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Lenin H. Balza
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Does Income Growth in Latin America and the Caribbean Drive Disproportionate Energy Consumption?*

Lenin H. Balza† Sofia Castro Vargas‡ Nicolas Gomez-Parra§

Raul Jimenez Mori¶ Osmel Manzano‖ Tomas Serebrisky**

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Abstract

We examine the relationship between energy consumption and economic growth in Latin America and the Caribbean using panel data from 1971 to 2019. Employing both parametric and non-parametric methods, we find a robust positive correlation between Latin America and the Caribbean's economic activity and energy consumption. Specifically, a 1% increase in income is associated with a 0.4% increase in total energy use in the short term, rising to a 0.9% in the long term. Further analysis highlights that Latin America and the Caribbean countries consistently display higher income elasticities compared to other global regions and this relationship exhibits discernible non-linearities. A temporal breakdown indicates an increased correlation in Latin America and the Caribbean post-1991 confirming the non-linear, region-specific, and temporally evolving characteristics of the income-energy relationship. Our results are robust to multiple methodological approaches and to variations in how income and consumption are measured. These findings hold significant implications for energy policy in the region, especially in the context of climate change mitigation efforts.

Keywords: Energy consumption; economic development; Latin America and the Caribbean; panel data analysis.

JEL classification: Q40, Q43, O13, O54.

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†Infrastructure and Energy Sector, Inter-American Development Bank (✉:leninb@iadb.org).

‡Inter-American Development Bank (✉:sofiacv@iadb.org).

§Infrastructure and Energy Sector, Inter-American Development Bank (✉:ngomezparra@iadb.org).

¶Development Effectiveness Division, IDB Invest (✉:rjimenez@iadb.org).

‖Country Department Andean Group, Inter-American Development Bank (✉:osmelm@iadb.org).

**Infrastructure and Energy Sector, Inter-American Development Bank (✉:tserebrisky@iadb.org).

1 Introduction

In the current era of global climate change, the relationship between economic growth and energy consumption emerges as both a puzzle and a problem. Climate change has set a demanding agenda for the transformation of energy systems, compelling economies, particularly in Latin America and the Caribbean (LAC), to align with the Paris Agreement and transition to sustainable energy sources. While the energy matrix composition in LAC is predominantly characterized by significant country differences, the reliance of some countries on conventional fossil fuels highlights the urgency of transformation. Yet, the intricate relationship between energy consumption and economic growth in the region remains underexplored and inconclusive. Understanding this is imperative, not only for energy policy design but also for realizing climate goals.

The energy-growth dynamic has profound implications due to notable elasticities, affecting environmental sustainability, economic development, and energy security. In LAC, the situation is more complex due to specific structural conditions and historical energy reliance. The region's energy matrix, characterized by its reliance on particular energy sources and the impacts of energy prices, presents a complex landscape that requires a customized analysis. Regional economies grapple with balancing the goals of energy transition and economic growth in the face of the challenges that climate change presents.

Set against this backdrop, enriched by a vast yet inconclusive literature, and heightened by LAC's unique structural and historical complexities, this paper examines the relationship between energy consumption and economic growth in LAC. The paper is guided by a research question of substantive empirical weight: What are the short- and long-run relationships between energy consumption and economic growth in LAC? And, how do these relationships differ from global patterns? Specifically, does an increase in energy consumption precede economic growth or does this link run in the opposite direction? Furthermore, are these relationships stable over time or influenced by exogenous variables, such as energy prices, technological changes, or policy interventions? The research question builds upon existing frameworks but extends them by employing a range of methodological approaches, thereby providing a robust examination tailored to the region's idiosyncrasies.

In particular, when addressing these intricate research questions, this study employs an econometric analysis grounded in robust methodological rigor. In contrast to preceding works that often confine their inquiry to isolated methodologies or geographies, we utilize a comprehensive panel data set from 1971 to 2019 across 140 countries. Our empirical framework incorporates multiple specifications, covering parametric and non-parametric models that address both short-term dynamics and long-term equilibrium relationships. These specifications are selected to disentangle the heterogeneities inherent in LAC's energy landscape: varied energy sources, diverse economic structures, and disparate stages of development.

Central to our models is the estimation of the income and price elasticities of energy demand, providing insights into the responsiveness of energy consumption to fluctuations in economic indicators. This analytical framework allows us to explore both contemporaneous and lagged effects, thereby accounting for potential endogeneity and omitted variable biases that have historically confounded causal interpretations in the existing literature. Thus, our method seeks to synthesize the vast empirical complexities into a cohesive analysis, aimed at unveiling the short-run and long-run relationships between energy demand and economic growth in LAC by employing a multi-methodological approach.

We find a robust positive correlation between economic activity and energy demand, with high heterogeneity based on variations across diverse income groups and geographical regions. Using ordinary least squares (OLS) regressions with delta method standard error corrections, we find strong positive correlations between income and the total energy supply (TES) per capita. [1] Our study segments results into different dimensions: short- and long-term linear elasticities, non-linear elasticities, and their temporal trajectories. Parametric OLS estimates indicate that a 1% rise in income corresponds to at least a 0.4% increase in TES in the short term, which rises to 0.9% in the long term. Additionally, stratification shows that countries in LAC consistently display higher elasticities compared to other global regions. For instance, long-term income elasticity in the region measures at 0.9%, while it is capped at 0.7% outside the LAC region. High-income countries (HICs) generally display larger elasticity magnitudes than middle-income countries (MICs), reinforcing the hypothesis of non-linearity in the income-TES relationship. Moreover, temporal analysis post-1991 indicates an increase in estimated elasticities in LAC and low-income countries (LICs), while HICs and MICs show a downward trend post-1991.

Expanding these results, we use a non-parametric methodology employing Kernel-Based Regularized Least Squares (KRLS) to further examine the elasticity estimates. This method relaxes assumptions about the functional form of the relationship between income and TES, enabling us to calculate pointwise marginal effects along the income distribution. The findings confirm those from the parametric approach: LAC countries display the highest elasticities. Additionally, elasticity magnitudes display heterogeneity across income levels within regions. Specifically, in the LAC region, a 1% rise in income at the 25th percentile increases TES by 0.6%, whereas at the 75th percentile, the effect is larger, registering a 0.9% increase. An analysis of pointwise derivatives confirms countries' income levels influence these estimates, offering further support for the non-linear relationship hypothesis. For HICs, higher income levels correspond to lower estimated elasticities, whereas the opposite pattern is evident for the LAC region, corroborating earlier findings.

Temporal analysis using the non-parametric model confirms observations from the parametric model, highlighting specific distinctions in the evolution of estimated elasticities over time. The LAC region consistently shows higher estimated elasticities. Between 1971 and 1986, LAC, MICs, and HICs estimates elasticities are around 0.4%. By 1996–2005, LAC's estimated elasticity doubles to 0.8%, diverging noticeably from that of MICs and HICs. While the estimated elasticities of MICs and HICs remain stable, that of LICs exhibits a significant surge, reaching 0.9% during 2006–2019 from near-zero levels in the early study period. This temporal evolution reveals an increasing elasticity gap among regions, indicating a dynamic interplay between income and TES over time. Consequently, we confirm the non-linear, region-specific, and temporally evolving characteristics of the income-TES relationship, substantiated by evidence across both parametric and non-parametric methodologies. These results are also robust to variations in how income and price are measured throughout our empirical estimations.

[1] Throughout the paper, total energy supply (TES) reflects energy demand. TES measures the use of the total amount of primary energy available to domestic users in the economy.

In additional analyses, we introduce quantile regressions to assess elasticity variations along the energy supply distribution. This methodological refinement augments the understanding of income's impact on varied levels of energy consumption. The results show that MICs and HICs maintain stable elasticities across different energy supply quantiles. Conversely, LAC countries exhibit a monotonic decrease in elasticity as the energy supply rises, implying that higher energy-consuming nations within the LAC region have lower income elasticities. Furthermore, we incorporate an evaluation of the relevance of renewable energy shares in electricity generation on income elasticities. The results show that in the LAC region and for HICs, the differences in estimated elasticities between high and low renewable shares are statistically insignificant. For LICs, however, countries with a low renewable share display an estimated elasticity nearly five times larger than their high-renewable-share counterparts. These outcomes suggest a complex relationship between income elasticity and renewable energy shares relevant for economies transitioning to other energy sources.

Our results highlight how the study of the relationship between energy consumption and economic growth remains a critical research area, marked by layered and multifaceted findings. These insights align with the diverse findings found in the existing literature. The complexities stem from the particularities involved in analyzing varying methodologies, geographical contexts, economic structures, and energy sources. To fully understand this intricate relationship, we carried out a detailed examination of the literature. Beginning with foundational works, Kraft and Kraft (1978) initiated the empirical study of the link between income growth and energy consumption. This unidirectional interpretation since then has been expanded and diversified. Galli (1998), Judson et al. (1999) and Jimenez and Mercado (2014) significantly contribute to previous work by focusing on energy intensity in developing countries, discovering varied patterns across different economies and sectors. Subsequent research has found inconclusive results, however, with Payne (2010) providing an extensive survey that outlines four major hypotheses—growth, conservation, neutrality, and feedback—and reveals mixed outcomes across countries.[2] This study parallels the findings of Ozturk (2010), who conducts a comprehensive review of previous studies, arguing that conflicting results have produced no consensus on the existence or direction of change between these variables.[3] This finding opens the door to a broad spectrum of methodologies and analyses, with subsequent studies still reflecting both unidirectional and bidirectional links.

Other studies, such as Asafu-Adjaye (2000), Lee et al. (2008), Kahouli (2017) and Chiou-Wei et al. (2008) also have introduced both complexity and significant disagreements into the current literature.[4] This diversity is evident in the prevalence of different hypotheses, especially in regional and country-specific studies.[5] Similarly, innovative studies highlight

[2]Four hypotheses in energy economics: (a) "Growth" - energy consumption fosters economic growth, energy conservation may impede growth; (b) "Conservation" - energy conservation policies do not harm real GDP; (c) "Neutrality" - energy consumption's impact on economic growth is negligible; (d) "Feedback" - a bi-directional relationship exists between energy consumption and real GDP, with efficiency policies likely benign to economic growth.

[3]The author also recommends using more sophisticated methodologies and including new variables, classifying the relationship into the same four types tested by Payne (2010), each with unique policy implications.

[4]The discordance in the literature is further deepened by diverse studies such as Medlock III and Soligo (2001), Lee (2005), Lee and Chang (2007), and AlKhars et al. (2020).

[5]See Mutumba et al. (2021) for a meta-analysis about the dynamic causal relationship between energy consumption and economic growth.

different aspects such as pro-poor growth patterns, long-term relationships, and renewable energy interplays, with some showing counter-intuitive findings. For example, Costantini and Martini (2010) explore short and long-run relationships and find the results are hardly affected by the country sample. Fuchs et al. (2013) show that pro-poor growth patterns nearly double energy-income elasticity. In a meta-analysis by Bruns et al. (2014), the authors cannot find a direct effect, but do find a robust impact from output to energy use when controlling for energy prices. van Benthem (2015) provides counter-intuitive evidence that developing countries are not less energy-intensive at comparable developmental stages, challenging conventional wisdom and underscoring the need for nuanced policy design. Leitão and Balsalobre-Lorente (2020) find a clear link between electric power consumption, urban population, carbon dioxide emissions, and economic growth. Last, Ghoshray et al. (2018) find the neutrality hypothesis is not robust to all specifications and there is causality from energy consumption to growth. The authors suggest reducing energy consumption might have detrimental effects on economic growth.

Similarly, as the debate around renewable and non-renewable energy has gained further interest, it has led to a proliferation of research on the subject. Recent works, like Shahbaz et al. (2020), aim to re-examine the impact of renewable energy consumption on the economic growth of 38 countries. Their results confirm a long-term correlation and show that renewable energy consumption promotes growth in a majority of the countries studied. Destek and Aslan (2017) examine renewable and non-renewable energy consumption and its impact on economic growth, revealing mixed results across 17 emerging economies, showing the complexity of the relationship. Troster et al. (2018) analyze U.S. renewable energy, oil prices, and economic activity from 1989 to 2016. The analysis differentiates the results within quantiles of the distribution of changes in energy consumption or prices and shows a bi-directional link between renewable energy consumption and growth only at the lowest quantile, and unidirectional causality from energy consumption to growth at the highest tail of the distribution. Similarly, the fluctuations in oil prices lead economic growth at the extreme quantiles.

A noteworthy study by Alvarado et al. (2019) investigates the links between sustainable energy consumption, non-sustainable energy, and real per capita output in Latin America. The authors highlight the increasing use of renewable energy in Latin America, a region with significant potential for clean energy generation. They identify a strong equilibrium relationship between the growth rates of both renewable and non-renewable energy consumption and the growth of real per capita output. Notably, the connection between output and renewable energy proves more robust in medium-high and medium-low-income countries. In contrast, the relationship between output and non-renewable energy is more evident in high-income countries. Their research suggests high-income nations should seek alternative energy sources to ensure sustainable growth, while medium-high and medium-low-income countries should promote clean energy use that does not inhibit their economic expansion. Studies such as Pasten et al. (2015), Rodríguez-Caballero and Ventosa-Santaulària (2017), Damette and Seghir (2013), and Hasanov et al. (2017) have furthered the understanding of the energy-growth nexus in LAC using various econometric techniques to uncover long-term equilibrium correlations and growth hypotheses.

