to implement regulations for environmental protection and market-based incentives. According to the luxury good approach, pollution abatement is less of a concern at initial stages of development. With higher incomes, people increasingly demand a cleaner environment and also have the economic resources available to supply it (Panayotou 1997).

Another popular view is that with economic development, institutional reforms to protect the environment evolve, leading to countries offshoring their pollution intensive activities to developing countries with loser regulations (Peters & Hertwich 2008). According to this displacement hypothesis, the EKC is rather an outcome of international trade, based on comparative advantage, than of improving environmental quality.

The validity of an EKC would lead to the conclusion that economic growth is beneficial for the environment, having far-reaching policy implications as countries only need to focus on their growth and problems of pollution would solve automatically. However, the EKC is also widely criticised for its limitations. Criticism can be divided into conceptional and methodological limitations.

As proposed by Arrow, Bolin, Costanza, Dasgupta, Folke, Holling, Jansson, Levin, Mäler and Perrings (1995), one fundamental conceptional limitation is the consideration of economic growth as an independent variable, not incorporating environmental effects on the economy. Thus, the EKC does not reflect the finite base of natural resources and ecosystem services that contain economic activity. Furthermore, the EKC cannot be applied for all environmental factors. Some environmental damages, such as biodiversity loss, are irreversible (Dinda 2004), for other stocks of waste or pollutants, having rather long-term and dispersed costs, the EKC does not hold (Arrow et al. 1995). Another critique is the missing empirical analysis on how trade and globalisation affects the EKC (Dinda 2004; Stern 2004). As previously discussed, carbon leakage could account for a large part of the EKC, which would have implications for developing countries, as they do not have other countries to which they can outsource their pollution. However, results of studies on displacement hypothesis show ambiguous results, strongly depending on the country and accounting method (Kander, Jiborn, Moran & Wiedmann 2015; Nielsen, Baumert, Kander, Jiborn & Kulionis 2021).

On the methodological site, Stern (2017) notes econometric shortcomings affecting the analysis of EKC estimates. First, particularly early studies whose models do not include controls are criticised for being too simplistic because they exhibit omitted variable bias. In addition, Perman and Stern (2003) emphasise the importance of testing for simultaneity, as the economic outcome and environmental pollution may be integrated. The authors also suggest strong time effects of reducing emissions worldwide, this non-stationarity would result in spurious regressions.

3.3 Economic Complexity

The concept of the EKC is closely linked to technological change and the structural transformation of an economy. Within the scope of structural transformation, countries develop from agriculture to energy-intensive polluting industries and then proceed to skill- and knowledge-intensive economies. Thereby, the mix of goods a country produces has important implications for its growth trajectory. Countries that specialise in products that rich countries export tend to grow and countries that produce "poor-country" goods remain poor (Hausmann, Hwang & Rodrik 2007).

One way to measure an economy's structural transformation is the Economic Complexity Index (ECI) as proposed by Hidalgo and Hausmann (2009). The authors base their concept on economic performance deriving from the availability of non-tradable capabilities including labour skills, infrastructure, or institutional settings. Economic complexity is defined as the relative number of capabilities available in a country, which combines its level of diversification (number of products) and the ubiquity of products (number of countries that export the product) (Hausmann & Hidalgo 2010). Thereby, the ubiquity indicates the number of capabilities needed for a product, as products that require many capabilities will be produced by only a few countries. Hence, poorly diversified countries, on average, produce goods that are made by many other countries as well, and highly diversified countries are often the only ones to produce less ubiquitous products (Hausmann & Hidalgo 2010). A circular argument evolves, as products that are exported by a location provide information on the location's complexity, and the sum of locations where the activity is present provides information on the complexity necessary to produce it.

Mathematically speaking, the bipartite network connecting locations and industries is represented with the adjacency matrix M_{cp}, where $M_{cp} = 1$ if country c exports product p with a Revealed Comparative Advantage (RCA) above a certain threshold and $M_{cp} = 0$ otherwise (Hausmann & Hidalgo 2011).

The RCA in turn makes locations and products more comparable, as it is the ratio between the export share of product p in country c and the share of product p in the world market. Hausmann and Hidalgo (2011) used the RCA as proposed by Balassa (1964), which is defined as:

$$RCA_{cp} = \frac{X_{cp}}{\sum_p X_{cp}} \Big/ \frac{\sum_c X_{cp}}{\sum_{c,p} X_{cp}},$$

with X_{cp} representing the exports of country c of product p. A value of RCA ≥ 1 indicates a country's comparative advantage in a product. The diversification of a country c is the sum M_{cp} over all products:

$$Diversification = k_{c,0} = \sum_p M_{cp},$$

and the ubiquity of a product p is defined as the sum of M_{cp} over all countries:

$$Ubiquity = k_{p,0} = \sum_c M_{cp.}$$

Out of the information on diversification and ubiquity the ECI and the Product Complexity Index (PCI) can be calculated. Hidalgo and Hausmann (2009) define the calculation as a "network of reflections" with two types of nodes in the network (countries and products). Continuous iterations between the two indices can be performed to obtain information on the economic complexity of countries and products. The ECI is the solution to the system of equations:

$$K_c = \frac{1}{M_c} \sum_p M_{cp} K_p,$$

$$K_p = \frac{1}{M_p} \sum_c M_{cp} K_c,$$

where c' denotes all countries other than c, and p' denotes all products other than p. Substituting the second equation in the first is equivalent to the matrix:

$$\widetilde{M}_{cc'} = \sum_{p} \frac{M_{cp}M_{c'p}}{M_c M_p},$$

As the eigenvector with the highest eigenvalue is a vectors of 1s, the eigenvector with the second highest eigenvalue of $M_{cc'}$ (K_c) becomes the metric of economic complexity, which is used to capture most of the variance of the system (Romero & Gramkow 2021). Thus, the ECI formula is defined as:

$$ECI_c = \frac{K_c - mean\,(K_c)}{std\,(K_c)}$$

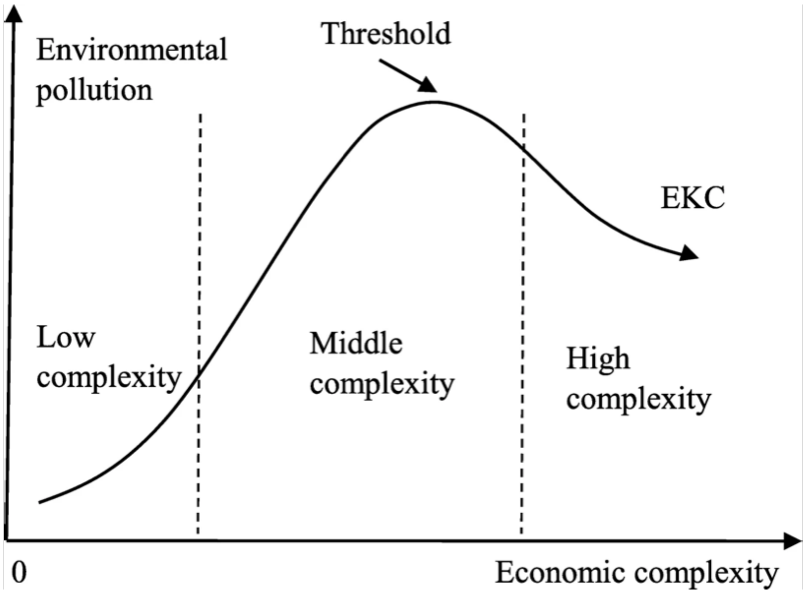
The metric of economic complexity is relative, leading commonly to normalisation using a Z-transform. Consequently, ECI > 0 implies a country to have an economic complexity above the average of the dataset.

The relationship between ECI and various other economic factors has been tested, and Hidalgo and Hausmann (2009) found out that economic complexity is an accurate predictor for economic growth. The authors suggest that countries tend to approach income levels that correspond to their measured complexity. Economies having technology-intensive sectors tend to have a higher Gross Domestic Product (GDP) (Hidalgo & Hausmann 2009) and countries depending on commodities are often associated with slow economic growth, high macroeconomic instability, and political fragility (Nkurunziza, Tsowou & Cazzaniga 2017). Also in the Latin American context, resource dependency accompanied by Dutch Disease effects led to an increasing technological gap with Asian countries and macroeconomic vulnerability (Ocampo 2017).

Besides the economic output, the influence of ECI has been tested for different aspects of economic development including inequality, institutions and human development (for a general literature review on economic complexity see Hidalgo (2021)).

As structural transformation is also having direct implications of an economy's energy intensity and technological advancement, economic complexity has been implemented as an explanatory variable for the EKC hypothesis. Can and Gozgor (2017) firstly investigated the effect of ECI on CO2 emissions for France and imply economic complexity representing the scale, the composition, and the technique effects of the EKC hypothesis. The question arises, whether ECI follows an inverted U-path with regards to environmental pollution as well (see Figure 7).

Figure 7 The EKC hypothesis between economic complexity and environmental pollution



Source: Pata (2021)

The rationale behind the consideration of economic complexity as an influencing factor for environmental pollution is the close connection to the technical capabilities of country's industry sector (Swart & Brinkmann 2020). Here, agricultural societies have a low environmental impact, and with the onset of industrialisation economies are becoming more complex and environmental degradation takes off. A structural transformation towards a knowledge-based economy further increases economic complexity and the capabilities emerge for an energy-efficient green economy (Swart & Brinkmann 2020). As a result, greater complexity can bring breakthroughs in clean technologies and the knowledge needed to improve environmental standards (Pata 2021).

4 Literature Review

The following literature review is intended to provide an overview about the most important empirical studies of the energy-growth-emissions nexus with a special focus on RES and economic complexity.

4.1 Economic Growth, Energy Consumption, and Environmental Pollution

In the last three decades, literature surrounding the energy-emission-growth nexus has expanded considerably, and available studies can be classified under three strands (Antonakakis et al. 2017; Bölük & Mert 2015).

The first strand focuses on the causal link between economic output and energy consumption. Kraft and Kraft (1978) firstly found a unidirectional causal relationship between the Gross National Product and energy consumption, confirming the conservation hypothesis and meaning that with increasing economic activity, the consumption of energy rises.

General surveys of the wealthy literature on the energy-growth nexus are provided by Ozturk (2010) and Payne (2010). Overall, the results of the studies are inconsistent with regard to the presence or direction of causality, and so far none of the four hypotheses has prevailed, due to different time periods, regional focus, variables used, and econometric approaches (Ozturk 2010; Payne 2010). Studies in this area mainly focus on the impact of total energy consumption for a single country or a subgroup of countries, without distinguishing between energy sources.

The findings of Akarca and Long (1980) and Stern (1993) contradict with the results of Kraft and Kraft (1978). While Akarca and Long (1980) note that the findings strongly depend on the selected time period and did not detect a causal relationship, Stern (1993) confirms the growth hypothesis, indicating energy to be a limiting factor for economic output.

Some studies focus on the implications of the income level or stage of development and detect large differences, depending on the country group (Chontanawat, Hunt & Pierse 2006; Huang, Hwang & Yang 2008; Ozturk, Aslan & Kalyoncu 2010). These studies found that causality between energy and GDP is weaker in low-income countries. Moreover, Huang et al. (2008) conclude that the impact of economic growth on energy consumption is positive in middle-income countries and negative for high-income countries.

The boom in RES brought a new aspect to the discussion, and significant gaps of knowledge on the role of renewable energy transitions for economic development persist (Fankhauser & Jotzo 2017). Apart from its crucial role in the transition to a less carbon-intensive economy, researchers started to look at the linkages between separate energy sources and economic growth. On the one hand, especially earlier studies focus on additional costs caused by subsidies for RES and for the introduction of new technologies. Ragwitz, Schade, Breitschopf, Walz, Helfrich, Rathmann, Resch, Panzer, Faber and Haas (2009) discuss an increased cost burden for energy-intensive industries and higher energy consumption costs for private households. On the other hand, the technology improvements of the low-carbon energy innovations can enhance the overall productivity (Fankhauser & Jotzo 2017).

Besides, existing literature on the economic effects of RES primarily focuses on the European Union and other high-income countries. While the transition to RES had positive effects on direct and indirect job creation in the European Union (Proença & Fortes 2020), there are doubts about similar employment linkages in developing countries because of missing human capital and expertise in the area of RES. On the contrary, Singh et al. (2019) found a strong positive impact of renewable energy production on economic growth and suggested a more pronounced relation for developing countries. This implication may be linked to energy constraints limiting economic growth in developing countries. Adom, Amuakwa-Mensah, Agradi and Nsabimana (2021) focus on the adverse effects of energy poverty on GDP and how the usage of RES can improve resilience against energy shocks. As RES contribute to sustainable supply of affordable energy, adopting renewable energy technology can improve development outcomes such as GDP per capita, employment or inequality (Adom et al. 2021).

The second strand encompasses studies on the relation between economic growth and the environment, whose mutual influence is complex.

Grossman and Krueger (1991) were the first to suggest an inverted U-shape relationship in their seminal work. They analyse the relation of air quality and economic growth to assess the environmental impacts of the North American Free Trade Agreement (NAFTA), concluding that the concentration of air pollution increases with growing GDP per capita until a certain point but then decreases at high levels of income. After Shafik and Bandyopadhyay (1992) and Selden and Song (1994) confirmed the findings, research on the EKC expanded considerably.

Dinda (2004) and Shahbaz and Sinha (2019) provide literature reviews on the extensive number of EKC studies. The EKC hypothesis has been tested for different environmental indicators, with most studies referring to air pollution, but also to water pollution or the ecological footprint (Shahbaz & Sinha 2019).

Furthermore, the explanatory variables vary, with most earlier studies solely including GDP and population (Panayotou 1993). To overcome the omitted variable bias, as criticised by Stern (2004), authors included more variables in their analysis. Adewuyi and Awodumi (2017) identified in their literature review that since 2009 an increasing number of studies incorporated RES, with about 107 studies 2006-2016. Suri and Chapman (1998) were among the first to use energy consumption as a dependent variable to represent environmental stress, as it is the main source of various pollutants. The authors found the turning point at 55,000 USD, which is out of the range of the GDPs of the included countries. Furthermore, they argue that industrialised countries have reached a flatter part of the curve and explain this finding with structural change (Suri & Chapman 1998). Subsequently, several studies tested the so-called energy Environmental Kuznets Curve (Luzzati & Orsini 2009; Saboori & Sulaiman 2013; Shahbaz, Shafiullah, Khalid & Song 2020).

Overall, the results of studies testing the EKC come to different conclusions. Several studies validate the EKC using panel data, for instance Galeotti and Lanza (2005) with a panel of over 100 countries, Heidari, Katircioğlu and Saeidpour (2015) for the five ASEAN countries, and Apergis (2016) for 12 of 15 high-income countries. Similar results are obtained in many time series analyses, including Bölük and Mert (2015) on Turkey and Sinha and Shahbaz (2018) on India. Furthermore, both studies conclude that renewable energy generation has a significant reducing effect on CO2 emissions. Nonetheless, while there are numerous studies confirming the EKC, some authors also fail to detect a turning point (Martínez-Zarzoso & Maruotti 2011) or suggest an N-shaped curve (Alvarez-Herranz & Balsalobre-Lorente 2015).

Despite the large body of literature on the EKC, the effects of the transition to RES and economic growth on CO2 emissions in the LAC region are scarcely investigated (Koengkan & Fuinhas 2020). Using deforestation rates as the outcome variable, Culas (2007) confirms the EKC for a panel of five tropical Latin-American countries, applying pooled Ordinary Least Squares (OLS) with country and year effects. In contrast, Pablo-Romero and De Jesús (2016) use energy consumption as the dependent variable and find no EKC for energy use. They suggest that energy usage in LAC countries is highly sensitive to economic growth, leading to an exponential increase in energy consumption. Koengkan and Fuinhas (2020) do not test for a non-linear relationship between GDP and CO2 in their study on LAC. However, the authors find a short and long-run negative impact of the share of RES on CO2 emissions.

The incorporation of energy in the discussion on economic growth and emissions led to the third strand of literature, a synthesis of the energy-growth nexus and the EKC (see Adewuyi and Awodumi (2017) for a literature survey).

Richmond and Kaufmann (2006), Ang (2007), and Soytas, Sari and Ewing (2007) introduced energy consumption into the EKC and investigated the causal relationships. Ang (2007) claims that the three variables are strongly inter-related and conduct their analysis by using a vector error correction model, to account for the endogeneity of the variables. By using time series data of France, the author confirms a unidirectional causality, running from energy to economic output and the presence of an EKC.

While the previous studies focus on time series, Apergis and Payne (2009) find a bidirectional causality between energy use and emissions and confirmed the EKC for Central America.

Applying a panel fully modified OLS, Al-mulali, Tang and Ozturk (2015) suggest the existence of a U-shaped relationship between GDP growth and CO2 emissions for 18 LAC countries. They found no significant influence of electricity consumption from RES on CO2 emissions.

While these studies apply a more holistic approach, their findings remain inconclusive, and the studies mainly focus on a small subset of countries. Antonakakis et al. (2017) argue that understanding the dynamic linkages between economic activity, energy consumption and environmental waste is particularly prevalent for emerging economies, as increasing environmental damage stresses the necessity to identify efficient policies of energy consumption and growth.

4.2 Economic Complexity in the Energy-Growth-Emissions Literature

In order to disentangle the effect of structural transformation on environmental degradation, the relatively new concept of economic complexity has been integrated in a few recent studies of the wealthy energy-growth-emission literature. Despite the importance of economic structure for environmental degradation, the aspect of economic complexity, has mainly been neglected in EKC research. Since the structure and not only the size of an economy influences environmental impacts, economic complexity is expected to be an important indicator for structural change and innovation performance. There is evidence that industrialisation drives up CO2 emissions and energy consumption (York, Rosa & Dietz 2003). On the other hand, a country's productive structure also "embeds knowledge and capabilities, research and innovation, which can help to stimulate greener products and environmentally friendly technologies" (Neagu & Teodoru 2019).

Can and Gozgor (2017) were the first to link economic complexity to the EKC by using data for the case of France from 1964 to 2014. Applying a unit root test with two structural breaks and a dynamic OLS estimation, they found ECI to be a significant indicator for the level of CO2 emissions. Can and Gozgor (2017) suggest ECI and energy consumption to be the main determinants of emissions and conclude that higher economic complexity decreases emissions.

Focusing on 25 European Union countries, Neagu and Teodoru (2019) conducted the first panel data study to include ECI as a determining variable for emissions. In contrast to Can and Gozgor (2017), they did not include GDP per capita in their model and refined energy consumption on the share of final energy consumption generating pollution. Using heterogeneous panel estimators, Neagu and Teodoru (2019) determine economic complexity to be associated with increasing CO2 emissions and suggest that with more complex products, more polluting industrial technologies are applied. After dividing the countries into two subpanels according to their average ECI, they found the positive effect of ECI, and the energy consumption structure to be more pronounced for the group with lower economic complexity.

The findings of Neagu and Teodoru (2019) indicate that the influence of ECI on emissions depends on the stage of development. In a similar vein, Doğan et al. (2019) examined the effect for 55 countries from 1971 to 2014 and divided them into three income groups. They confirm the EKC for all country groups, and reveal that economic complexity increases emissions for lower and higher middle-income countries emissions but reduces them in the high-income group.

Testing the energy EKC hypothesis, Boleti et al. (2021) examined that with economic complexity energy consumption increases, although it is less intense at higher income levels. The authors verify a positive effect of economic complexity on environmental performance for a dataset of 88 developed and developing countries from 2002 to 2012, using fixed-effects instrumental variables estimation techniques. In contrast to other studies, they apply a synthetic measure for environmental pollution, namely the Environmental Performance Index. Moreover, Boleti et al. (2021) show that economic complexity has a negative effect on renewable energy consumption. This finding contradicts with the expectation of economic complexity promoting innovative renewable-based infrastructures. The authors suspect that this effect is due to the still high costs associated with renewable energy technologies (Boleti et al. 2021).

In addition, Romero and Gramkow (2021) propose a Product Emission Intensity Index, measuring a country's GHG emissions by unit of output. With the help of fixed effects and System-generalised method of moments estimators, they found an increase of 0.1 in the economic complexity index to generate a 2% decrease in next period's emissions of kilotons of CO2e per billion dollars of output.

Doğan et al. (2021) determined that economic complexity is negatively related to carbon emissions in OECD countries, controlling for RES usage, total population size and GDP. Furthermore, they included a statistically significant interaction factor of renewable energy consumption and economic complexity and suggest economic complexity to be a crucial factor in shaping the energy structure and trade-related policies (Doğan et al. 2021).

In a study on the relation between economic complexity and different environmental indicators in Brazil, Swart and Brinkmann (2020) introduce the variables ECI and ECI squared in order to test whether economic complexity follows an inverted U-shape. They propose that, after a certain threshold, economies have the capabilities embedded in technology and human capital to limit environmental degradation.

Despite conflicting results, the existing literature suggests economic complexity to be significant for environmental pollution and energy usage. More research is necessary to understand how structural change, accompanied by technological advancement, impacts the energy system, environmental damage, and economic development. In addition, the findings of Doğan et al. (2019) for different income groups and Neagu and Teodoru (2019) for different complexity levels indicate that the impact of ECI depends on regional circumstances and levels of development. Thus, studies on economic complexity that focus on specific regions other than high income countries are still missing. At the same time, LAC is the least researched region with regards to energy consumption, economic growth, and carbon emissions (Adewuyi & Awodumi 2017).

5 Data and Methodology

This chapter describes the data and methodology used in this study, taking the literature review as guidance. The variables with their sources, the overall methodology, and model specifications are described. Thereby, also the limitations will be critically reviewed.