In light of this comprehensive review, our paper contributes to the literature by revisiting the relationship between energy demand and economic growth in LAC using a variety of methodological approaches. Through comparative analysis with other regions and a long battery of analyses, we uncover the high energy dependence in LAC. Our findings also provide new empirical insights that are essential for evaluating and designing effective energy policies, in particular, considering new relevant factors such as the composition of the energy matrix in the region. While our study builds upon existing frameworks, it extends them by employing a range of methodological approaches, thereby providing a thorough examination that considers the region's unique characteristics.

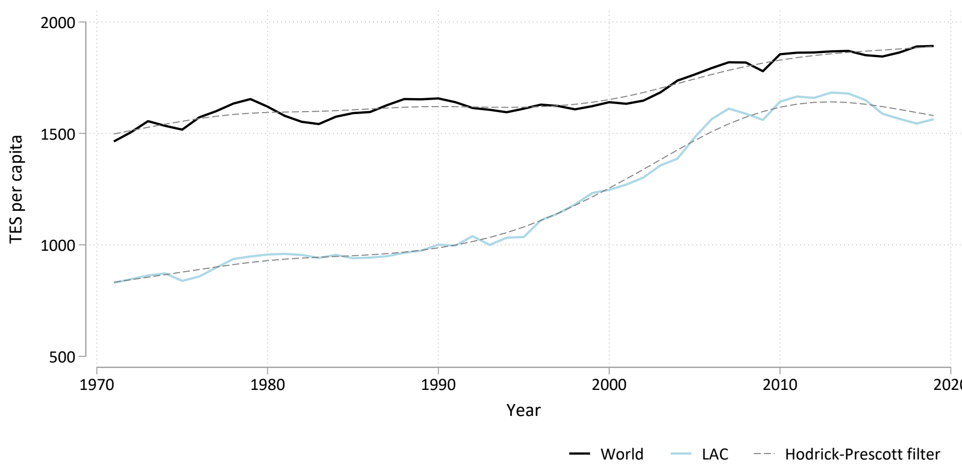
The paper proceeds as follows. Section 2 outlines an overview of the main stylized facts detailing the structural linkages between energy consumption and economic growth. Section 3 describes the data and the estimation framework. Section 4 discusses the main results, and Section 5 concludes.

2 Structural linkages between energy and growth

In this section, we summarize a set of basic patterns that demonstrate the link between energy and growth observed in our data.

Stylized Fact # 1: Rising energy use per capita. Figure 1 shows the sustained increase in energy consumption from 1971 to 2020 both globally and for the LAC region. Even when removing short-term fluctuations, it is clear the average person has been consuming more energy over time in the last 50 years.[6]

Figure 1: Evolution of TES per capita

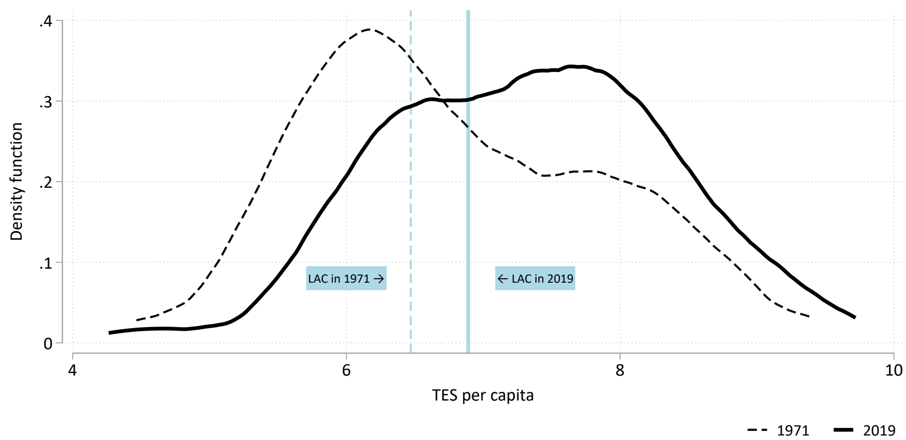


Notes: This figure shows statistics about the evolution of Total Energy Supply (TES) per capita * 1000 worldwide and in Latin America and the Caribbean (LAC) using data from the International Energy Agency (IEA) for the 1970–2019 period. Variable definitions are available in Appendix Table A1.

[6]Using the Hodrick-Prescott filter, data is divided into trend and cyclical components. The trend component reflects the long-term pattern in energy supply, smoothing short-term fluctuations. The cyclical component captures short-term deviations from this trend, often linked to economic cycles, seasonal variations, or temporary changes in energy supply.

This result, however, does not necessarily mean that energy use per capita has increased in all countries. To evaluate this, Figure 2 depicts the world distribution of TES for 1971 and 2019. Comparing the 1971 distribution to that of 2019 reveals that the distribution of energy use has shifted to the right, meaning that most countries worldwide have, in fact, increased their energy use, shifting the corresponding distribution. The vertical lines in the figure represent the median for energy use per capita in LAC, illustrating an increase in LAC's energy use over the study period.

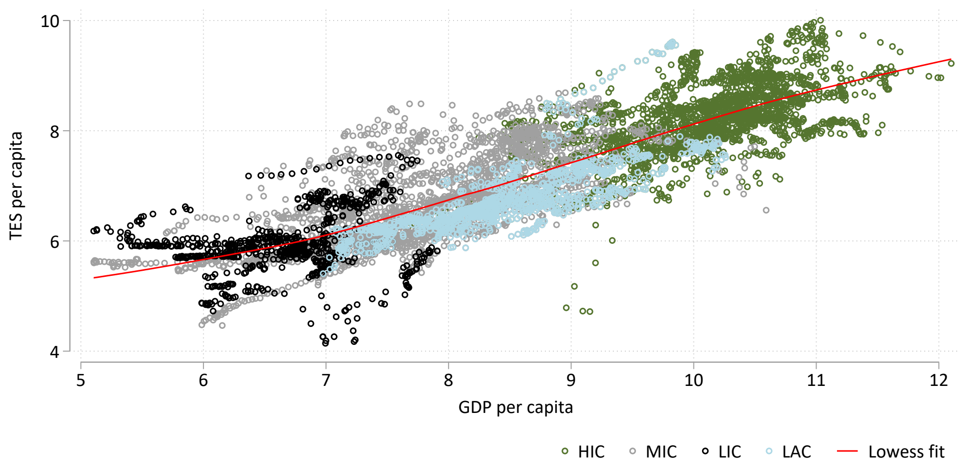
Figure 2: Distribution of TES per capita



Notes: This figure presents the world distribution of energy consumption for 1971 and 2019 using data from the International Energy Agency. The dashed vertical lines represent the median country in LAC's energy use distribution for both years.

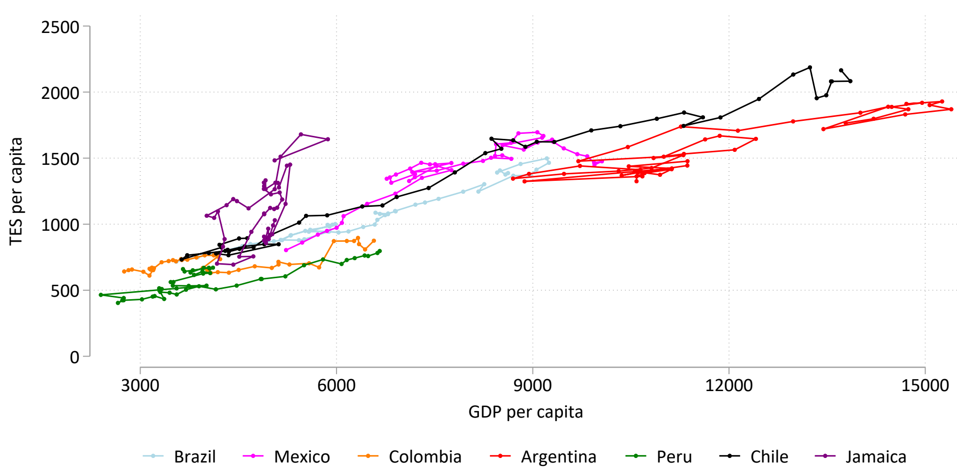
Stylized Fact # 2: Positive relationship between energy use and economic activity. Figure 3 illustrates the relationship between GDP per capita and energy use from 1971 to 2019 for all countries. Across the whole sample, a striking observation is the correlation between energy consumption and income per capita along the development path. HICs exhibit more energy consumption, whereas LAC countries show average consumption levels when compared to global consumption. Furthermore, the slope of the non-parametric best-fit curve, which connects energy consumption and economic activity (highlighted by the lowess fit), suggests a positive relationship between energy use and economic activity across different income levels. Furthermore, Figure 4 provides a contemporary snapshot of how the relationship between TES per capita and GDP per capita varies in several LAC countries, confirming that this relationship is also consistent within the LAC region.

Figure 3: TES and GDP per capita



Notes: This figure presents a scatter plot between GDP per capita (log) and TES (log) using country data from the World Development Indicators and the International Energy Agency for the 1971–2019 period. The red line represents the lowess fit of the data. Observations can be distinguished by region (LAC) and income level (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). Variable definitions are available in Appendix Table A1.

Figure 4: TES and GDP per capita in selected LAC countries

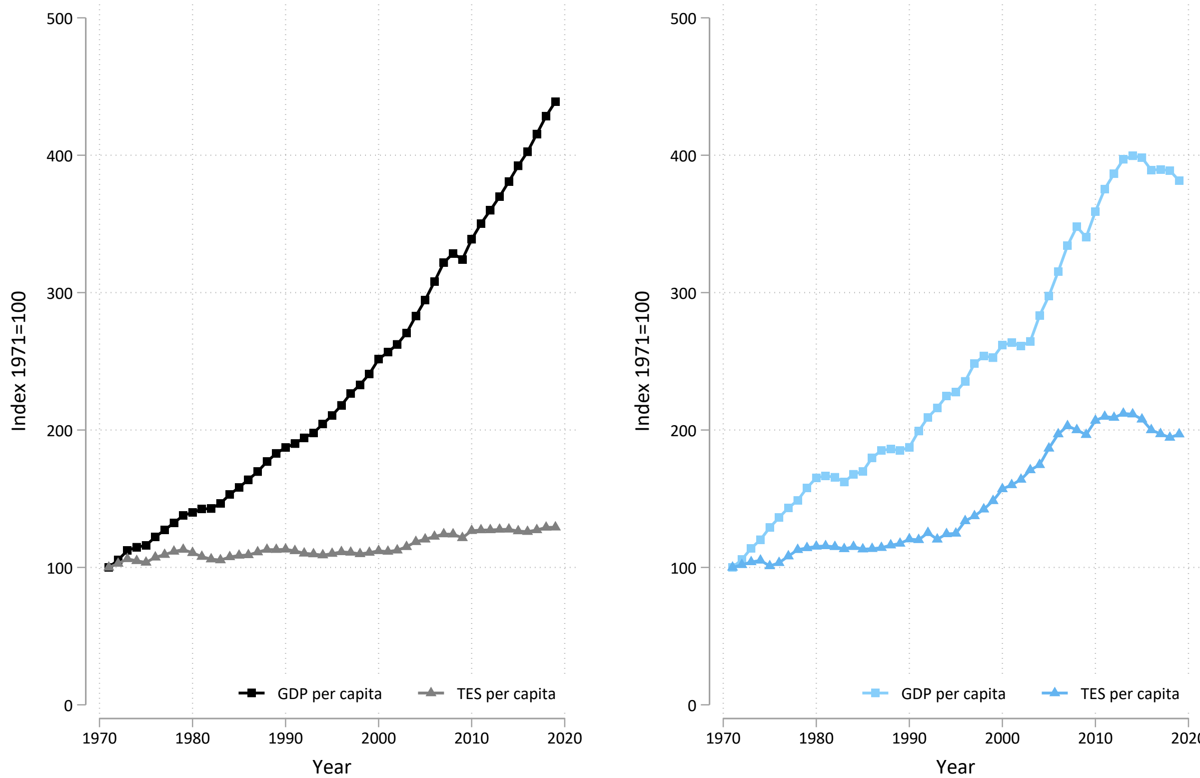


Notes: This figure presents connected scatter plots between GDP per capita and TES per capita *1000 in LAC using country data from the World Development Indicators and the International Energy Agency for the 1971–2019 period. Variable definitions are available in Appendix Table A1.

Stylized Fact # 3: Energy use and economic activity has been linked overtime. Figure 5 illustrates that energy use and income have grown closely connected over time. Much has been recently written about the decoupling between GDP and energy worldwide, a trend that can be observed in panel (a). However, panel (b) suggests this has not happened in LAC. In fact, energy use in this region has increased in tandem with the economy, and there appears to be very little, if any, decoupling between income and energy use in the region.