5.1 Data Description

In order to investigate the effect of RES and economic complexity on environmental degradation, the data of the following countries is taken into consideration: Costa Rica, Cuba, Dominican Republic, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, El Salvador, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Peru, Paraguay, Uruguay, Venezuela. For these 20 countries the ECI is available, and they can, with about 96 per cent of the population and 92 per cent of GDP, be classified as a representative sample for LAC. The time period is also constrained by the data availability of the ECI. The investigated period spans from 1998 to 2018, being a relevant period with increasing investments in RES. The data is gathered from multiple sources and is publicly available. All variables are either directly obtained or transformed into relative values, meaning that they are expressed as percentages or per capita values.

Table 1 Variable description and sources

VARIABLE	SPECIFICATION	SOURCE
GHG	GHG emissions per capita (tCO2e/capita)	CEPALSTAT
GDP	GDP per capita (constant 2015 US$)	World Development Indicators
ECI	Economic Complexity Index	OEC
ENERGY	Total energy supply per capita (KJ/capita)	IEA
RENEW	Share of renewable electricity generation	IRENASTAT, IEA
POP	Population, total	World Development Indicators
URBAN	Urban population (% of total population)	World Development Indicators
TRADE	Sum of imports and exports (% of GDP)	World Development Indicators
EDU	Education Index	UNDP
FINANCE	Financial Development Index	IMF
AGRI	Agriculture, forestry, and fishing, value added (% of GDP)	World Development Indicators
MANU	Manufacturing, value added (% of GDP)	World Development Indicators

The Dependent Variables

- **GHG emissions**

The variable GHG emissions per capita is selected as a proxy for environmental degradation in order to test the EKC hypothesis. The gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6), generated through activities in the following sectors: energy, industrial processes, agriculture, waste, and bunker fuel (CEPALSTAT 2021). Although there are other measures of the state of the environment, GHG emissions are a commonly used variable in the literature to represent global warming in the study of EKC. The GHG emissions are measured in tons of carbon dioxide equivalent (tCO_2e) per inhabitant.

- **Energy**

The total energy supply per capita indicates the amount of energy needed for the respective country and is an often-used variable to test the energy EKC. As fossil fuel consumption is the main driver of CO_2 emissions and the energy systems still rely heavily on its usage, energy supply is taken as an indicator of environmental pressure. The total energy supply represents the amount of energy that is available in the national territory during the reference period, including energy imports and excluding exports (UN 2017). Data on the total energy supply per capita is not available for El Salvador.

The Independent Variables

- **GDP and GDP squared**

As with the presence of an EKC, the relation between GHG emissions and GDP is expected to follow an inverted U-shape, GDP and GDP squared per capita are introduced as the most common indicator of economic growth. The different influencing factors behind the U-shaped relation such as scale effect, income elasticity or structural transformation are explained in detail in the theory section. With the presence of an EKC, GDP is expected to have a positive sign and GDP squared to have a negative.

The data on GDP per capita was only available in current USD for Venezuela, and it is limited to the period from 1998 to 2014. Thus, to deflate the data, the GDP was divided by the US consumer price index (CPI) of the referring year and then multiplied with the 2015 CPI. The CPI is provided by the World Development Indicators of the World Bank (2022b).

- **ECI and ECI squared**

The economic complexity index is obtained from MIT's Observatory of Economic Complexity (Simoes & Hidalgo 2011). The international product-level trade data for the calculation of the ECI is retrieved from UN Comtrade, leading to a product coverage of approximately 5000 goods across 10 categories (Hausmann, Hidalgo, Bustos, Coscia & Simoes 2014). The ECI indicates the sophistication of a country's productive structure, by quantifying the diversification and sophistication of production. The ECI is increasing with an economy's structural transformation, having different implications on emissions. On the one hand, new technologies may have greater environmental impact than the technologies they replace, and industrialisation is exacerbating pollution (Pata 2021). On the other hand, greater economic complexity can induce eco-innovations and energy saving technologies (Neagu & Teodoru 2019).

LAC countries, for which the ECI (provided by the observatory) is available, are included in the study. However, the data is not available for Bolivia 1998-2000, Paraguay 1998-1999, Cuba 1998 and 2016-2018, Jamaica 2003-2004 and 2016-1017, and Nicaragua 1998-2005.

- **Renew**

This study investigates the role of renewable electricity generation on emissions. The variable *renew* is representing the share of renewables in the total electricity generation. It includes electricity generation from hydro, solar, wind, geothermal energy, biofuels, and energy from waste.

The data on electricity generation is obtained from IRENASTAT, which provides information on national electricity generation in Gigawatt hour (GWh) per source and per year. However, the International Renewable Energy Agency (IRENA) only publishes data from 2000 onwards, resulting in the 1998 and 1999 figures being taken from charts of the International Energy Agency (IEA). The full data set of the IEA is not publicly available, which causes this discontinuity. However, both data sets are checked for consistency to not distort the results. To ensure comparability between countries, the total share of electricity from RES is calculated by adding the total electricity generation to the renewable electricity generation, and then dividing the RES by the sum of the total electricity generation from all sources.

<u>The Control Variables</u>

- **Pop**

This variable controls for changes in total population and is expected to have a positive effect on emissions (Boleti et al. 2021). Growing populations lead to more energy demand and product consumption, and the higher population density is associated with greater use of transport, causing increasing transport energy consumption (Liddle & Lung 2010). In addition, people in the ages of 20-34 are expected to have a larger environmental impact (Liddle & Lung 2010), a group that has a larger share in the growing populations of LAC.

- **Urban**

The urbanisation rate is the second variable depicting a country's demographic change. The variable *urban* specifies the population share living in urban areas as defined by national statistical offices. On the one hand, urbanisation processes, being associated with industrialisation and increased access to national power grids, are expected to rise emissions due to intensive energy consumption (Liddle & Lung 2010). On the other hand, urbanisation may increase environmental awareness and resource efficiency (Boleti et al. 2021)

- **Trade**

The variable *trade* is describing the sum of exports and imports of goods and services measured as a share of GDP. Trade openness is a common investigated variable in the EKC literature. Its association with environmental degradation can be twofold. Trade openness may raises the demand for eco-friendly products and higher environmental standards (Doğan et al. 2019), but increased trade can also higher pollution, resource extraction and lead to the specialisation in energy-intensive industries.

- **Edu**

The variable *edu* represents the educational index, which is part of the Human Development Index (UNDP 2020) and combines the average of the two indicators: mean years of schooling (of adults) and expected years of schooling (of children). Both measurements are equally weighted and expressed as an index between 0 and 1. The index was taken as the measurement for education as World Bank data on school enrolment was not available for the investigated period and countries. Education is expected to have a negative impact on emissions as awareness of environmental degradation is raised and the public demands stricter environmental regulations.

- **Finance**

The data on financial development is provided by the IMF (2021). It is a country ranking based on depth, access, and efficiency of their financial institutions and markets, taking a value from 0 to 1. There are several channels through which financial development can impact emissions, including the acceleration of financing low-carbon technologies and its research and development (R&D) as well as greater consumer loans that increase the consumption of energy-intensive goods (Kirikkaleli, Güngör & Adebayo 2022). For Cuba, no data on the financial development index is available.

- **Agri and Manu**

The variables *agri* and *manu* depict the value added of the respective sector as a share of GDP. Agriculture is considered to be positively associated with emissions and to play an increasing role in global pollution due to the impact of fertilisers, irrigation and CO2 emissions from livestock farming (Ridzuan, Marwan, Khalid, Ali & Tseng 2020). Also, the manufacturing sector is expected to increase emissions, as it usually is more energy-intensive than other sectors.

5.2 Methodology

This study intents to examine the impacts of economic complexity and RES on the dependent variables GHG emissions and energy generation, leading to important implications for synergetic green growth policies. Thereby, the EKC and the energy EKC are tested. The panel data methodology is used, improving the control of heterogeneity and collinearity between variables, increasing the degrees of freedom, and providing more reliable parameter estimates than timeseries data (Baltagi 2005).

In order to first gain insights into the broader coherence of the variables of interest, namely GHG emissions, ECI, energy and renewable electricity generation, the data is analysed in a descriptive way. No causal inferences can be drawn with visual trend analyses and correlations, but indications of linkages between the variables can be identified.

Afterwards, to measure the effects of the different variables on environmental pollution, an econometric analysis is conducted. As other authors suggest that the impact of ECI on environmental pollution depends on the level of complexity (Doğan et al. 2019; Neagu & Teodoru 2019), the econometric analysis is also conducted for two subgroups of the panel. Moreover, running the regression for the two sub-groups after the analysis for the whole panel serves as a sensitivity analysis for the previously obtained results. Therefore, the average ECI for the period 1998-2018 is taken, and then divided into two groups with a threshold of ECI=0. This leads to the division of countries with higher complexity: Argentina, Brazil, Colombia, Costa Rica, Mexico, Panama, Uruguay, and countries with lower complexity: Cuba, Nicaragua, Jamaica, El Salvador, Venezuela, Peru, Paraguay, Honduras, Guatemala, Ecuador, Dominican Republic, Chile, Bolivia.

To check whether fixed-effect (FE) and random-effect (RE) regressions are the right choice, a Hausmann test is conducted at first. The null hypothesis of the Hausmann test is that the FE and RE estimators do not differ substantially (Gujarati & Porter 2009). After conducting the Hausmann the null hypothesis is rejected, leading to the conclusion that the RE would probably correlate with one or more regressors. This result indicates that FE are appropriate, which, at the same time, leads to the conclusion that a pooled OLS regression would be biased and inconsistent. For pooled OLS models to be consistent, a strict exogeneity assumption must apply, requiring that the individual-specific covariates are not correlated with the error term (Collischon & Eberl 2020).

Subsequently, a decision is made whether country FE, time FE or both have to be considered. After running a Wald test, the null hypothesis that all dummies for all years are equal to zero cannot be rejected, indicating that no time FE are needed. For country FE, on the other hand, the null hypothesis is rejected, and country-specific error terms need to be included in the model, allowing each entity to have its own intercept (Gujarati & Porter 2009). As already indicated in the contextualisation part, the countries under investigation differ substantially in terms of their economic development, structure, environmental degradation, size, and population. With FE, the country-specific heterogeneity can be captured with country dummies, limiting potential biases in comparison to pooled OLS and RE. Thereby, the FE estimation allows for arbitrary correlation between the unobserved country effect and the observed explanatory variables (Wooldridge 2010)

As previously described, FE regression results are generally more reliable than OLS, however, the estimation with FE also has its disadvantages. Firstly, the many dummy variables introduced may cause problems of multicollinearity, which might hinder the precise estimation of the parameters (Gujarati & Porter 2009). Additionally, as the fixed effects model absorbs the country specific variability, there can be little inference drawn on absolute country differences, which may be partly also due to the variables under investigation. Especially for variables with little variations, the results have a relatively low statistical power and the time-invariant variables do not contribute much information to the analysis (Hill, Davis, Roos & French 2020). Furthermore, while taking into account the country fixed-effects, the time fixed-effects remain.

5.3 Model Specification

The models are formulated in a log-linear form. This specification provides more efficient results and reduce data fluctuations (Neagu & Teodoru 2019; Shahbaz et al. 2012). In addition, the data on GHG emissions and GDP is skewed to the right, and the distribution becomes more normal and symmetric after the log transformation. Since the ECI can also take values as low as -

1.2, two units are added to all ECI values before they are squared and brought into the log transformation.

Model 1 tests whether there is an EKC between economic complexity and GHG emissions, without considering the control variables.

Model 1:

$$ln\_GHG_{it} = \beta_{1i} + ln\_ECI_{it}\beta_2 + ln\_ECI2_{it}\beta_3 + \varepsilon_i + u_{it}$$

Thereby, the error term ε_i expresses individual differences in the intercept values of every country and the error term u_{it} is the general regression error term. The first model without further controls aims to give a first impression on how the variables of interest interact. Consistent with the EKC hypothesis, the introduction of squared ECI allows the variable to take a U-shaped form, if there is one.

In a next step the interest variables renew, to test the effect of renewables, as well as seven control variables are added, following the studies of Sharma (2011) and Romero and Gramkow (2021): population, trade, urbanisation rate, education index, financial development, agriculture and manufacturing.

Model 2:

$$\begin{aligned} ln\_GHG_{it} = \beta_{1i} &+ ln\_ECI_{it}\beta_2 + ln\_ECI2_{it}\beta_3 + ln\_Renew_{it}\beta_4 + ln\_pop_{it}\beta_5 \\ &+ ln\_trade_{it}\beta_6 + ln\_urban_{it}\beta_7 + ln\_edu_{it}\beta_8 + ln\_finance_{it}\beta_9 \\ &+ ln\_agri_{it}\beta_{10} + ln\_manu_{it}\beta_{11} + \varepsilon_i + u_{it} \end{aligned}$$

To compare the results of the models with the conventional environmental EKC specification, a third model is introduced, containing the same variables as model 2 but replacing ECI with GDP.

Model 3:

$$ln\_GHG_{it} = \beta_{1i} + ln\_GDP_{it}\beta_2 + ln\_GDP2_{it}\beta_3 + \varepsilon_i + u_{it}$$

Model 4:

$$\begin{aligned} ln\_GHG_{it} = \beta_{1i} &+ ln\_GDP_{it}\beta_2 + ln\_GDP2_{it}\beta_3 + ln\_Renew_{it}\beta_4 + ln\_pop_{it}\beta_5 \\ &+ ln\_trade_{it}\beta_6 + ln\_urban_{it}\beta_7 + ln\_edu_{it}\beta_8 + ln\_finance_{it}\beta_9 \\ &+ ln\_agri_{it}\beta_{10} + ln\_manu_{it}\beta_{11} + \varepsilon_i + u_{it} \end{aligned}$$

In a last step the effect of GDP and ECI will be measured in one Model, as proposed by (Can & Gozgor 2017; Doğan et al. 2021; Doğan et al. 2019). Thereby, the variables GDP and ECI are introduced in either the linear or non-linear from, depending on the results of the previous modelling.

Model 5:

$$ln\_GHG_{it} = \beta_{1i} + ln\_GDP_{it}\beta_2 + ln\_ECI_{it}\beta_3 + ln\_Renew_{it}\beta_4 + ln\_pop_{it}\beta_5 + ln\_trade_{it}\beta_6 + ln\_urban_{it}\beta_7 + ln\_edu_{it}\beta_8 + ln\_finance_{it}\beta_9 + ln\_agri_{it}\beta_{10} + ln\_manu_{it}\beta_{11} + \varepsilon_i + u_{it}$$

Similarly, the energy EKC will be tested. Thus, energy supply is used as indicator of environmental pressure, based on the reality that the energy system in LAC is largely dependent on fossil fuel combustion. To test the effect of economic complexity on energy and to check the robustness of the relationship, the same models are applied using the natural logarithm of energy supply as the dependent variable.

Model 6:

$$ln\_energy_{it} = \beta_{1i} + ln\_ECI_{it}\beta_2 + ln\_ECI2_{it}\beta_3 + \varepsilon_i + u_{it}$$

Model 7:

$$ln\_energy_{it} = \beta_{1i} + ln\_ECI_{it}\beta_2 + ln\_ECI2_{it}\beta_3 + ln\_pop_{it}\beta_4 + ln\_trade_{it}\beta_5 + ln\_urban_{it}\beta_6 + ln\_edu_{it}\beta_7 + ln\_finance_{it}\beta_8 + ln\_agri_{it}\beta_9 + ln\_manu_{it}\beta_{10} + \varepsilon_i + u_{it}$$

Model 8:

$$ln\_energy_{it} = \beta_{1i} + ln\_GDP_{it}\beta_2 + ln\_GDP2_{it}\beta_3 + \varepsilon_i + u_{it}$$

Model 9:

$$ln\_energy_{it} = \beta_{1i} + ln\_GDP_{it}\beta_2 + ln\_GDP2_{it}\beta_3 + ln\_pop_{it}\beta_4 + ln\_trade_{it}\beta_5 + ln\_urban_{it}\beta_6 + ln\_edu_{it}\beta_7 + ln\_finance_{it}\beta_8 + ln\_agri_{it}\beta_9 + ln\_manu_{it}\beta_{10} + \varepsilon_i + u_{it}$$

Model 10:

$$ln\_energy_{it} = \beta_{1i} + ln\_GDP_{it}\beta_2 + ln\_ECI_{it}\beta_3 + ln\_pop_{it}\beta_4 + ln\_trade_{it}\beta_5 + ln\_urban_{it}\beta_6 + ln\_edu_{it}\beta_7 + ln\_finance_{it}\beta_8 + ln\_agri_{it}\beta_9 + ln\_manu_{it}\beta_{10} + \varepsilon_i + u_{it}$$

5.4 Limitations

As discussed in the literature review, studies on the energy-growth-emissions nexus have obtained different results, largely depending on the chosen econometric method, model specification, and data. The largest limitation of these nonexperimental econometric analysis is the implication of a causal relationship. One solution to obtain convincing estimates of causal effects would be the application of the instrumental variable method, however, credible instrumental variables are hard to find (Angrist & Pischke 2014) and were therefore not applied in this study.

In addition, the direction of causality of the interest variables is still debated in the literature. Thus, the presence of reverse causality and endogeneity is likely, as there probably is a feedback effect of environmental pollution on economic development. The FE model is not able to capture this simultaneity issue. At the same time, it is not possible to include all factors influencing GHG emissions and energy supply, implying the risk of omitted variable bias.

Apart from that, there are limitations of the data applied. First, the ECI for some countries, energy data for El Salvador, data on financial development for Cuba, as well as World Bank data for Venezuela is not available for every year, leading to an unbalanced dataset. However, all countries are still taken into consideration for the analysis, as excluding countries would lead to a selection bias and fewer observations.

Moreover, several similar studies included renewable and non-renewable energy consumption as variables, which however is not publicly available for all countries included in the panel. Thus, alternative measures suggested by other authors were used: the share of renewable electricity generation as a proxy for the energy transition and the total energy supply to account for the overall energy needed for the economic activity of the respective country. This data may deviate from the commonly used energy consumption measures but depicts nevertheless the same trends.

Besides, the quality of the data has to be considered. The data is stemming from different sources in developing country settings, which can impede data reliability.

6 Empirical Results

This chapter presents the results of the research, being divided in a first descriptive analysis, followed by the results of the FE models on GHG emissions and energy. With the help of the descriptive part, the first research question on the interrelations of economic complexity, energy, and emissions is addressed. The FE models examine the effect of economic complexity on GHG emissions and energy generation in order to answer the second research question.

6.1 Descriptive Analysis

Table 2 depicts the basic properties of the individual variables. As explained above, some data was not available for each country or year, making the dataset unbalanced. To illustrate the significant differences in this sample, it is interesting to look at the GHG emissions per capita, ECI, and renewable electricity generation. The average GHG emissions amount to 4.57 tCO2e per capita. Within in the sample, Uruguay has the highest per capita GHG emissions, with 11.63 in 2008, and Guatemala had the lowest value of 1.71 in 1998. For energy, different countries represent the extremes, with Bolivia accounting for the lowest and Venezuela for the highest energy supply per capita. The heterogeneity of the region can also be observed when looking at the within and between variances in Annex A.

Table 2 Summary descriptive statistics

Variable	**Number of Observations**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
GHG	420	4.569619	2.35368	1.71	11.63
ENERGY	399	44.05589	20.92852	18	112.2
ECI	399	-0.2028033	0.5207639	-1.284718	1.203621
GDP	416	6537.565	3652.894	1338.681	16074.69
RENEW	418	0.5232745	0.2898863	0.0285086	0.9999919
POP	420	2.79e+07	4.47e+07	2608874	2.09e+08
TRADE	416	64.40024	28.36706	16.43858	166.6981
URBAN	420	70.58252	13.64984	44.447	95.334
EDU	420	0.6236167	0.0995981	0.339	0.842
FINANCE	399	0.2501697	0.1227281	0.061636	0.6332957
AGRI	416	7.883486	3.957016	2.248462	23.4399
MANU	416	14.51882	3.373966	5.877236	22.48675

The mean GDP per capita of the sample amounts 6537.6 USD, which falls into the range of upper middle-income countries. Looking at the ECI, it becomes apparent that the economic complexity of LAC with -0.2 is below the average of the world ECI sample that through its mathematical derivation amounts to zero. Thereby, Mexico is the most complex country, with an index of 1.2 in 2017.

The share of renewable electricity generation has a maximum of 0.99, with Costa Rica, Paraguay, and Uruguay almost entirely producing electricity from renewable resources. Also, Brazil, as the largest country of the region, has a share of renewable electricity close to 90 per cent. Overall, with a mean of 44.1 per cent, almost half of the sample's electricity is produced from RES.

Looking at the correlations between the variables of interest, it becomes visible that GDP is strongly correlated with the two outcome variables GHG and energy, indicating a positive relationship. The correlations are stronger than in the case of ECI, although ECI is positively correlated with both variables as well. Contrary to the previous expectation, there is weak positive correlation between the share of renewable electricity generation and GHG emissions. Furthermore, *renew* is not correlated with economic complexity, indicating no relationship between the two variables.