Figure 5: Energy use and GDP trend

(a) World (b) LAC



Notes: This figure presents a comparison between GDP per capita and energy use per capita, both normalized (i.e., 1971=100), for all countries (panel (a)) and in LAC (panel (b)) using country data from the World Development Indicators and the International Energy Agency for the 1971–2019 period. Variable definitions are available in Appendix Table A1.

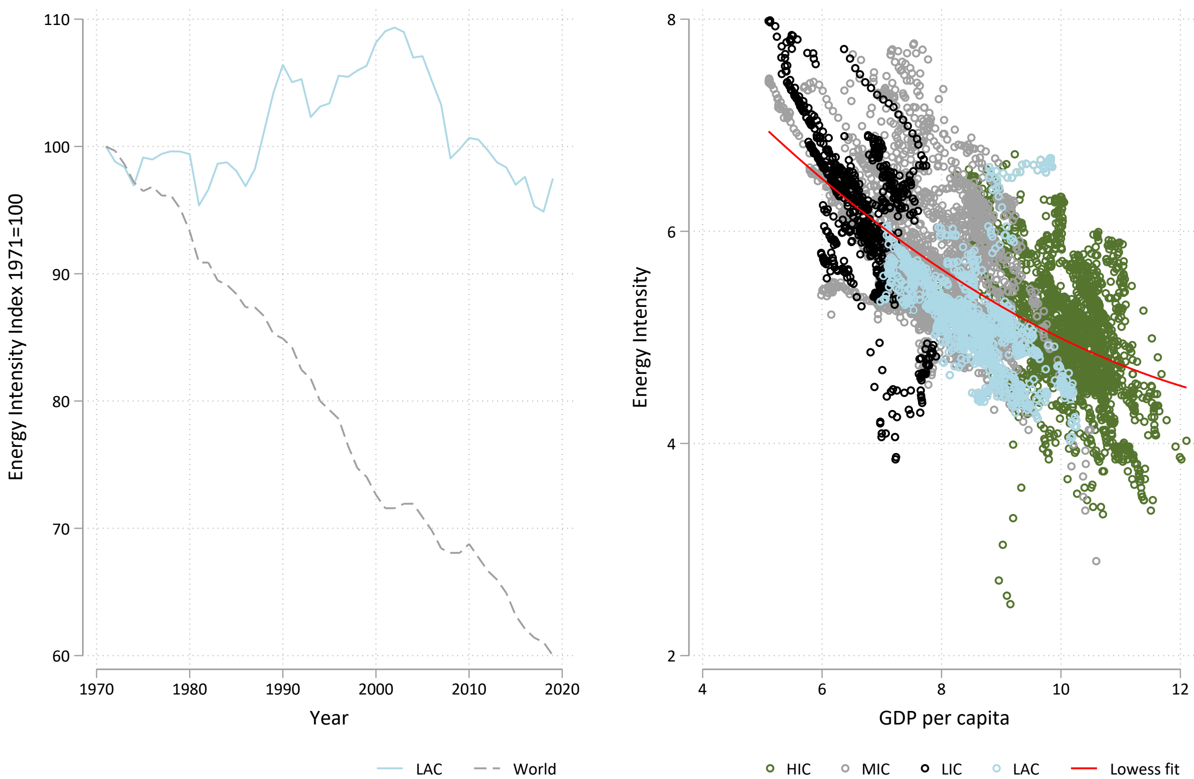
Stylized Fact # 4: Energy intensity has generally declined. In recent years, energy intensity has been in constant decline, suggesting that the world has become more efficient—achieving more with less energy. This implies an increase in energy consumption productivity. As depicted in panel (a) of Figure 6, energy intensity has been on a downward trend for the past 50 years both globally and within the LAC region, however, these aggregate figures may hide heterogeneity among individual countries. Panel (b) shows a decrease in energy intensity relative to GDP per capita.

For the LAC region, there has been a 17% decrease in energy intensity over the same time frame. [7] This decrease, however, has experienced considerable decade-to-decade variations, which does not seem to be the case for the world as a whole.

[7]This figure indicates that energy intensity is continuing its downward trend, as pointed out by Jimenez and Mercado (2014) and Balza et al. (2016)

Figure 6: Energy intensity

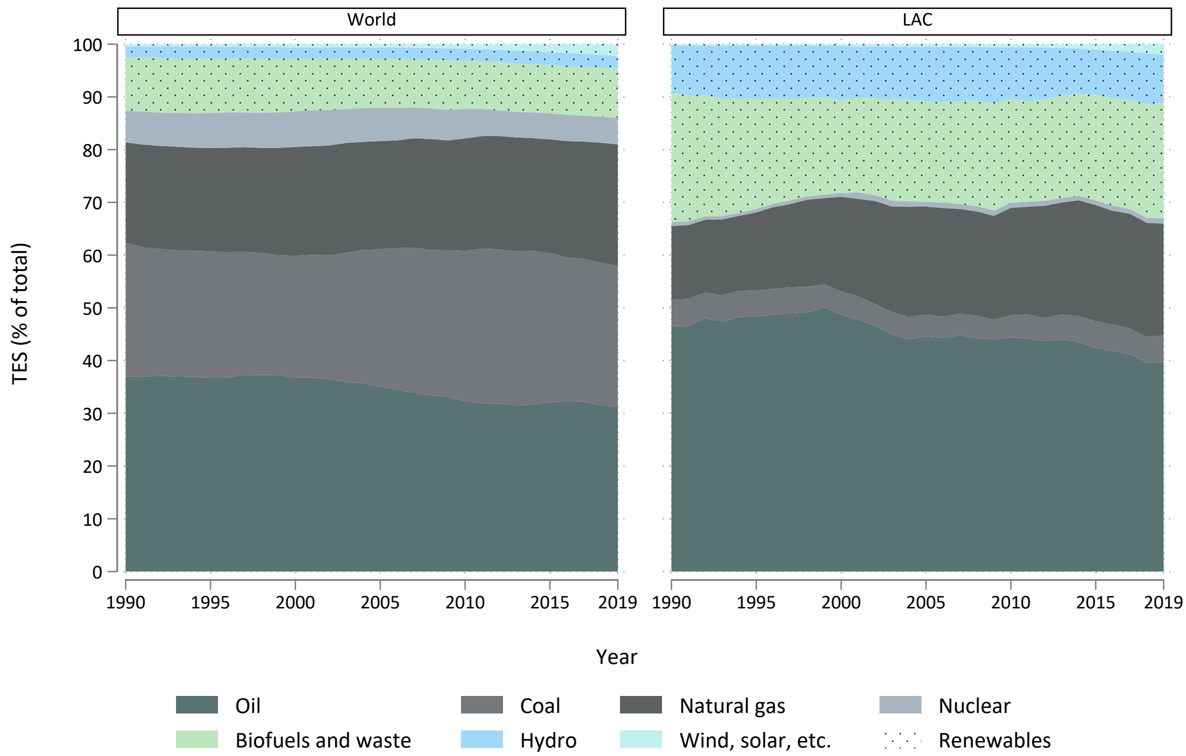
(a) Energy intensity over time | (b) GDP per capita and energy intensity



Notes: This figure illustrates statistics about GDP per capita (constant 2010 USD) and energy intensity (energy use per 1,000 USD of GDP) using country data from the World Development Indicators and the International Energy Agency for the 1971–2019 period. In panel (a), energy intensity is normalized (i.e., 1971=100) to compare long-term growth in all countries (world) against Latin America and the Caribbean (LAC). Panel (b) presents a scatter plot between GDP per capita (log) and energy intensity (log). The red line represents the lowess fit of the data. Observations can be distinguished by region (Latin America and the Caribbean (LAC)) and income level (Low-Income Countries (LICs), Middle-Income Countries (MICs), and High-Income Countries (HICs)). Variable definitions are available in Appendix Table A1.

Stylized Fact # 5: Not all energies are the same. Figure 7 contrasts the TES composition in the world versus LAC, segmented into renewable and non-renewable energy sources. While LAC demonstrates a slightly higher proportion of renewable energy compared to the global average, non-renewable sources continue to dominate the energy matrix. This persistent predominance of non-renewable energy underscores a critical challenge in shifting towards more sustainable energy practices. The data reflect a gradual yet inadequate transition pace, suggesting the need for accelerated policy efforts and infrastructure investments to enhance the renewable energy share. The entrenched reliance on non-renewable sources is a critical factor when considering the nexus between energy and growth for country and regional analyses. This is particularly pertinent for LAC, where the energy transition could leverage its renewable potential to meet future economic growth sustainably.

Figure 7: TES by source



Notes: This figure presents the composition of the total energy supply (TES) by source and group of countries. Statistics are presented for all countries and LAC using data from the International Energy Agency for the 1990–2019 period. TES here excludes electricity and heat trade. Coal also includes peat and oil shale where relevant. Renewable sources include: biofuels and waste, hydro, and wind, solar, etc. Variable definitions are available in Appendix Table A1.

3 Data and empirical framework

3.1 Data

We combine country-year data from several sources to construct a strongly balanced panel spanning the years 1971–2019.[8] Data on *Energy use*[9] and country's population[10] is taken from the World Energy Statistics and Balances published by the International Energy Agency (IEA). Energy balances are recorded in thousand tons of oil equivalent (toe), and the database records basic energy statistics for over 150 countries. After implementing screenings, we are left with 140 countries, including 23 LAC countries for 49 years total. One key limitation in working with aggregate country-level data is losing the capacity to detect struc-

[8]We exclude the year 2020 from the analysis to avoid any bias in our results due to the COVID-19 pandemic, which could have generated many outliers in our data.

[9]Energy use/consumption refers to the use of primary energy before it is transformed to other end-use fuels, which is defined as indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

[10]Population data are used to obtain energy demand and GDP per capita.

tural changes between different sectors. Nevertheless, we focus on the IEA's country-level data given its country coverage and availability for such a long time horizon.

Data on income come from the World Bank's World Development Indicators and are measured as GDP at constant 2010 USD. Data on energy prices come from the World Bank's Global Economic Monitor Commodities, a collection of commodity prices known as the Pink Sheet. These prices are measured by the simple average of global real oil prices, including Brent, West Texas Intermediate (WTI), and Dubai prices, and are reported in USD per barrel (USD/bbl). Our main specifications rely on the convention of taking international oil prices as a driver of general energy prices.

Table 1 presents descriptive statistics of the variables used in our main estimations. Throughout the study period, oil prices average 42.67 USD per barrel of crude oil, reaching a minimum of 6.83 and a maximum of almost 100 USD per barrel. The average TES per capita is 2,258; HICs have a TES per capita that reaches 4,300, while the average TES for LAC countries is only 1,200. For both HICs and LAC countries, TES displays substantial heterogeneity, with standard deviations almost matching the average values. Similarly, total final consumption (TFC) per capita reaches an average of 1,500, with a much smaller average for LAC countries (873 per capita) and a much higher one for HICs (2,893). This pattern also is observed for the average values of electricity consumption.

The average GDP per capita for our sample is 12,855, with higher values for HICs and lower ones for LICs, as expected. LAC countries have GDPs that are around half of the average for the world and are similar to the average of MICs. Finally, when analyzing the share of renewable sources in electricity generation, we find the average share worldwide is 34%, with HICs having the smallest share (24%) and LAC countries having the highest (53%).

Table 1: Descriptive statistics

	All				LAC		LIC		MIC		HIC	
	Mean	SD	Min	Max	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Oil prices	42.67	24.88	6.83	95.29								
TES per capita	2,258	2,653	63	22,140	1,206	1,732	440	294	1,067	887	4,377	3,161
TFC per capita	1,523	1,666	46	11,414	873	1,164	360	242	750	575	2,893	1,932
EC per capita	3,296	4,744	6	55,054	1,212	1,072	313	501	1,256	1,282	6,885	5,963
GDP per capita	12,855	17,390	165	180,134	6,374	5,172	919	514	4,000	4,076	28,098	19,739
Renewable sources	0.34	0.34	0.00	1.00	0.53	0.31	0.49	0.39	0.39	0.33	0.24	0.30

Notes: This table presents descriptive statistics for the data collected for our analyses. We combine country-year data from the World Development Indicators (WDI) and the International Energy Agency (IEAD) for the 1971-2019 period. Data are collected for the total energy supply (TES), the total final consumption (TFC), electricity consumption (EC), gross domestic product (GDP), and oil prices. TES and TFC are expressed in TOES per capita*1000, EC in KwH per capita*1000, GDP in constant 2010 USD, and oil prices in USD per barrel of crude oil. Renewable sources are the share of renewable sources in electricity generation. Variable definitions are available in Appendix Table A1.

3.2 Empirical framework

In this subsection, we outline our estimation framework. Throughout the paper, we provide a long battery of estimations reviewing the linkages between energy demand and economic activity. Following Galli (1998), Medlock III and Soligo (2001), van Benthem and Romani (2009) and Jimenez Mori et al. (2022), we propose the following baseline equation to examine the relationship between energy demand and economic activity for the period 1971–2019:

$$ED_i = \alpha_0 + \beta_{gdp} Income_{it} + \beta_p Price_t + \gamma_i + \gamma_t + \sum_i \lambda_i tr_i + e_{it} \tag{1}$$

where ED_i denotes energy demand per capita, for country i and year t, and is measured by TES in our main specifications and by TFC and electricity consumption in alternative specifications. $Income_{it}$ denotes, and is measured by, GDP per capita. $Price_t$ denotes energy prices and is measured by average international crude oil prices for each year t. γ_i denotes country-specific fixed effects, which control for unobserved variables that do not change in time and are unique to each country. γ_t denotes time fixed effects to control for unobserved temporal global shocks through the study period. We also include tr_i, which denotes a country-specific trend that controls for dynamic effects that are otherwise uncontrolled for in our baseline equation. e_{it} is the normally distributed error term.

In general, we follow two types of estimations: parametric and non-parametric. For all of our estimates, we provide a set of six different estimations, each one corresponding to the group of countries that belong to the following groups: LAC, Non-LAC, world, HICs, MICs, and LICs. Parametric estimates evaluate our coefficients of interest using OLS and correct standard errors using the delta method. For the basic parametric setting, we evaluate the natural logarithms of Equation (1) to obtain the following:

$$ln(ED_i) = \alpha_0 + \beta_{gdp} ln(Income_{it}) + \beta_p ln(Price_t) + \gamma_i + \gamma_t + \sum_i \lambda_i tr_i + e_{it} \tag{2}$$

Since energy demand, income, and price variables are expressed in logarithmic scale, the estimates from Equation (3) can be interpreted as elasticities. It may be difficult to believe that when income and price change, energy consumption immediately adjusts. Thus, β_{gdp} and β_p from Equation (3) only capture contemporary effects. That is, the elasticities derived are referred to as short-run elasticities as follows: $\xi^{SR}_{income} = \beta_{gdp}$ and $\xi^{SR}_{price} = \beta_p$.

Following Koyck (1955), we employ the Koyck transformation to allow for long-run dynamics in our estimates. After employing the adjustment mechanism, we estimate the following equation, which adds a lag-dependent variable to Equation (3):

$$ln(ED_i) = \alpha_0 + \beta_{gpd} ln(Income_{it}) + \beta_p ln(Price_t) + ... + \rho ln(ed_{i,t-1}) + \gamma_i + \gamma_t + \sum_i \lambda_i tr_i + e_{it} \tag{3}$$

where ρ can be interpreted as the speed of the adjustment mechanisms toward the long-run equilibrium relationship.[11][12] Considering the adjusted specification, long-run elasticities can be obtained by the corresponding derivative, which in our setting is expressed as follows:

$$\xi^{LR}_{income} = \frac{\beta_{gdp}}{1-\rho}, \text{ and } \xi^{LR}_{price} = \frac{\beta_p}{1-\rho}$$

Finally, to further explore the relationship between energy demand and income, we allow for a non-monotonic relationship between the two. By taking this approach, we allow the effect of income on energy demand to vary along the income distribution. To do this, we replace the linear income regressor with a second-order polynomial and assume that energy demand follows the following form:

$$\begin{aligned} ln(ED_i) = \alpha_0 + \beta_{gpd} ln(Income_{it}) + \beta_{gdp^2}(ln(Income_{it}))^2 + \\ \beta_p ln(Price_t) + \gamma_i + \gamma_t + \sum_i \lambda_i tr_i + e_{it} \end{aligned} \tag{4}$$

Based on Equation (4), the short-run elasticities of energy to income and price in the non–linear setting can be obtained as follows:

$$\eta^{SR}_{income} = \beta_{gdp} + 2\beta_{gdp^2} ln(\overline{Income}), \text{ and } \eta^{SR}_{price} = \beta_p$$

When using the same adjustment mechanism as before, the long-run elasticities under the non-linear setting can be expressed as follows:

$$\begin{aligned} ln(ED_i) = \alpha_0 + \beta_{gpd} ln(Income_{it}) + \beta_{gdp^2}(ln(Income_{it}))^2 + \\ \beta_p ln(Price_t) + ... + \rho ln(ED_{i,t-1}) + \gamma_i + \gamma_t + \sum_i \lambda_i tr_i + e_{it} \end{aligned} \tag{5}$$

Based on Equation (5), the long-run elasticities of energy to income and price can be obtained as follows:

$$\eta^{LR}_{income} = \frac{\beta_{gdp} + 2\beta_{gdp^2} ln(\overline{Income})}{1-\rho}, \text{ and } \eta^{LR}_{price} = \frac{\beta_p}{1-\rho}$$

where the value of income we use varies according to the specification being used. In our main specification, we use the average income in each region in the last year of our sample. Namely, in η^{SR}_{income} and η^{LR}_{income}, the value $ln(\overline{Income})$ refers to the average value of income

[11] See Galli (1998), Medlock III and Soligo (2001), van Benthem and Romani (2009) and van Benthem (2015).

[12] This could introduce a source of bias in our estimations as the new regressor—the lagged variable $ed_{i,t-1}$— is, by definition, not strictly exogenous. Numerous techniques have been developed to address this potential threat (Bond, 2002, Judson and Owen, 1999, and Wooldridge, 2001). When a time-series dimension gets large enough (T>30), it is expected that the least squares dummy variable (LSDV) estimator for dynamic panel data models performs well.

for each group (LAC, non-LAC, etc.) in 2019. In alternative specifications, this value is also specific to each country or different time frames, as specified in Section 4.

By initially employing parametric estimates, we can obtain very valuable insights on the relationship between the variables of interest. The efficacy of this method is limited, however, especially as we are confronted with non-linear patterns. To address this issue, we also use non-parametric estimates to evaluate our baseline Equation (1). In particular, we estimate our parameters of interest using a Kernel Regularized Least Square (KRLS) estimation, following Hainmueller and Hazlett (2014) and Ferweda et al. (2015). This non-parametric approach breaks free from the constraints imposed by parametric estimates since it can capture complex non-linearities between the variables by using kernel functions that map data into higher-dimensional spaces.

One way to understand how this method works is to use the similarity-based approach of Hainmueller and Hazlett (2014), who propose a kernel function that takes two different arguments to produce one output, which measures the similitude of input patterns. The KRLS method uses the Gaussian kernel, which is very close to the normal distribution. This kernel uses information from the different covariates proposed in the specification, from Equation (3) in our case, to calculate the Euclidean distance between those covariate vectors. From this view, the target function is approximated by a function that has the kernel as an input. This target function does not model $ln(ED_i)$ as a linear function of $ln(Income_{it})$; rather, it uses information on the similarity between the observations to estimate our parameters of interest.[13]

4 Results

Our results are divided into three main parts. We first assess the relationship between income and TES using parametric estimates. Next, we use non-parametric estimates, with a focus on comparing the two approaches. Finally, we conduct additional exercises to further explore this relationship.

4.1 Parametric estimates

This section explores the relationship between income and TES. We estimate elasticities using OLS estimates and correct standard errors using the delta method. Tables 2 and 3 show the estimates of elasticities of income and price on the TES using linear and non-linear specifications.

Panel A in Table 2 shows the results for short-run linear elasticities, which indicate a positive and statistically significant effect of income on TES throughout the different specifications. Namely, a 1% increase in income corresponds to at least a 0.4% increase in TES. The results for long-run linear elasticities (Panel B) suggest similar results. A 1% increase in income corresponds to at least a 0.6% increase in TES, however, unlike the short-run elasticities, the estimated coefficients suggest up to 0.9% increases.

[13] See Hainmueller and Hazlett (2014) for a theoretical explanation on the estimates produced by KRLS and Ferweda et al. (2015) for an explanation of the algorithm used to produce our non-parametric estimates.

Once TES is disaggregated by region and income levels, two major facts stand out. First, LAC countries (column 1 of Table 2) always have higher magnitudes when compared to other countries in the world. For example, the estimated long-run income elasticity for the LAC region is 0.9%, while the same estimate for countries outside the LAC region, at most, 0.7%. Similarly, the short-run income elasticity for LAC countries is 0.6% as opposed to a 0.4% estimated elasticity for non-LAC countries.

Second, the estimated short and long-run elasticities for HICs (column 6 of Table 2) are somewhat larger in size than the estimates for MICs. For example, for HICs, the estimated long-run elasticity is 0.7% compared to 0.5% for MICs, and the estimated short-run elasticity for HICs is 0.4% compared to 0.3% for MICs. The differences observed in estimates along income groups shed light on a potential non-linearity in the relationship between income and TES.

Table 2: Linear elasticities (ξ) of income and price on TES by region and income level

	Region			Income level		
	(1) LAC	(2) Non-LAC	(3) All	(4) LIC	(5) MIC	(6) HIC
Panel A: Short-run elasticities (ξ^{SR})						
Income	0.656***	0.464***	0.473***	0.557***	0.376***	0.462***
	(0.101)	(0.057)	(0.063)	(0.117)	(0.085)	(0.143)
Price	-0.177**	-0.165***	-0.172***	-0.230***	-0.139***	0.131**
	(0.078)	(0.015)	(0.015)	(0.051)	(0.012)	(0.053)
N	1094	5286	6281	752	3125	2404
Panel B: Long-run elasticities (ξ^{LR})						
Income	0.935***	0.661***	0.644***	0.604**	0.555***	0.711***
	(0.137)	(0.084)	(0.079)	(0.256)	(0.120)	(0.154)
Price	-0.890**	-0.175***	-0.177***	-0.109*	-0.155***	0.090
	(0.442)	(0.034)	(0.031)	(0.059)	(0.021)	(0.242)
N	1072	5167	6143	735	3055	2353

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on Total Energy Supply per capita (TES) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific time trends, time and country-fixed effects. Delta method calculated standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Variable definitions are available in Appendix Table A1.

Table 3 shows the results for elasticities, assuming a second-order polynomial, as explained previously. These results also suggest a positive and statistically significant effect of income on TES, which provides statistical evidence of a non-linear effect. Following Equations (4) and (5), we evaluate the estimated non-linear elasticities at the average GDP per capita for 2019 in each region (LAC, non-LAC, LICs, MICs, and HICs) to obtain a single value for each estimate.

Even when assuming this functional form, the results consistently show that LAC countries have higher elasticities than other countries in the world. In fact, the divergence seems even more pronounced in the estimates found in Panel B. Here, the estimated non-linear, long-run elasticity for the LAC region is around 0.9%, in contrast to only 0.6% for countries outside the region. Similarly, the estimated short-run non-linear elasticity for LAC countries is around 0.7%, while estimates for the rest of the world are not larger than 0.4%. In contrast to the results found in Table 2, the long-run elasticities in HIC are not higher than other income groups. In fact, as shown in Panel B, LICs exhibit the highest long-run elasticities (reaching 0.7%) as opposed to lower values of 0.5% for HICs.

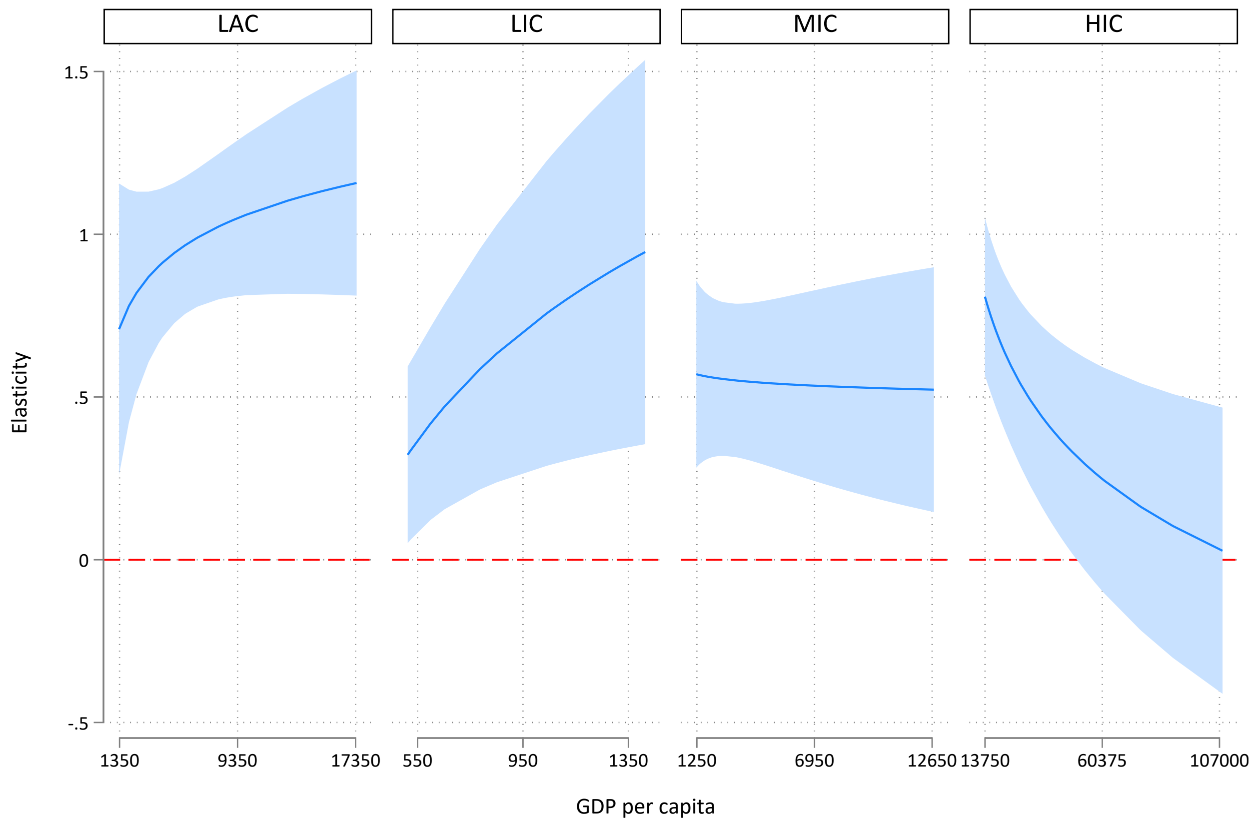
Table 3: Non-linear elasticities (η) of income and price on TES by region and income level

	Region			Income level		
	(1) LAC	(2) Non-LAC	(3) All	(4) LIC	(5) MIC	(6) HIC
Panel A: Short-run elasticities (η^{SR})						
Income	0.707***	0.460***	0.458***	0.641***	0.388***	0.303**
	(0.082)	(0.095)	(0.084)	(0.100)	(0.096)	(0.121)
Price	-0.192**	-0.165***	-0.174***	-0.273***	-0.139***	0.109**
	(0.079)	(0.015)	(0.016)	(0.050)	(0.012)	(0.054)
N	1094	5286	6281	752	3125	2404
Panel B: Long-run elasticities (η^{LR})						
Income	0.994***	0.657***	0.647***	0.706***	0.544***	0.489***
	(0.109)	(0.114)	(0.099)	(0.223)	(0.128)	(0.135)
Price	-0.893**	-0.175***	-0.177***	-0.192**	-0.155***	0.067
	(0.442)	(0.034)	(0.031)	(0.076)	(0.021)	(0.225)
N	1072	5167	6143	735	3055	2353

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on Total Energy Supply per capita (TES) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific time trends, time and country-fixed effects. Delta method calculated standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Variable definitions are available in Appendix Table A1.