Table 3 Correlation matrix

	GHG	energy	ECI	GDP	renew	urban	trade	edu	pop	fin ance	agri	manu
GHG	1.000											
energy	0.674	1.000										
ECI	0.403	0.534	1.000									
GDP	0.647	0.697	0.663	1.000								
renew	0.169	-0.119	0.046	0.125	1.000							
urban	0.715	0.660	0.615	0.737	0.142	1.000						
trade	-0.332	-0.315	-0.371	-0.246	-0.163	-0.594	1.000					
edu	0.521	0.476	0.362	0.728	-0.023	0.709	-0.294	1.000				
pop	0.080	0.285	0.644	0.165	0.049	0.364	-0.472	0.068	1.000			
finance	0.059	0.409	0.623	0.484	0.004	0.477	-0.212	0.437	0.662	1.000		
agri	-0.338	-0.616	-0.665	-0.653	0.125	-0.629	0.2415	-0.583	-0.379	-0.633	1.000	
manu	-0.076	-0.114	-0.135	-0.306	0.059	-0.142	-0.125	-0.433	-0.014	-0.421	0.361	1.000

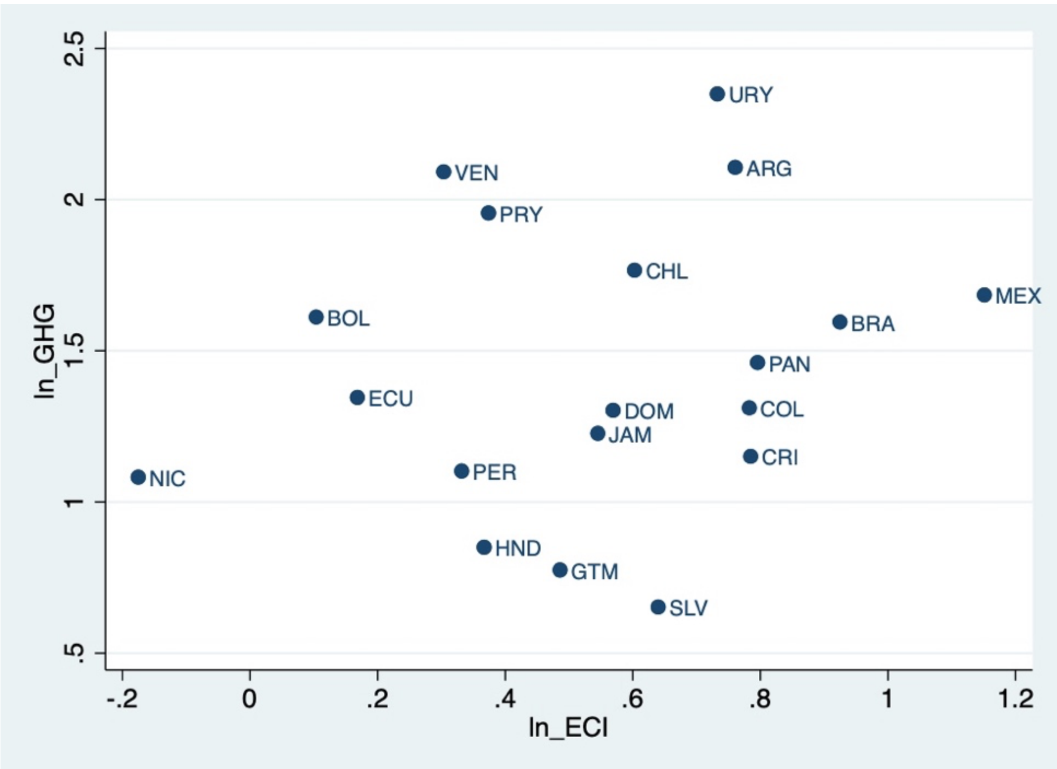
(obs=374)

In addition, correlations can reveal possible problems of multicollinearity. Multicollinearity is a common feature for non-natural experiments (Gujarati & Porter 2009). Although none of the correlations exceed the critical value of 0.8, which indicates multicollinearity to be serious problem (Gujarati & Porter 2009), there is still a high correlation between some variables. In addition, the

VIF test is conducted for the different regressions, and only the variables that are also included as a squared term exceed the critical value of 10 (Gujarati & Porter 2009).

Figure 8 displays the relation between economic complexity and GHG emissions for 2018 (diagrams for 1998 and 2008 can be found in Annex B). The diagrams show that the observations are rather spread, which is in line with the weak correlation previously detected. Countries with a high ECI do not necessarily have the highest emissions, as countries such as Brazil, Mexico, or Panama, with the highest ECIs in 2018, are not the largest emitters. However, there is a trend visible between the two variables, and it seems that throughout the panel an increasing ECI is associated with higher GHG emissions. At the same time, it becomes apparent that the Central American countries Honduras, El Salvador, Guatemala, and Nicaragua have comparably a rather low complexity and low emissions per capita. Paraguay and Uruguay, countries with almost a 100% renewable electricity, account for high GHG emissions and a moderate ECI in 2018. Additionally, Mexico has a very high complexity in comparison to its GHG emissions per capita.

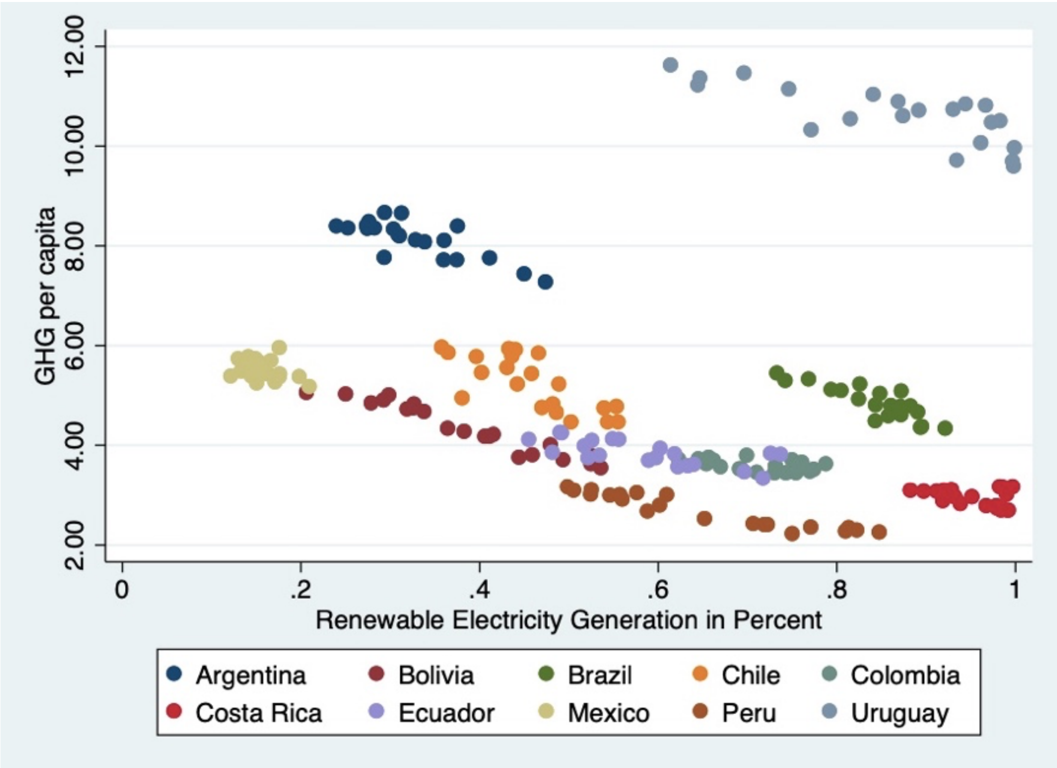
Figure 8 Scatter plot of the variables ln_ECI and ln_GHG for 2018



Note: Scatter Plot for 1998 and 2008 and Country Codes in Annex B

In Figure 9, no clear general trend between the share of renewables and emissions becomes visible. However, looking at single countries, it seems that an increasing share of renewable electricity generation is associated with declining GHG emissions. This visual inspection has been done for all countries, and there is a similar trend for the whole region. Nevertheless, for Venezuela, the trend is the opposite, and for Paraguay no trend is visible as renewable electricity generation is close to 100% for all years.

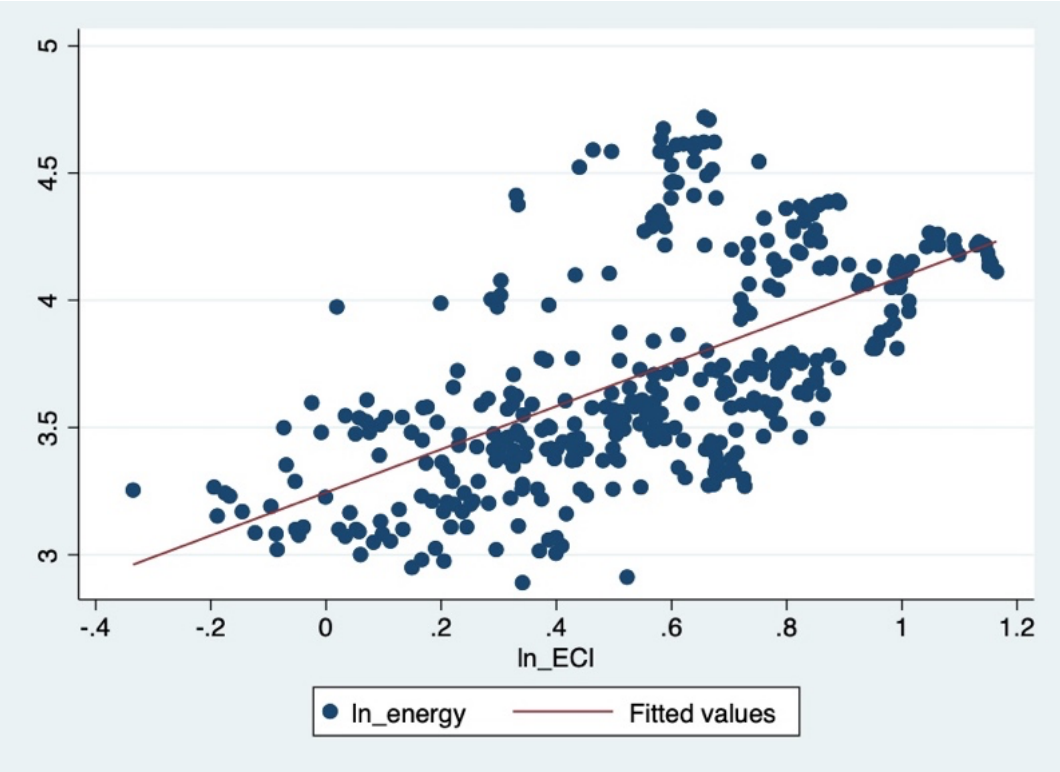
Figure 9 Scatter plot of the variables renew and GHG



Note: Includes observations for only 10 countries to improve visibility

Figure 10 depicts the positive relation between economic complexity and energy supply with the observations being rather spread. After looking at the relation for single countries, it became apparent that Venezuela accounts for the outlier point with particularly high energy supply per capita compared to its ECI.

Figure 10 Scatter plot of the variables ln_ECI and ln_energy, with trend line



6.2 Results for GHG Emissions

Table 4 shows the results of the six FE models on GHG emissions. Regression (1), the specification with GHG, ECI and ECI2 without controls, suggest a U-shaped relationship between the variables. However, when introducing the controls in the second regression, the coefficient of the square term gets insignificant and the linear term of ECI stays significant at a 5% level, which indicates a linear relationship between ln_ECI and ln_GHG. Therefore, the regression is run again only including the linear term of ECI, which led to the coefficients and R squared roughly remaining the same. The effect can be interpreted as a 1% increase in economic complexity leads to 0.1% decline in GHG emissions per capita. Thus, no inverted U-shaped relationship between ECI and GHG can be confirmed. Furthermore, the R squared significantly increases with the introduction of the control variables in comparison to regression (1).