As the results in Table 3 provide statistical evidence of a non-linear relationship between income and TES, we follow Equation (5) to estimate long-run non-linear elasticities, with the difference being that in this case, we use specific values of income for each country in 2019. Figure 8 plots the long-run estimated elasticities along the income distribution and shows three main results. First, the estimated elasticities for LAC countries are increasing with respect to country-specific income. Second, a consistent finding is the pronouncedly high estimated elasticities in LAC countries. Third, LICs and HICs show opposite trends: While LICs show increasing elasticities on income, HICs show decreasing ones. It should be noted these results most likely are influenced by the quadratic functional form imposed in the non-linear estimates, however, the statistical significance of the coefficients in Table 3 provides evidence of this functional form.

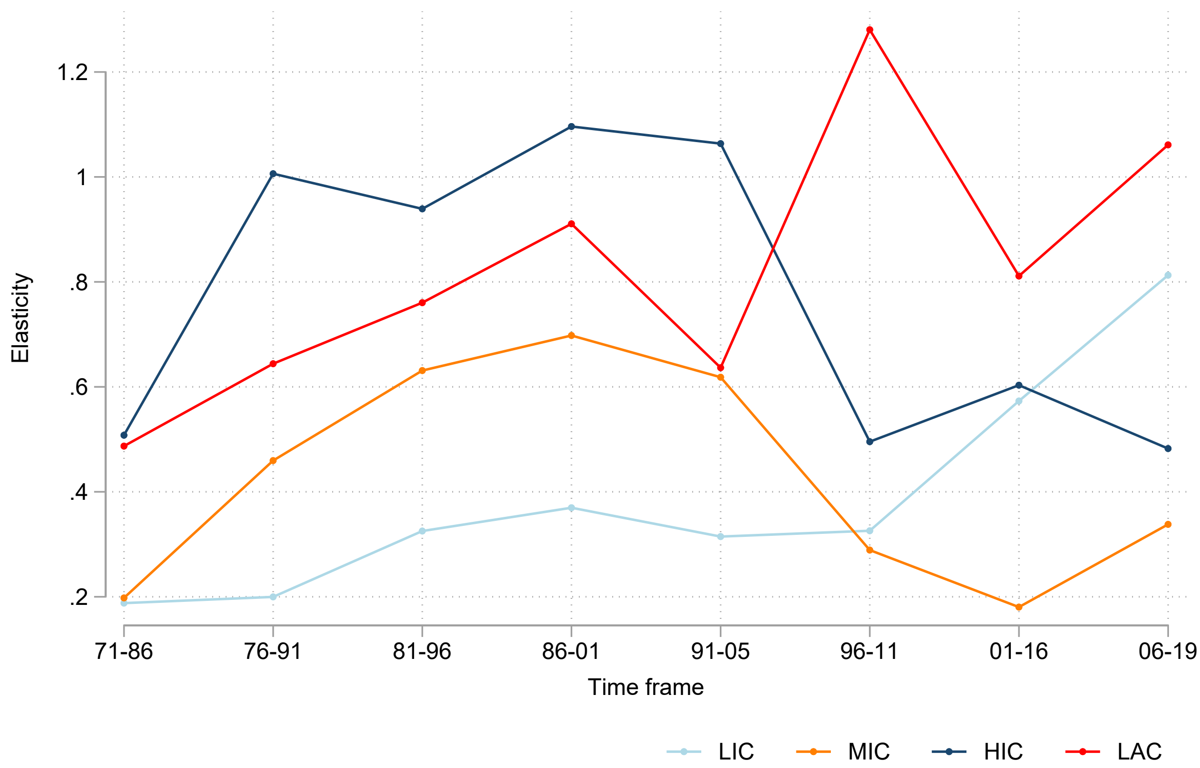
Figure 8: Non-linear, long-term elasticities (η^{LR}_{income}) of income on TES by region and income level along the income distribution in 2019



Notes: This figure presents non-linear, long-run elasticities of income on TES using Ordinary Least Squares (OLS) estimations. Elasticities are disaggregated by regions (LAC, non-LAC, and all countries) and income levels (LICs, MICs, and HICs). Elasticities are calculated for all levels of GDP per capita (log) in 2019 for each group of countries. All estimations include country-specific time trends and time and country-fixed effects. Variable definitions are available in Appendix Table A1.

Finally, we explore how our estimated elasticities may have evolved over time. Once again, we follow Equation (5) to estimate long-run non-linear elasticities, but in this case, we use specific values of income for each time frame and in each region. Namely, we estimate one elasticity for each time frame shown in Figure 9. The figure shows a turning point in the last 30 years for the long-run non-linear elasticities. After 1991, the estimated elasticities for HICs and MICs begin to decrease, but before 1991, HICs have the highest estimated elasticities between groups of countries. On the other hand, elasticities for LAC and LICs continue to rise after 1991, with a sharp increase in the 1991–2005 period for LAC.

Figure 9: Dynamic non-linear long-term elasticities (η^{LR}_{income}) of income on TES by region and income level



Notes: This figure presents non-linear, long-run elasticities of income on TES using Ordinary Least Squares (OLS) estimations. Elasticities are disaggregated by regions (LAC, non-LAC, and all countries) and income levels (LICs, MICs, and HICs). Elasticities are calculated for the average GDP per capita (log) in different time frames for each group of countries. All estimations include country-specific time trends and time and country-fixed effects. Variable definitions are available in Appendix Table A1.

Across all our parametric results, a consistent trend emerges: The LAC region always has the highest estimated elasticities when compared to the rest of the world. This indicates that for LAC countries, increasing incomes lead to more than proportional increases in TES.

4.2 Non-parametric estimates

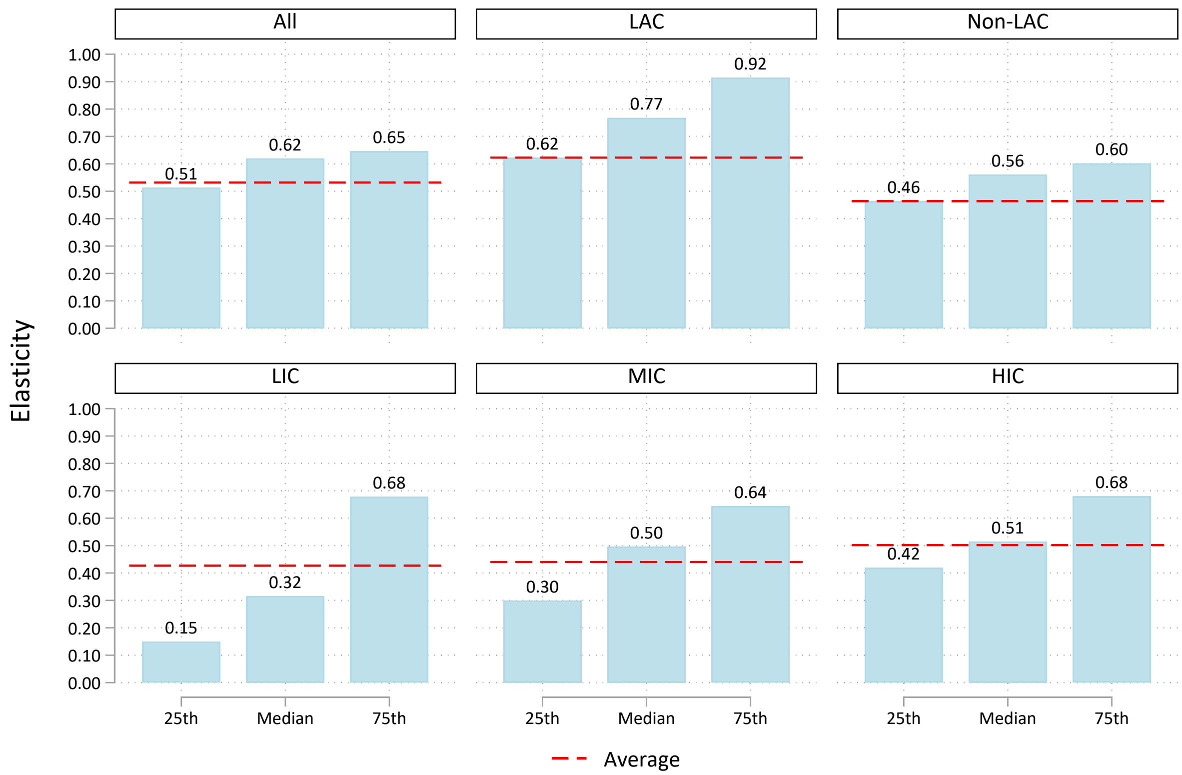
As in Jimenez Mori et al. (2022), this section explores a non-parametric approach to these elasticities using the Kernel-Based Regularized Least Squares (KRLS) method. By using this method, we can relax some of the assumptions made in the OLS estimates regarding the functional form of the relationship between income and TES. This allows us to estimate not only average elasticities but also the elasticities along the income distribution.[14]

Figure 10 summarizes results of the KRLS estimation of variables. It reports the average of the pointwise marginal effects of income on TES as well as the 25th, 50th, and 75th percentile of those marginal effects. Similar to our previous estimates, the figure shows

[14]We present evidence for the short-run elasticities; however, our conclusions are consistent with the long-run results.

that a 1% increase in income corresponds to an increase in TES of around 0.5% for all specifications. Consistent with results from the parametric estimates, LAC countries have the highest elasticities when compared to other regions and to countries in all the different income groups.

Figure 10: Non-parametric, short-run linear elasticities (ξ^{SR}_{income}) of income on TES by region and income level



Notes: This figure summarizes the estimations for non-parametric short-run elasticities of income on TES using the Kernel-Based Regularized Least Squares (KRLS) method. Elasticities are disaggregated by regions LAC, non-LAC, and all countries) and income levels (LICs, MICs, and HICs). The red dashed line represents the average elasticity for each particular group of countries. All estimations include country-specific trends and country-fixed effects. Variable definitions are available in Appendix Table A1.

As previously mentioned, KRLS estimates calculate one marginal effect for each observation, and the different percentiles of the marginal effects provide some insights into their heterogeneity. For the LAC region, at the 25th percentile, a 1% increase in income is associated with a 0.6% increase in TES, while at the 75th percentile, the same increase in income corresponds to a 0.9% increase in TES, which is a much larger effect. The trend is similar for all the regions, where estimated marginal effects at the 75th percentile are significantly larger than those at the 25th and 50th percentiles.

KRLS estimates do not impose any functional form on the relationship between income and energy supply. However, the heterogeneity of the marginal effects found in Figure 10 and our OLS estimates provide enough evidence for us to believe that this relationship could be non-linear. One simple way to further evaluate this for our KRLS estimates, we correlate the pointwise derivatives estimated in the figure with the income variable.

The results, presented in Table 4, suggest the pointwise derivatives strongly depend on income levels of each country. For all specifications in Panel B, the pointwise derivatives show a negative dependence on income levels, suggesting the calculated elasticities are lower for countries with higher income levels. In contrast, pointwise derivatives calculated for the LAC region depend positively on income levels. This is consistent with our previous results, where we find that for the LAC region, countries with higher incomes have even higher estimated elasticities—as opposed to the trend observed in HICs, where higher incomes suggest lower estimates elasticities.