The regressions (4) and (5) include GDP and GDP2 instead of ECI. The results suggest an inverted U-shaped relationship between the two variables, as GDP takes a positive and GDP2 a negative value. The last specification combines the effects of ECI and GDP. The three coefficients keep their signs, and the significance remains, indicating the robustness of the results. Overall, the coefficient of the linear GDP has the largest effect on GHG emissions, taking the value 1.298. Furthermore, a 1% increase in GDP2 is associated with a -0.0621% change in GHG. Thus, the relation between GDP and GHG is expected to take an inverted U-shape. In comparison, it is estimated that the per capita GHG emissions will reduce by -0.0859% if the ECI rises by 1%.

Throughout the regressions, the share of renewable electricity generation is negatively associated with emissions, and the final regression implies that a 1% increase in *renew* leads to an emission reduction of 0.14%. Besides, the total population and trade have both a statistically significant positive correlation with GHG emissions, and the effect of education is negative.

For the last model, a stepwise introduction of the control variables is conducted (see Annex C). Throughout the process the sign and the significance of the three coefficients on GDP, GDP2 and ECI remains. Only ECI turns insignificant when introducing *renew*. Furthermore, the explanatory power of the variables can be observed when looking at the "within" R squared. It becomes apparent that GDP and GDP2 explain most of the "within" variance, taking an R squared value of 0.4252, followed by the explanatory power of *renew*.

Table 4 Fixed effects regressions for GHG emissions

	(1) ln_GHG	(2) ln_GHG	(3) ln_GHG	(4) ln_GHG	(5) ln_GHG	(6) ln_GHG
ln_ECI	-0.150*	-0.0997*	-0.104**			-0.0859**
	(-2.10)	(-1.99)	(-3.23)			(-2.83)
ln_ECI2	0.217**	-0.00708				
	(2.85)	(-0.12)				
ln_GDP				1.663***	1.712***	1.298***
				(5.35)	(5.02)	(3.57)
ln_GDP2				-0.0799***	-0.0836***	-0.0621**
				(-4.52)	(-4.43)	(-3.09)
ln_renew		-0.156***	-0.156***		-0.147***	-0.141***
		(-8.12)	(-8.19)		(-9.11)	(-7.88)
ln_pop		0.743***	0.741***		0.499***	0.520***
		(7.81)	(7.91)		(5.26)	(5.46)
ln_trade		0.0649**	0.0647**		0.0726***	0.0626**
		(3.06)	(3.07)		(3.82)	(3.16)
ln_urban		-0.0921	-0.0917		-0.285**	-0.171
		(-0.86)	(-0.86)		(-2.81)	(-1.65)
ln_edu		-0.473***	-0.472***		-0.441***	-0.467***
		(-5.67)	(-5.70)		(-5.61)	(-5.82)
ln_finance		0.0574*	0.0577*		-0.0310	-0.00831
		(2.18)	(2.21)		(-1.25)	(-0.32)
ln_agri		-0.0326	-0.0321		-0.0608**	-0.0450*
		(-1.61)	(-1.62)		(-3.19)	(-2.38)
ln_manu		-0.136***	-0.136***		-0.0451	-0.0795*
		(-4.39)	(-4.40)		(-1.47)	(-2.47)
_cons	1.410***	-10.47***	-10.44***	-6.972***	-14.53***	-13.23***
	(63.98)	(-7.02)	(-7.11)	(-5.11)	(-9.25)	(-7.84)
R squared						
Within	0.0216	0.5813	0.5813	0.3809	0.6411	0.6350
Between	0.1139	0.0111	0.0111	0.3911	0.0469	0.0371
Overall	0.1136	0.0094	0.0094	0.3849	0.0469	0.0336
N	399	376	376	416	393	376

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

6.3 Results for Energy Supply

In a second set of regressions, the association of the variables with energy supply are measured (see Table 5). The first three specifications look at the effect of economic complexity. It becomes apparent that there is no non-linear relationship between ECI and energy, as there is no statistically significant effect of ECI and ECI2 on energy at a 95% confidence level. After the introduction of the control variables in regression (5), the same applies for GDP and GDP2. With the introduction of GDP as a linear term in the sixth specification, the variable gets significant and is correlated with an increase in energy generation. Thus, there is no inverted U-shaped relationship for both interest variables ECI and GDP with energy supply. This result is confirmed in the last regression with the combined implementation of ECI and GDP. A 1% increase in ECI is associated with a -0.221% decrease in energy generation. While a 1% rise GDP, ceteris paribus, increases energy by 0.298%. Consequently, the effect of both variables is similarly strong but in the opposite direction. Additionally, the reducing effect of ECI is more pronounced in the case of energy compared to GHG.

Looking at the control variables, it becomes apparent that education has the strongest effect on energy generation and is negatively correlated. Apart from that, financial development and trade have an increasing effect on energy.

6.4 Results of Sampling Check

In a final step, the same specifications as before were carried out for the two complexity groups (see division in Chapter 5.2) and presented in Table 6. As the variable *pop* had a high correlation with the other variables and high VIF value (25.48) for the high complexity group, it is taken out for the regressions concerning that group.

Specifications (1) and (3) depict the results for the high complexity group. Interestingly, there is no non-linear relation found for high complexity countries, as the GDP2 becomes insignificant. While there is no significant effect of ECI on GHG, the results suggest that a 1% increase in ECI is correlated with a -0.352 decline in energy generation.

For the country group with low complexity (specification (2) and (4)), the ECI turns insignificant for energy at a 95% confidence level, and only negative correlation between economic complexity and GHG can be confirmed (-0.0839). This overall decreased significance of ECI may be partially explained by the fact that the already small effect was cancelled out by the smaller sample size. In the case of the country group with low complexity, an inverted U-shaped relation between GDP and the dependent variables energy and GHG is confirmed. Besides, the effect of *renew* and *edu* remains negative for the two sub-panels as well.

Table 5 Fixed effects regression for energy generation

	(1) ln_ energy	(2) ln_ energy	(3) ln_ energy	(4) ln_ energy	(5) ln_ energy	(6) ln_ energy	(7) ln_ energy
ln_ECI	-0.126	-0.124	-0.251***				-0.221***
	(-1.04)	(-1.44)	(-4.50)				(-4.16)
ln_ECI2	0.228	-0.190					
	(1.76)	(-1.92)					
ln_GDP				1.608**	0.658	0.350***	0.298***
				(3.19)	(1.11)	(7.39)	(6.28)
ln_GDP2				-0.0680*	-0.0171		
				(-2.37)	(-0.52)		
ln_pop		0.654***	0.607***		0.306	0.339*	0.386*
		(3.88)	(3.62)		(1.77)	(2.10)	(2.37)
ln_trade		0.106**	0.102**		0.0981**	0.102**	0.101**
		(2.96)	(2.83)		(2.96)	(3.13)	(2.98)
ln_urban		0.106	0.117		-0.130	-0.114	0.140
		(0.52)	(0.57)		(-0.68)	(-0.60)	(0.73)
ln_edu		-0.646***	-0.625***		-0.685***	-0.701***	-0.700***
		(-4.63)	(-4.47)		(-5.14)	(-5.42)	(-5.27)
ln_finance		0.325***	0.337***		0.239***	0.244***	0.257***
		(7.19)	(7.47)		(5.52)	(5.78)	(5.77)
ln_agri		-0.121***	-0.107**		-0.130***	-0.127***	-0.110***
		(-3.44)	(-3.10)		(-3.88)	(-3.86)	(-3.38)
ln_manu		-0.223***	-0.219***		-0.0257	-0.0180	-0.0755
		(-4.26)	(-4.17)		(-0.48)	(-0.35)	(-1.38)
_cons	3.684***	-6.848**	-6.103*	-5.111*	-5.266	-4.528	-5.686*
	(98.47)	(-2.64)	(-2.37)	(-2.31)	(-1.90)	(-1.90)	(-2.33)
R-squared							
Within	0.0102	0.5499	0.5449	0.3719	0.5694	0.5690	0.5934
Between	0.2564	0.1278	0.1330	0.6089	0.3995	0.3749	0.3087
Overall	0.2231	0.1266	0.1334	0.5942	0.4069	0.3816	0.3062
N	378	357	357	395	374	374	357

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6 Fixed effects regression for sampling check

	(1) ln_GHG	(2) ln_GHG	(3) ln_energy	(4) ln_energy
ln_ECI	0.0923	-0.0839*	-0.352**	0.0292
	(1.56)	(-2.17)	(-2.90)	(0.56)
ln_GDP	0.263***	3.064***	0.699***	4.806***
	(7.73)	(4.82)	(9.98)	(6.00)
ln_GDP2		-0.160***		-0.254***
		(-4.50)		(-5.66)
ln_trade	0.117***	-0.0380	-0.0183	-0.0464
	(4.35)	(-1.15)	(-0.33)	(-1.08)
ln_urban	0.291**	-0.649***	0.684**	-2.257***
	(2.78)	(-3.83)	(3.17)	(-8.56)
ln_edu	-0.385***	-0.427***	-0.478**	-1.282***
	(-4.54)	(-3.39)	(-2.76)	(-8.17)
ln_finance	-0.0199	-0.0379	0.230***	0.0615
	(-0.62)	(-1.01)	(3.48)	(1.28)
ln_agri	0.00645	-0.134***	0.173**	-0.259***
	(0.25)	(-3.80)	(3.22)	(-5.59)
ln_manu	-0.115**	-0.0879*	-0.125	-0.0867
	(-2.89)	(-2.05)	(-1.54)	(-1.60)
ln_renew	-0.151***	-0.131***		
	(-6.27)	(-5.37)		
ln_pop		0.450**		1.586***
		(3.02)		(7.55)
_cons	-2.547***	-17.40***	-5.041***	-34.75***
	(-4.19)	(-6.63)	(-4.03)	(-9.99)
R-squared				
Within	0.7742	0.6437	0.7874	0.7367
Between	0.1812	0.0594	0.2536	0.0823
Overall	0.1932	0.0516	0.3436	0.0632
N	147	229	147	210

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

7 Discussion and Implications

This chapter discusses the results of the econometric analysis with the help of the previously elaborated literature. The results are compared to previous studies and the possible underlying mechanisms of the findings are explored. The implications of the results for the EKC hypothesis are derived and, together with the limitations, the relevance for policymakers is determined.