Table 4: Non-parametric, short-run non-linear elasticities (η^{SR}_{income}) of income on TES by region and income level

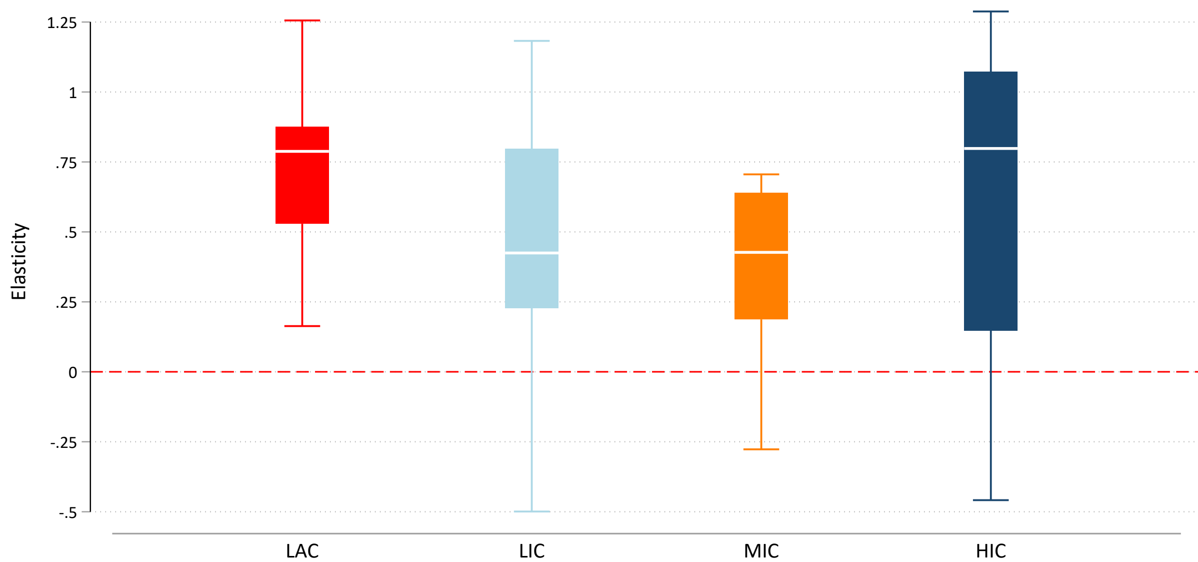
	Region			Income level		
	(1) LAC	(2) Non-LAC	(3) All	(4) LIC	(5) MIC	(6) HIC
Income	1.479***	-0.079***	-0.003	-0.232***	-0.074**	-0.194***
	(0.108)	(0.020)	(0.020)	(0.080)	(0.029)	(0.054)
N	1094	5286	6281	752	3125	2404

Notes: This table presents pointwise derivatives to estimate non–parametric short-run non-linear elasticities of income on total energy supply per capita (TES) using the Kernel-Based Regularized Least Squares method (KRLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific trends and country-fixed effects. Variable definitions are available in Appendix Table A1.

As previously noted, KRLS estimates are calculated using pointwise derivatives along the income distribution. Figure 11 summarizes these estimates to show several aspects. First, the range of estimated elasticities for MICs is smaller than for the other groups, between –0.4% and 0.6%. The estimates for LICs range from –0.5% to more than 1%. HIC estimates also range from negative to positive, suggesting that for all income groups, some particular values of elasticities are estimated as negative. However, as shown in the figure, these negative value estimates pertain only to countries with income levels far below average for each specific group.

Second, for countries with income levels in the median, estimated elasticities are very similar for LICs and MICs but are slightly higher for HICs. This suggests the elasticity estimates do depend on the income levels of each country, providing more evidence on the non-linearity of the relationship between both variables. Once again, results for the LAC region stand out from the rest of the world. The estimated elasticities are always greater than 0 and are generally higher than for the rest of the world. In addition, for LAC countries with income levels in the 50th percentile, the estimated elasticity is as large as that for HICs.

Figure 11: Non-parametric, short-run non-linear elasticities (η^{SR}_{income}) of income on TES per capita by region and income level

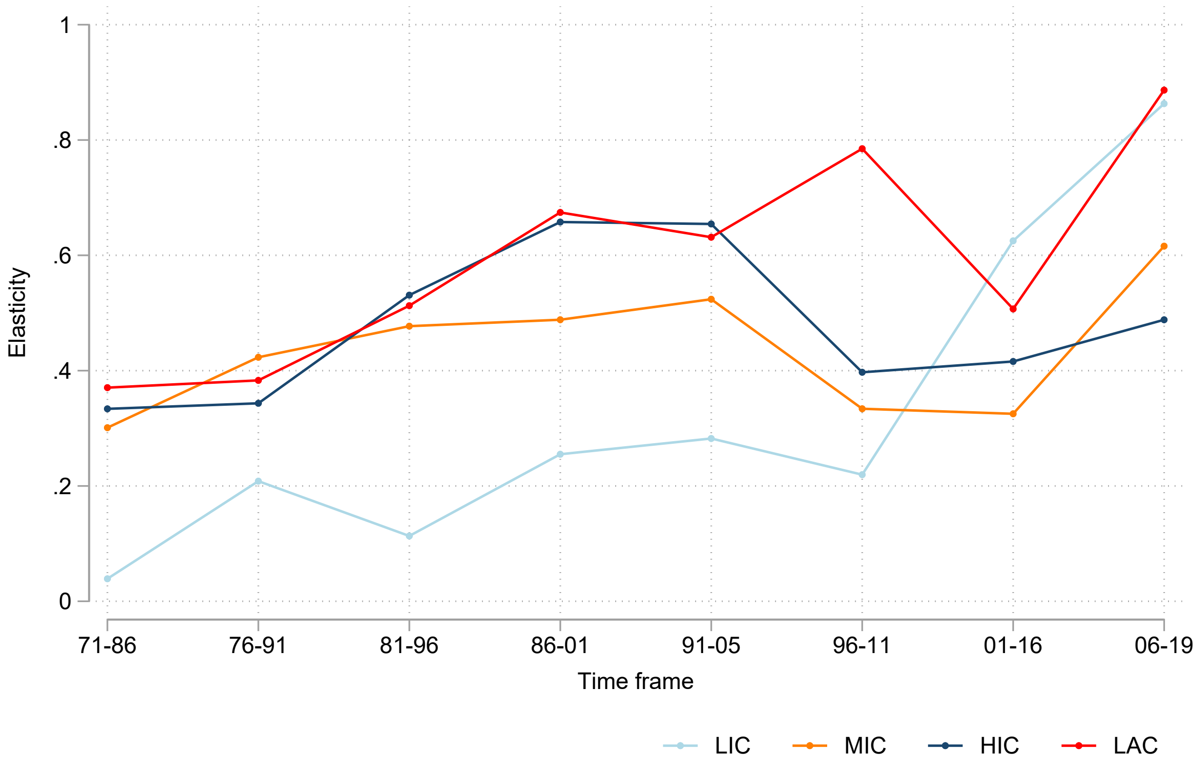


Notes: This figure summarizes the estimations for non-parametric short-run, elasticities of income on TES using the Kernel-Based Regularized Least Squares (KRLS) method. Elasticities are presented in box plots and disaggregated by regions (LAC) and income levels (LICs, MICs, and HICs). Country elasticities are used to construct the group distribution. All estimations include country-specific trends and country-fixed effects. Variable definitions are available in Appendix Table A1.

In line with the proposed estimates for the parametric section, we extended our analysis by applying the non-parametric approach to estimations for various time frames. Our findings indicate consistent results across both approaches. Figure 12 visually represents the evolution of estimated elasticities over time using the non-parametric approach. Each time point on the graph corresponds to the estimated average marginal effect for the respective region. Similar to the parametric approach, HICs show a downward trend in elasticities starting in 1991, while LICs and LAC countries show an upward trend. Notably, we also find that unlike the parametric estimates, the LAC region consistently has higher estimated elasticities throughout the study period, not just in recent years.

Furthermore, Figure 12 indicates a widening gap in estimated elasticities among the regions over time. For the 1971–1986 period, the estimated elasticities for the LAC region, MICs, and HICs are approximately 0.4%, with LAC countries showing slightly higher values. By the 1996-2005 period, however, the estimated elasticity for the LAC region doubles to 0.8%, while MICs and HICs maintain estimated elasticities around 0.4%. Notably, MICs and HICs follow similar trends throughout the entire study period. In contrast, LICs initially exhibit elasticities close to 0 during the 1971–1986 period, but by 2006–2019, their elasticities increase substantially to nearly 0.9%. Furthermore, LICs have smaller magnitude elasticities compared to the rest of the world until a significant point of change occurred, causing their elasticities to surpass those of other income groups in the remaining time frames.

Figure 12: Dynamic non-parametric, short-run non-linear elasticities (η^{SR}_{income}) of income on TES by region and income level

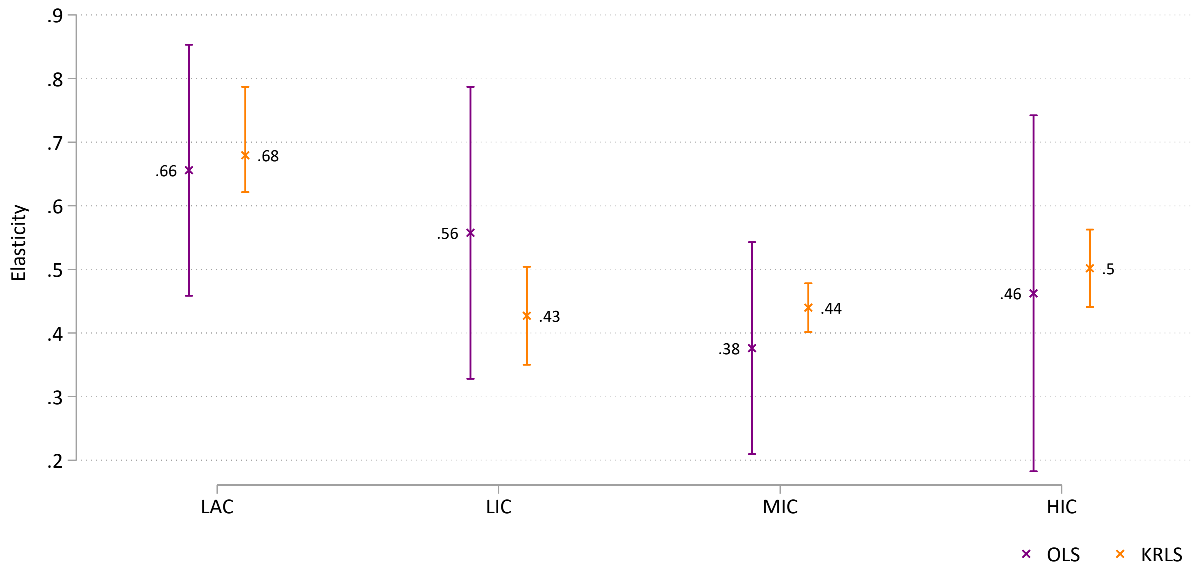


Notes: This figure summarizes the estimations for non–parametric short-run elasticities of income on TES using the Kernel-Based Regularized Least Squares (KRLS) method. Elasticities are disaggregated by regions (LAC) and income levels (LICs, MIs, HICs) and they are calculated for the average GDP (log) in different time frames for each group of countries. All estimations include country-specific trends and country-fixed effects. Variable definitions are available in Appendix Table A1.

Reiterating our earlier observation, both the parametric and non-parametric approaches yield similar outcomes, with the recurring main result being that the estimated elasticities for LAC countries is always larger in magnitude.[15] Figure 13 shows the estimated short-run linear elasticities from the parametric approach and those using the non-parametric approach side by side. Several facts stand out. First, the delta method estimates are slightly more imprecise than the KRLS estimates, and the KRLS estimates and delta method estimates for elasticities are equal in statistical terms. In addition, estimates for the income elasticity on TES range from 0.66% to 0.68% for LAC countries. Estimates follow for LICs, between 0.43% and 0.56%; for HICs, between 0.46% and 0.5%; and for MICs, between 0.38% and 0.44%.

[15]Our results are robust also to alternative measures for income and energy consumption. See Appendix Tables A3 –A6 for these results.

Figure 13: Short-run, non-linear elasticities (η^{SR}_{income}) of income on TES by region and income level: OLS vs KRLS



Notes: This figure highlights the differences in estimations for the short-run elasticities of income on TES when using Ordinary Least Squares (OLS) against the Kernel-Based Regularized Least Squares (KRLS) method. Standard errors for the OLS estimations are calculated using the delta method. Elasticities are disaggregated by regions (LAC) and income levels (LICs, MICs, and HICs), and they are calculated for the average GDP (log) for each group of countries. All estimations include country-specific trends and country-fixed effects. Variable definitions are available in Appendix Table A1.