The first research question refers to the general correlations between the interest variables. With the help of correlations and visual inspections, it became apparent that ECI is positively correlated with energy and GHG. Although causality cannot be proven in this way, this observation suggests that countries with higher economic complexity tend to have a higher energy supply and higher GHG emissions. If the relationship between economic complexity and pollution is described by the EKC hypothesis in the form of an inverted U, as proposed by Swart and Brinkmann (2020) and Romero and Gramkow (2021), Latin America and the Caribbean would not have reached the turning point yet. This hypothesis would mean that LAC has not achieved the threshold ECI value required to possess the human capabilities and technology to limit environmental degradation (Swart & Brinkmann 2020).

Further, the concept of economic complexity is closely linked to the process of structural change. Another possible explanation for the increasing environmental degradation is that LAC countries are at an early stage of development, undergoing the transition from agriculture to industry, and have not yet established knowledge- and skill-based production structures that would be associated with lower emissions intensity (Romero & Gramkow 2021). Thereby, new production technologies can have a greater environmental impact than the ones they replace, and industrialisation and urbanisation processes are accompanied by increasing emissions and energy usage (Boleti et al. 2021; York et al. 2003).

However, other studies suggest a linear relationship between economic complexity and environmental degradation (Doğan et al. 2021; Romero & Gramkow 2021). The visual inspection and correlations give the impression that GHG emissions and energy supply increase with ECI, however, its effect will be isolated and identified in the FE regression.

Within the sample, economic complexity and the share of renewable energies are not correlated with each other (0.046). Several authors suggest the conservation hypothesis to describe the relation between the two variables, meaning a unidirectional causality running from ECI to renewable energy consumption. Neagu and Teodoru (2019) and Doğan et al. (2021) argue that economic complexity can drive green growth, enhancing energy technology innovations and the expansion of renewable energies. Furthermore, Mealy and Teytelboym (2020) found that countries with higher economic complexity tend to have higher environmental patenting rates, lower CO2 emissions and more stringent environmental policies. These considerations in the literature cannot be observed as a general trend in LAC. This may be attributed to the fact that more sophisticated renewable energy technologies other than hydro still account for a small fraction of the energy matrix, and the exploitation of wind and solar energy is a very recent development in rather few countries of LAC. In addition, economic sophistication remains rather low in the region, which may undermine the effect of ECI driving renewable energy technologies.

Furthermore, the transition to RES are also discussed in the context of the growth hypothesis, which signifies a causality in the other direction and states that the use of renewable energies would lead to economic development. Adom et al. (2021) measured a positive effect of renewables for human capital and employment in developing countries and Singh et al. (2019) for economic growth. As economic complexity is closely related to other outcomes of development, one may have also suspected a link between renewables and ECI. In the context of LAC, there may be no linkages between the two variables, as spill over effects of RES largely depends on whether the technology is imported or manufactured locally, as Simas and Pacca (2014) conclude for the job creation effects of wind energy development in Brazil.

In summary, although the literature suggests a relation between the two variables, no correlation between RES and economic complexity is visible from the observation across the panel. However, this does not exclude the possibility of a relation, which may be found when focusing on single countries or regions with a high share of renewables or with more advanced econometric methods.

The second research question focuses on the effect of economic complexity on GHG emissions and energy generation. With the help of FE regressions, the EKC hypothesis was tested and the association between various indicators was observed. For the whole sample, economic complexity is associated with a decrease of GHG emissions and energy supply. Thus, the ECI does not take an inverted U-shaped relation to environmental pollution as proposed by Swart and Brinkmann (2020) and Pata (2021). However, it was found that, all other things being equal, higher economic complexity is associated with a lower emission and energy intensity of a country's economy, which could also indicate that the turning point of the complexity EKC happened previously to the investigated time period.

The mitigating effect of the ECI can be attributed to the capacity of countries with high economic complexity to export green and renewable energy products (Mealy & Teytelboym 2020) and increasing economic efficiency due to the production of more complex goods (Romero & Gramkow 2021). Thus, more economic value is obtained per unit of pollution emitted. However, the results for the index of economic complexity are more ambiguous in the case of the two sub-samples, taking a positive and unsignificant value for two specifications. Hence, the findings for the regional context of LAC are less conclusive than other studies (Romero & Gramkow 2021; Doğan et al. 2021) and the mitigating effect is rather small. This result may be attributed to the economic structure of LAC, as many countries are mainly natural resource exporters. This resource dependency can lead to higher GHG emissions and to a higher GDP than the level of ECI would suggest. This specificity of LAC economies may also explain the rather weak correlation between GHG and ECI found in the visual inspection.

Nevertheless, the empirical results show that more complex economic systems, that are accompanied by technological innovation, can promote sustainable economic development. Since increasing economic complexity leads to a rise of green production capabilities (Mealy & Teytelboym 2020), this study suggests economic complexity to be an important policy factor to promote climate change mitigation and economic growth.

Even though the ECI has been shown to be associated with GHG emissions and energy supply, this does not mean that GDP does not need to be considered when testing the EKC hypothesis. The increasing R squared, when including GDP, indicates that economic output is an important factor, impacting the environmental performance of a country. This finding implies that models only including economic complexity are missing an important explanatory factor.

The results of the FE regressions suggest the presence of an EKC for GDP and GHG emissions. This finding is in line with previous studies of Al-mulali et al. (2015) and Apergis and Payne (2009). With the help of the formula provided by Stern (2004), the level GDP marking the turning point could be calculated. For the whole sample, GDP per capita is assumed to have a GHG emission reduction effect when the threshold of 34,574.98 USD is reached. This value is far above the maximum GDP per capita of the panel, indicating that no mitigating effect is expected for LAC. Interestingly, in the sub-panel analysis, the squared term of GDP was only significant for the country group with lower economic complexity, which are the countries that are on average even further away from the threshold. The calculated turning points for the group with low complexity are 14,400.24 USD for GHG emissions and 12,843.97 USD for energy generation. Within the group of countries with low ECI only Chile is within this range of GDP. The large differences in calculated turning points reflect the common critics on EKC of being very sensitive on the chosen sample (Stern & Common 2001).

Consequently, the results imply that in Latin-American countries environmental pressure increases with economic activity and LAC cannot improve environmental performance by the pure expansion of economic activity.

Regardless of the specification and sample, the share of renewable electricity is associated with lower GHG emissions. The empirical results indicate that an increase of 1% in renewable electricity generation leads to a 0.141% GHG emissions reduction. Those findings contradict with Al-mulali et al. (2015), who found no long-term effect of renewable energy consumption on CO2 in LAC, applying Granger causality tests. However, besides using slightly different measures and methods, their analysis only refers to data until 2010, which could be the reason for the different results. Moreover, it became apparent in the visual inspection, that there is no general GHG reducing effect of RES visible. An increasing share of renewables is correlated with declining GHG emissions within countries, but it cannot explain differences between countries (see Figure 9). One reason is the large share of agriculture and land-use change in the overall emissions in LAC, and electricity only accounts for 13 per cent of GHG emissions (Climate Watch 2021). Thus, a low-carbon electricity supply seems not to have the influence of absolute decoupling. Furthermore, other sectors, such as transport, are lagging behind in the energy transition, and the total amount of GHG and other climate pollutants from this sector has steadily increased in the region since the 1970s (Martínez Salgado & Castellanos 2019). The lack of energy transition in sectors other than electricity generation could be the reason for the only relative decoupling effect of *renew*.

Another striking factor is the mitigating effect of education on emissions and energy supply. The results indicate that a 1% improvement in the education index is associated with a 0.467% reduction in greenhouse gas emissions and a 0.700% reduction in energy provision. Thus, this study suggests that renewable energy and education are crucial policy factors that can shape a country's sustainable development and energy structure.

Coming back to the four hypotheses concerning the energy-growth nexus, an effect of economic complexity and GDP on energy was measured with the help of FE, proposing a causal relationship. However, a possible bi-directional interdependency could not be measured with the FE model, which is a limitation of the study. Similarly, a possible causality running from energy to economic complexity could not be measured. With dynamic regression models, solving the problem of endogeneity, future research may measure this relationship. Furthermore, one cannot draw conclusions on other samples with the FE results, as the results are conditional on the country fixed effects (Stern 2004). Thus, the study has limited implications for individual country experiences.

In spite of these limitations, the conducted study still has important policy implications for the region. Economic complexity has been shown to be an important factor for sustainable development and has been found to mitigate environmental damage in LAC. Thus, when Latin-American countries move towards more complex production structures, it can have a reducing effect on GHG emissions and energy supply. An opposite effect was observed for GDP, suggesting a trade-off for policy makers in LAC between economic growth and environmental protection. Besides, clean energy sources contribute to the mitigation of emissions in LAC, making the promotion of RES crucial for achieving green growth. As the parameters of renewable electricity generation, economic complexity, and the education index have been found to mitigate emissions, synergies may emerge with governmental R&D and education programmes to advance human capital, awareness, and innovations.

8 Conclusion

The threats of global warming and increasing environmental pollution require urgent transformations of economic structures, leading to environmentally sustainable low-carbon economies. Latin America and the Caribbean stand out with a large share of clean energy production, with advantageous factor endowments and, since around 2010, strongly growing investments in renewable energy technologies. At the same time, the economic structure of the region is characterised by a low level of sophistication, premature deindustrialisation, and unsustainable resource exploitation. These circumstances make LAC a particularly interesting region to look at the linkages between economic complexity, GHG emissions and the renewable energy transition.

The growing concerns of the climate crisis have considerably risen the attention of economists on the environmental effects of economic growth. The literature review reveals that there is an increasing number of studies that combine the interrelations of energy, economic growth, and environmental pollution. Furthermore, within the large body of literature testing the Environmental Kuznets Curve, recent studies include various indicators of the economy to overcome an omitted variable bias. The main contribution of this study is to look at scarcely investigated impact of economic complexity, and its effect in combination with other interest variables.

For a panel of 20 Latin American and Caribbean countries, GHG emissions and energy supply were chosen as indicators of environmental stress, and their relationship with economic development was investigated by testing the validity of the EKC hypothesis. It was found that economic complexity and renewable energies have a GHG emission reducing effect. Furthermore, the countries' GDP is an important determining factor for environmental pollution in LAC. A rising economic activity is associated with increasing energy supply as well as GHG emissions. For GHG emissions the relation was found to be an inverted U-curve, with the threshold above the income-levels of the panel. Thus, income only appears to have a reducing effect at very high levels of income, and emissions rise together with economic growth in LAC. Consequently, the simultaneous achievement of economic growth and environmental sustainability requires policy intervention.

The emission-reducing effect of economic complexity, which points to a more efficient consumption of energy and materials, should be emphasised. Economic complexity can enhance capabilities for low-carbon products and energy technology innovations (Mealy & Teytelboym 2020). Nevertheless, the inconclusive results of the two sub-groups suggest that also national characteristics play a role in the effect of economic complexity. In this context, the resource dependency of many LAC countries has to be considered, as it strongly impacts national environmental pollution and economic output. Thus, regional economic structures, energy systems, and infrastructure must be taken into account for the efficient promotion of green growth.