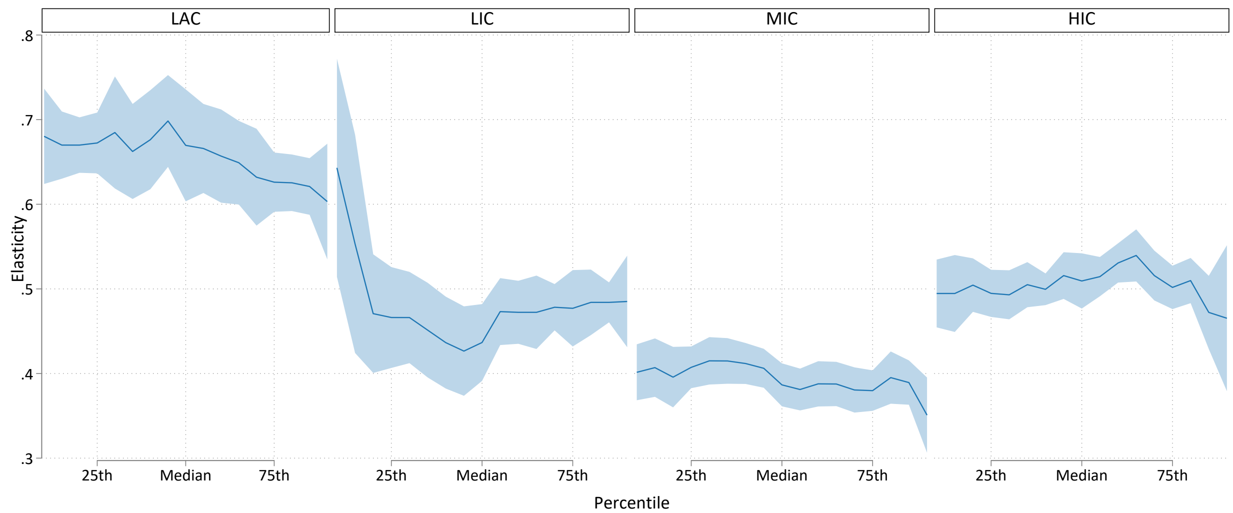
4.3 Additional exercises

Throughout this paper, we have documented that the elasticity of income on energy supply is positive, statistically significant, and dependent on each country's income levels. That is, the elasticity estimates change along the income distribution. However, another question that can arise is how estimated elasticities can differ along the distribution of energy supply. Using quantile regressions,[16] we are able to analyze the relationship between income and energy supply by estimating the effect of income on different conditional quantiles of energy supply, as opposed to just the mean, as we have done in previous sections. This allows us to explore how changes in income influence energy supply across various points of the distribution. Importantly, it helps us identify whether income has a stronger impact on energy supply for countries with lower energy consumption compared to those with higher consumption.

Figure 14 shows results of the estimation by income groups and for the LAC region. Two important facts stand out. First, MICs and HICs have rather constant elasticities along the energy distribution, with a slight decrease for higher levels of energy consumption. Second, LAC countries show a constant decrease in the magnitude of estimated elasticities as energy consumption increases. This suggests LAC countries with the highest energy use, have the smallest estimated income elasticities.

[16]See Koenker and Bassett (1978) for details on estimating quantile regressions.

Figure 14: Short-run linear elasticities (ξ^{SR}_{income}) of income on TES by region and income level: Quantile regressions

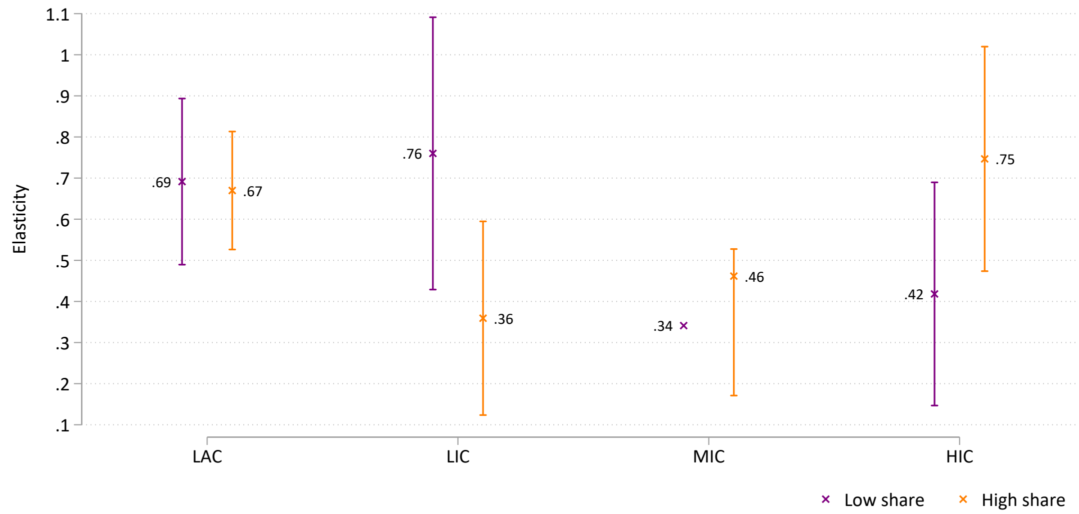


Notes: This figure presents short-run elasticities of income on TES using Ordinary Least Squares (OLS) with quantile regressions. Standard errors are calculated using the delta method. Elasticities are disaggregated by regions (LAC) and income levels (LICs, MICs, and HICs), and they are calculated for the average GDP (log) for each group of countries. All estimations include country-specific trends and country-fixed effects. Variable definitions are available in Appendix Table A1.

As discussed in the introduction, the imperatives of climate change have placed decarbonization efforts at the center of global policy agendas, thereby setting not only ambitious but also essential targets. The LAC region faces significant pressure to quickly adapt and transition toward sustainable and green energy sources. This urgency stems not merely from environmental considerations but also from the intertwined relationship between economic growth and energy use, which is especially pertinent in the context of renewable energy sources. Thus, a deeper exploration of the connection between income and energy use within the LAC region not only gains relevance but becomes pivotal in framing responsive and sustainable policies amidst the ongoing global challenge of climate change. As a final exercise, following Equation (3), Figure 15 shows the short-run linear elasticities estimated for countries with a high share of renewable sources in electricity generation against countries with a low share, in each group. We define countries with a high share of renewables as those in the upper interquartile range of the global distribution of shares and countries with a low share as those in the lower range.

Countries with a strong presence of renewable energy sources are also likely to implement policies to reduce greenhouse gas emissions, which are closely tied to energy production. The segmented linear regression analysis provides some insights into whether the income elasticities on energy supply are higher for countries with a lower share of renewable sources. Analyzing the results side-by-side yields several key observations. First, the estimated elasticities in the LAC region are slightly lower for countries with a high share of renewable sources, but the difference between these elasticities is not statistically significant. Second, the elasticities for LICs with a high share of renewables is significantly smaller (around 0.2%) than for LICs with a low share of renewables (almost 1%). Third, the story becomes the opposite for MICs and HICs, where countries with a high share of renewables have a slightly

Figure 15: Short-run linear elasticities (ξ^{SR}_{income}) of income on TES by region and income level: Share of renewable sources in electricity generation



Notes: This figure presents short-run elasticities of income on TES using Ordinary Least Squares (OLS). Standard errors are calculated using the delta method. Elasticities are disaggregated by regions (LAC) and income levels (LICs, MICs, and HICs), and they are calculated for the average GDP (log) for each group of countries according to their share of renewable sources in electricity generation. A country with a high share of renewables is defined as one in the upper interquartile range of the global distribution of shares, a country with a low share is defined as one in the lower range. All estimations include country-specific trends and country-fixed effects. Variable definitions are available in Appendix Table A1.

larger estimated elasticity. But, as with LAC countries, the difference between both estimates is not statistically significant. These results suggest that in general, and certainly in the LAC region, countries with higher or lower shares of renewable sources in electricity generation do not experience heterogeneous elasticities of income on energy supply.

5 Conclusion

This study presents a comprehensive exploration of the relationship between energy use and economic growth in Latin America and the Caribbean region from 1971 to 2019. As global urgency intensifies to align energy policies with the fight against climate change, understanding this relationship becomes increasingly critical, especially for the LAC region, where the energy-economy interplay is markedly complex and often diverges from global patterns. We find that a 1% increase in income levels is related to a 0.4–0.9% surge in TES, with the LAC region consistently exhibiting higher income elasticities compared to other country groups.

Our additional analyses dig deeper into these findings. First, non-parametric estimations confirm the parametric estimates but also reveal intriguing non-linearities in this relationship. Second, temporal dynamics indicate the values of our estimated elasticities have not remained static; they have increased significantly in the LAC region since 1991. Further, our quantile regression analysis reveals that as energy consumption increases, income elasticity tends to decrease within LAC. Our results thus underscore the intricate structural linkages between energy and economic variables, confirming that the dynamics of energy demand in the region are not only higher in their elasticity but also exhibit region-specific complexities, thus requiring tailored policy interventions. By employing expansive and robust methodologies and using comprehensive panel data, our study significantly enriches existing scholarly debates. It introduces a level of granularity and regional focus absent in much of the current discourse, which often paints with a broader brush. Moreover, our focus on short- and long-term effects, while accounting for measurement error and biases, offers a more nuanced understanding of the relationship between energy and economic growth.

As the global community contends with climate change imperatives, the policy implications of our study is manifold. First, given the proven positive correlation between income and energy demand, any economic stimulus in the LAC region should be paired with energy provision planning. Second, the higher income elasticity rates observed in the region relative to other regions imply that any income growth could lead to disproportionately higher energy consumption. This could exacerbate the carbon footprint if not managed judiciously. Policies must therefore prioritize energy efficiency and renewable energy sources to offset this potential surge in demand.

Furthermore, our findings could point to the need for "smart subsidies" that could be used to discourage fossil fuel consumption in higher income and higher elasticity sectors. The use of market-based mechanisms such as cap-and-trade or carbon taxes also should be considered, as they could provide economic incentives for businesses and households to reduce energy consumption while maintaining productivity. Last, as our study reveals that income elasticity tends to decrease at higher levels of energy consumption within LAC countries, tiered pricing structures could ensure that higher consumption levels are associated with higher prices, thus encouraging energy conservation. In closing, while our findings provide a foundational understanding of the energy-economic dynamics in the LAC region, whether the policy recommendations inferred are ultimately apt or not lies beyond the scope of this study and underscores the need for further, targeted research.

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Appendix

A Tables

Table A1: Variable description

Variable	*Description*
Electricity consumption per capita (EC)	EC is measured in kilowatts (TWh) and it comprises domestic consumption which is gross production plus imports minus exports minus losses. This variable is divided by the country's population to get electricity consumption per capita. The data is obtained from the International Energy Agency (IEA).
Energy intensity	This variable is measured in toes per thousand 2015 USD and is defined by dividing the total energy supply (TES) by the country's gross domestic product (GDP) and then multiplying it by 1000. The data is obtained from the International Energy Agency (IEA).
Gross domestic product per capita (GDP)	GDP is measured in constant 2010 USD$. This variable is divided by the population of the country and then multiplied by 1000. The data is obtained from the World Development Indicators (WDI).
Income	This variable represents the estimated elasticity of income (η and ξ) in the different tables throughout the paper.
Income level (dummies)	Dummy variables indicating whether a country is part of a particular income level groups. LIC takes the value of 1 for low-income countries, MIC takes the value of 1 for middle-income countries, and HIC takes the value of 1 for high-income countries. The income group is defined by the World Development Indicators Database. The complete list of countries is available in Appendix Table A2.
Oil prices	This variable is measured in USD per barrel (USD/bbl) and is defined as the simple average of global real oil prices, including Brent, West Texas Intermediate (WTI), and Dubai prices. The data is obtained from the World Bank's Global Economic Monitor Commodities.
Population	This variable is measured in millions and it is only used for the calculations of GDP per capita. The data is obtained from the World Development Indicators (WDI).

Price	This variable represents the estimated elasticity of price (η and ξ) in the different tables throughout the paper.
Region (dummies)	Dummy variables indicating whether a country is part of a particular region. LAC takes the value of 1 for countries in Latin America and the Caribbean region. ALL takes the value of 1 for all countries in our sample.
Total energy supply per capita (TES)	TES is measured in tonnes of oil equivalent (toe) per capita and multiplied by 1000. TES is constructed by the made of production plus imports minus exports minus international marine bunkers minus international aviation bunkers and accounts for stock changes. The data is obtained from the International Energy Agency (IEA).
Total final consumption per capita (TFC)	TFC is measured in tonnes of oil equivalent (toe) per capita and multiplied by 1000. The TFC is the sum of the consumption in the end-use sectors, and for non-energy use. Energy used for transformation processes and for own use of the energy-producing industries is excluded. Final consumption reflects for the most part deliveries to consumers. The data is obtained from the International Energy Agency (IEA).
Renewable source share (dummies)	Dummy variables indicating whether a country´s electricity generation mainly comes from a renewable source or not. We define countries with a high share of renewables as those in the upper interquartile range of the global distribution of shares, and low share as those in the lower range. The interquartile range is defined by the share of renewable sources in the electricity generation variable. This represents the output of electricity produced from renewable sources divided by the total output of electricity. Renewable sources include electricity from hydro, geothermal, solar, wind, tide, wave, biofuels and the renewable fraction of municipal waste. The data is obtained from the International Energy Agency (IEA).