Besides, the share of renewables was found to be negatively associated with GHG emissions at a 1% significance level in all specifications. This finding implies that the transition to RES sources is an important mitigating factor for sustainable development in LAC. Although a relation between RES and economic complexity is proposed in the literature, no correlation could be observed for the region. Given the emission reducing effect of both variables, their interaction should, however, be further investigated.

Particularly interesting questions beyond the scope of this thesis are the opportunities for job creation in more complex sectors in the context of the transition to renewable energy and how the promotion of economic complexity potentially fosters clean energy innovation. At the moment, LAC is a region with rather low economic complexity and high dependence on resource exports. Further research is needed to understand how the region can foster the transition to more complex economies and more should be found out about its role in sustainable development.

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Annex A

Table 7 Within and between variances

Variable		Mean	Std. dev.	Min	Max	Observations	
GHG	Overall	4.569619	2.35368	1.71	11.63	N=	420
	Between		2.383303	1.908571	10.64095	n=	20
	Within		.3616675	3.528667	5.607238	T=	21
energy	Overall	44.05589	20.92852	18	112.2	N=	399
	Between		20.62191	22.54286	96.44286	n=	19
	Within		5.840358	6.613033	60.55589	T=	21
ECI	Overall	-.2028033	.5207639	-1.284718	1.203621	N=	399
	Between		.5137765	-1.091519	.9265479	n=	20
	Within		.1619814	-.8748768	.2779135	T-bar=	19.95
GDP	Overall	6537.565	3652.894	1338.681	16074.69	N=	416
	Between		3415.836	1711.712	12423.69	n=	20
	Within		1482.729	1452.568	13310.73	T=	20.8
renew	Overall	.5232745	.2898863	.0285086	.9999919	N=	418
	Between		.2873583	.0461112	.9999543	n=	20
	Within		.0711264	.2754744	.7455663	T-bar=	20.9
urban	Overall	70.58252	13.64984	44.447	95.334	N=	420
	Between		13.66162	47.81943	93.77014	n=	20
	Within		2.930386	58.9509	81.0269	T=	21
trade	Overall	64.40024	28.36706	16.43858	166.6981	N=	416
	Between		26.87555	25.10447	129.5899	n=	20
	Within		10.59805	22.21877	101.5085	T=	20.8
edu	Overall	.6236167	.0995981	.339	.842	N=	420
	Between		.0903539	.4267143	.7898095	n=	20
	Within		.046321	.48495	.71795	T=	21
pop	Overall	2.79e+07	4.47e+07	2608874	2.09e+08	N=	420
	Between		4.57e+07	2781140	1.91e+08	n=	20
	Within		3620028	6521405	4.62e+07	T=	21

finance	Overall	.2501697	.1227281	.061636	.6332957	N=	399
	Between		.1180397	.1156021	.5421913	n=	19
	Within		.0427664	.0683335	.3683423	T=	21
agri	Overall	7.883486	3.957016	2.248462	23.4399	N=	416
	Between		3.675462	3.302827	16.55462	n=	20
	Within		1.668013	4.220707	18.2054	T=	20.8
manu	Overall	14.51882	3.373966	5.877236	22.48675	N=	416
	Between		2.865949	8.018959	18.31087	n=	20
	Within		1.867345	10.84809	21.47051	T=	20.8

Note:

N denotes the number of observations, n the number of countries, and T the number of years. The within standard deviation depicts the within-unit variation and is typically smaller than the cross-sectional variation, as the heterogeneity normally is larger between countries than within a country between years. The between standard deviation provides information on how much the countries differ from each other.

Looking at the interest variables, it becomes apparent that the countries differ more from each other than they variate over time. This observation is also reflected in the choice for country fixed effects. Nevertheless, all variables are time-variant as well, meaning that they potentially can have statistically significant explanatory power in the FE model.

Annex B

Figure 11 Scatter plot of the variables ln_ECI and ln_GHG for 1998

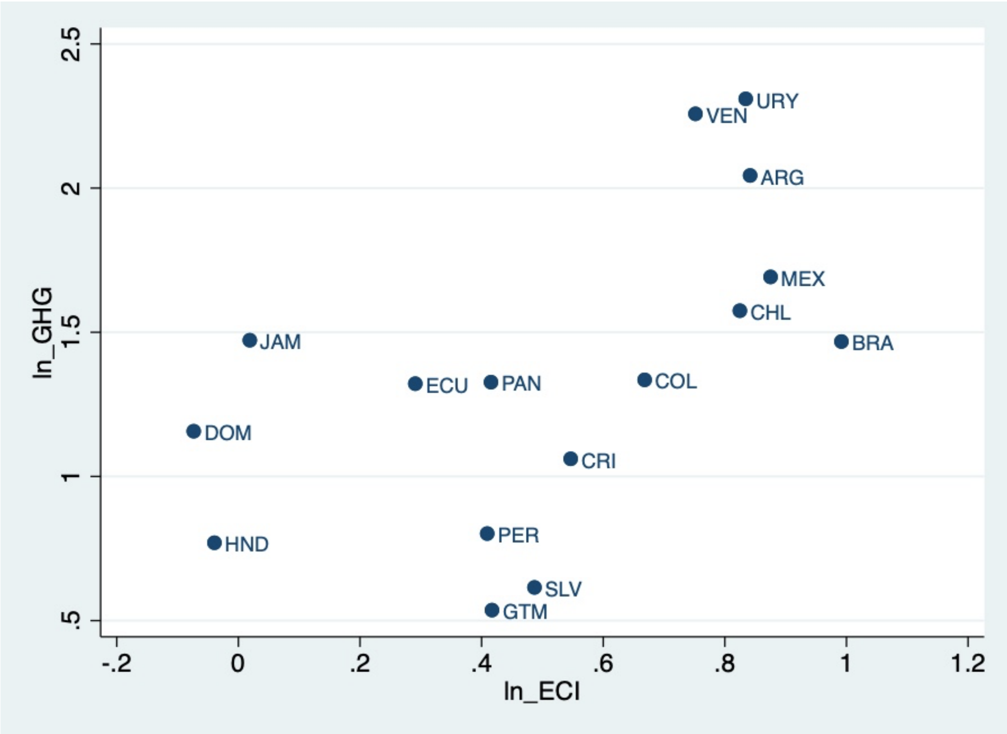

Figure 12 Scatter plot of the variables ln_ECI and ln_GHG for 2008

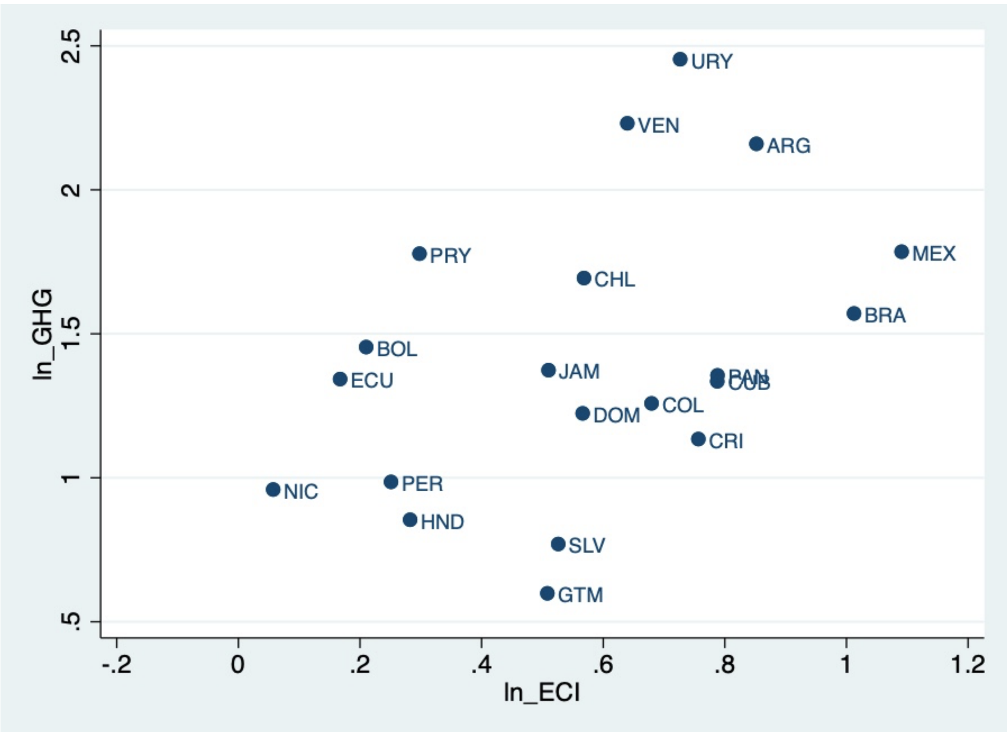

Table 8 Country codes

COUNTRY	COUNTRY CODE (WORLD BANK 2022B)
ARGENTINA	ARG
BOLIVIA	BOL
BRAZIL	BRA
CHILE	CHL
COLOMBIA	COL
COSTA RICA	CRI
CUBA	CUB
DOMINICAN REPUBLIC	DOM
ECUADOR	ECU
EL SALVADOR	SLV
GUATEMALA	GTM
HONDURAS	HND
JAMAICA	JAM
MEXICO	MEX
NICARAGUA	NIC
PANAMA	PAN
PARAGUAY	PRY
PERU	PER
URUGUAY	URY
VENEZUELA	VEN

Annex C

Table 9 Fixed effects regression of GHG emissions with stepwise introduction of variables

	(1) ln_GHG	(2) ln_GHG	(3) ln_GHG	(4) ln_GHG	(5) ln_GHG	(6) ln_GHG	(7) ln_GHG	(8) ln_GHG	(9) ln_GHG	(10) ln_GHG	(11) ln_GHG
ln_GDP	1.841***	1.86035***	1.736***	1.429***	1.733***	1.993***	2.093***	1.887***	1.834***	2.003***	1.298***
ln_GDP2	-0.0885***	-0.0889**	-0.0835***	-0.0678**	-0.0817***	-0.0958***	-0.0986***	-0.0903***	-0.0894***	-0.0996***	-0.0621**
ln_ECI		-0.1092***	-0.0512	-0.129***	-0.0899**	-0.0982**	-0.0950**	-0.109**	-0.134***	-0.134***	-0.0859**
ln_renew			-0.178***								-0.141***
ln_pop				0.175*							0.520***
ln_trade					0.0625**						0.0626**
ln_urban						-0.0827					-0.171
ln_edu							-0.211**				-0.467***
ln_finance								-0.00433			-0.00831
ln_agri									-0.0689***		-0.0450*
ln_manu										-0.0951**	-0.0795*
_cons	-7.857***	-7.9385	-7.443***	-8.664***	-7.650***	-8.229***	-9.338***	-8.074***	-7.526***	-8.106***	-13.23***
R^2 (Within)	0.4252	0.4425	0.5610	0.4515	0.4549	0.4435	0.4586	0.4425	0.4613	0.4536	0.6350
N	376	376	376	376	376	376	376	376	376	376	376

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Only observations without missing variables are included for a constant number of observations and improved comparability.