Notes: This table describes all the variables used in our analyses. Variables are organized in alphabetical order. The data obtained from the International Energy Agency are described in more detail in the database documentation (IEA, 2022). Date of access: June, 2023 [link]. Variable summary statistics are available in Table 1.

Table A2: Country income groups

LIC	MIC		HIC	
Benin	Albania	Kosovo	Argentina*	Poland
Congo	Algeria	Kyrgyzstan	Australia	Portugal
Eritrea	Angola	Lebanon	Austria	Qatar
Ethiopia	Armenia	Libya	Bahrain	Saudi Arabia
Haiti*	Azerbaijan	Malaysia	Belgium	Singapore
Mozambique	Bangladesh	Mauritius	Brunei	Slovak Republic
Nepal	Belarus	Mexico*	Canada	Slovenia
Niger	Bolivia*	Mongolia	Chile*	Spain
North Korea	Bosnia and Herzegovina	Montenegro	Croatia	Sweden
Senegal	Botswana	Morocco	Cyprus	Switzerland
South Sudan	Brazil*	Myanmar	Czech Republic	Trinidad and Tobago*
Syria	Bulgaria	Namibia	Denmark	United Arab Emirates
Tajikistan	Cambodia	Nicaragua*	Estonia	United Kingdom
Tanzania	Cameroon	Nigeria	Finland	United States
Togo	China	Pakistan	France	Uruguay*
Yemen	Colombia*	Paraguay*	Germany	
Zimbabwe	Costa Rica*	Peru*	Gibraltar	
	Côte d'Ivoire	Philippines	Greece	
	Cuba*	Moldova	Hong Kong	
	Dominican Republic*	Congo (RotC)	Hungary	
	Ecuador*	Romania	Iceland	
	Egypt	Russia	Ireland	
	El Salvador*	Serbia	Israel	
	Gabon	South Africa	Italy	
	Georgia	Sri Lanka	Japan	
	Ghana	Sudan	Korea	
	Guatemala*	Suriname*	Kuwait	
	Honduras*	Thailand	Latvia	
	India	Tunisia	Lithuania	
	Indonesia	Turkey	Luxembourg	
	Iran	Turkmenistan	Malta	
	Iraq	Ukraine	Netherlands	
	Jamaica*	Uzbekistan	New Zealand	
	Jordan	Venezuela*	Norway	
	Kazakhstan	Viet Nam	Oman	
	Kenya	Zambia	Panama*	

Notes: The income group is defined by the World Development Indicators Database.

Table A3: Linear elasticities (ξ) of income and price on total final consumption per capita (TFC) by region and income level

	Region			Income level		
	(1) LAC	(2) Non-LAC	(3) All	(4) LIC	(5) MIC	(6) HIC
Panel A: Short-run elasticities (ξ^{SR})						
Income	0.574***	0.465***	0.448***	0.547***	0.414***	0.328**
	(0.075)	(0.065)	(0.064)	(0.132)	(0.084)	(0.136)
Price	-0.082	-0.189***	-0.190***	-0.234***	-0.164***	0.084***
	(0.075)	(0.015)	(0.014)	(0.039)	(0.011)	(0.029)
N	1094	5286	6281	752	3125	2404
Panel B: Long-run elasticities (ξ^{LR})						
Income	0.910***	0.663***	0.629***	0.475**	0.655***	0.617***
	(0.143)	(0.081)	(0.067)	(0.212)	(0.091)	(0.140)
Price	-0.213	-0.212***	-0.208***	-0.165**	-0.213***	0.072
	(0.806)	(0.028)	(0.025)	(0.077)	(0.022)	(0.220)
N	1072	5167	6143	735	3055	2353

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on total final consumption per capita (TFC) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific trends and country-fixed effects. Delta method calculated standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Variable definitions are available in Appendix Table A1.

Table A4: Non-linear elasticities (η) of income and price on total final consumption per capita (TFC) by region and income level

	Region			Income level		
	(1) LAC	(2) Non-LAC	(3) All	(4) LIC	(5) MIC	(6) HIC
Panel A: Short-run elasticities (η^{SR})						
Income	0.591***	0.442***	0.417***	0.636***	0.437***	0.161
	(0.072)	(0.099)	(0.081)	(0.115)	(0.085)	(0.103)
Price	-0.087	-0.191***	-0.194***	-0.281***	-0.165***	0.061**
	(0.077)	(0.016)	(0.016)	(0.041)	(0.012)	(0.030)
N	1094	5286	6281	752	3125	2404
Panel B: Long-run elasticities (η^{LR})						
Income	0.961***	0.662***	0.643***	0.595***	0.686***	0.415***
	(0.116)	(0.099)	(0.085)	(0.188)	(0.093)	(0.123)
Price	-0.228	-0.212***	-0.206***	-0.237***	-0.213***	0.050
	(0.801)	(0.028)	(0.024)	(0.083)	(0.022)	(0.202)
N	1072	5167	6143	735	3055	2353

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on total final consumption per capita (TFC) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific trends and country-fixed effects. Delta method calculated standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Variable definitions are available in Appendix Table A1.

Table A5: Linear elasticities (ξ) of income and price on electricity consumption per capita (EC) by region and income level

	Region			Income level		
	(1) LAC	(2) Non-LAC	(3) All	(4) LIC	(5) MIC	(6) HIC
Panel A: Short-run elasticities (ξ^{SR})						
Income	0.807***	0.467***	0.564***	0.782***	0.560***	0.306**
	(0.151)	(0.092)	(0.084)	(0.218)	(0.104)	(0.139)
Price	0.041	-0.223***	-0.246***	-0.338***	-0.217***	0.243***
	(0.069)	(0.022)	(0.020)	(0.086)	(0.017)	(0.036)
N	1094	5286	6281	752	3125	2404
Panel B: Long-run elasticities (ξ^{LR})						
Income	1.084***	0.759***	0.818***	0.983***	0.801***	0.656***
	(0.219)	(0.089)	(0.095)	(0.252)	(0.141)	(0.134)
Price	0.209	-0.409***	-0.416***	-0.565***	-0.239***	0.429*
	(0.419)	(0.111)	(0.107)	(0.122)	(0.033)	(0.240)
N	1072	5167	6143	735	3055	2353

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on total electricity consumption per capita (TC) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific trends and country-fixed effects. Delta method calculated standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Variable definitions are available in Appendix Table A1.

Table A6: Non-linear elasticities (η) of income and price on electricity consumption per capita (EC) by region and income level

	Region			Income level		
	(1) LAC	(2) Non-LAC	(3) All	(4) LIC	(5) MIC	(6) HIC
Panel A: Short-run elasticities (η^{SR})						
Income	0.750***	0.374***	0.452***	0.701***	0.547***	0.174
	(0.148)	(0.085)	(0.082)	(0.170)	(0.112)	(0.128)
Price	0.057	-0.231***	-0.260***	-0.296***	-0.217***	0.225***
	(0.063)	(0.026)	(0.026)	(0.078)	(0.017)	(0.038)
N	1094	5286	6281	752	3125	2404
Panel B: Long-run elasticities (η^{LR})						
Income	1.010***	0.634***	0.683***	0.947***	0.731***	0.434***
	(0.230)	(0.082)	(0.083)	(0.241)	(0.142)	(0.103)
Price	0.226	-0.418***	-0.429***	-0.542***	-0.239***	0.391*
	(0.419)	(0.117)	(0.114)	(0.108)	(0.033)	(0.228)
N	1072	5167	6143	735	3055	2353

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on total electricity consumption per capita (TC) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific trends and country-fixed effects. Delta method calculated standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Variable definitions are available in Appendix Table A1.

Table A7: Linear elasticities (ξ) of income and price on total energy supply per capita (TES) by region: Share of renewable sources in electricity generation

	Low-share			High-share		
	(1) LAC	(2) Non-LAC	(3) All	(4) LAC	(5) Non-LAC	(6) All
Panel A: Short-run elasticities (ξ^{SR})						
Income	0.691***	0.457***	0.445***	0.670***	0.396***	0.451***
	(0.103)	(0.069)	(0.078)	(0.073)	(0.098)	(0.085)
Price	-0.149	-0.096**	-0.102***	-0.243***	-0.143***	-0.153***
	(0.167)	(0.041)	(0.038)	(0.092)	(0.017)	(0.015)
N	574	4045	4540	520	1241	1741
Panel B: Long-run elasticities (ξ^{LR})						
Income	0.949***	0.653***	0.600***	0.897***	0.434***	0.535***
	(0.133)	(0.098)	(0.092)	(0.105)	(0.151)	(0.127)
Price	-0.351	-0.160***	-0.152***	-0.829*	-0.231***	-0.214***
	(0.565)	(0.051)	(0.042)	(0.469)	(0.030)	(0.025)
N	561	3956	4440	511	1211	1703

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on total energy supply per capita (TES) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific trends and country-fixed effects. Delta method calculated standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Variable definitions are available in Appendix Table A1.

Table A8: Linear elasticities (ξ) of income and price on total energy supply per capita (TES) by income: Share of renewable sources in electricity generation

	Low-share			High-share		
	(1) LIC	(2) MIC	(3) HIC	(4) LIC	(5) MIC	(6) HIC
Panel A: Short-run elasticities (ξ^{SR})						
Income	0.760***	0.341***	0.418***	0.359***	0.462***	0.747***
	(0.169)	(0.095)	(0.138)	(0.120)	(0.148)	(0.139)
Price	-0.264**	-0.031	0.110	-0.113***	-0.151***	0.088
	(0.112)	(0.064)	(0.089)	(0.034)	(0.018)	(0.086)
N	411	2159	1970	341	966	434
Panel B: Long-run elasticities (ξ^{LR})						
Income	0.999***	0.431***	0.659***	0.178	0.698***	0.763***
	(0.272)	(0.113)	(0.156)	(0.130)	(0.207)	(0.125)
Price	-0.128	0.137	0.017	-0.063	-0.229***	0.266
	(0.155)	(0.368)	(0.258)	(0.045)	(0.033)	(0.390)
N	400	2112	1928	335	943	425

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on total energy supply per capita (TES) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific trends and country-fixed effects. Delta method calculated standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Variable definitions are available in Appendix Table A1.

Table A9: Non-linear elasticities (η) of income and price on total energy supply per capita (TES) by region: Share of renewable sources in electricity generation

	Low-share			High-share		
	(1) LAC	(2) Non-LAC	(3) All	(4) LAC	(5) Non-LAC	(6) All
Panel A: Short-run elasticities (η^{SR})						
Income	0.731***	0.454***	0.430***	0.698***	0.600***	0.648***
	(0.063)	(0.099)	(0.084)	(0.075)	(0.156)	(0.092)
Price	-0.151	-0.098**	-0.119**	-0.264***	-0.141***	-0.148***
	(0.158)	(0.039)	(0.047)	(0.095)	(0.017)	(0.015)
N	574	4045	4540	520	1241	1741
Panel B: Long-run elasticities (η^{LR})						
Income	0.970***	0.635***	0.586***	0.933***	0.745***	0.837***
	(0.113)	(0.118)	(0.100)	(0.076)	(0.210)	(0.117)
Price	-0.350	-0.172***	-0.167***	-0.850*	-0.223***	-0.201***
	(0.556)	(0.050)	(0.051)	(0.485)	(0.029)	(0.021)
N	561	3956	4440	511	1211	1703

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on total energy supply per capita (TES) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific trends and country-fixed effects. Delta method calculated standard errors in parenthesis. * p<0.1, ** p<0.05, *** p<0.01. Variable definitions are available in Appendix Table A1.

Table A10: Non-linear elasticities (η) of income and price on total energy supply per capita (TES) by region: Share of renewable sources in electricity generation

	Low-share			High-share		
	(1) LIC	(2) MIC	(3) HIC	(4) LIC	(5) MIC	(6) HIC
Panel A: Short-run elasticities (η^{SR})						
Income	0.656***	0.368***	0.314***	0.469***	0.525***	0.763**
	(0.137)	(0.102)	(0.119)	(0.095)	(0.124)	(0.302)
Price	-0.283***	-0.025	0.089	-0.133***	-0.149***	0.087
	(0.100)	(0.066)	(0.085)	(0.034)	(0.016)	(0.085)
N	411	2159	1970	341	966	434
Panel B: Long-run elasticities (η^{LR})						
Income	0.842***	0.440***	0.501***	0.296**	0.777***	0.828***
	(0.207)	(0.118)	(0.136)	(0.140)	(0.172)	(0.232)
Price	-0.160	0.139	-0.003	-0.093*	-0.222***	0.262
	(0.163)	(0.370)	(0.242)	(0.049)	(0.031)	(0.382)
N	400	2112	1928	335	943	425

Notes: This table presents both short-run (Panel A) and long-run (Panel B) elasticities of income and price on total energy supply per capita (TES) using Ordinary Least Squares estimations (OLS). Elasticities are disaggregated by regions (Latin America and the Caribbean (LAC), Non-LAC, and all countries) and income levels (Low-Income Countries (LIC), Middle-Income Countries (MIC), and High-Income Countries (HIC)). All estimations include country-specific trends and country-fixed effects. Delta method calculated standard errors in parenthesis. * $p<0.1$, ** $p<0.05$, *** $p<0.01$. Variable definitions are available in Appendix Table A1.