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Looking beyond subsidies: Understanding the complexity of household energy consumption dynamics of Ecuador's main cities

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ABSTRACT

Energy consumption serves the vital purposes of meeting needs, producing goods, and ensuring comfort. Notably, Ecuador's residential sector plays a significant role in the overall energy system, accounting for 13.2 % of the total energy demand. This study delves into Quito and Guayaquil's urban residential energy demand, employing a Bottom-up approach and introducing eco-innovation as an innovative management strategy. It aims to examine disparities among household profiles regarding energy consumption and associated factors, identify relations that elucidate critical concepts such as energy expenditure and eco-innovation, and assess the extent to which eco-innovation facilitates responsible household energy consumption practices. Various factors driving energy consumption are identified, including socio-demographic features, housing arrangements, infrastructure, energy consumption patterns, and environmental awareness. Additionally, it explores cross-sectional factors such as energy costs, technological advances, cultural influences, and energy policies. Robust statistical analysis reveals significant differences between socioeconomic profiles, including ANOVA and the Tukey HSD posthoc test. Moreover, the Multiple Correspondence Analysis technique uncovers relationships between variables, shedding light on energy expenditure and eco-innovation related to household energy consumption. The findings underscore that high-income households predominantly benefit from energy subsidies, and the eco-innovation process varies based on socioeconomic profiles. This study fills a crucial gap in the literature on domestic energy consumption in urban settings like Ecuador, characterized by enduring energy subsidies. It offers a comprehensive model for understanding household behavior diversity and underscores the pivotal role of eco-innovation in fostering responsible energy consumption.

1. Introduction

Energy plays a pivotal role in economic development (Katircioglu et al., 2019), enhancing living standards and fostering individual and collective advancement of societies (González-Eguino, 2015). Consequently, energy consumption facilitates fulfilling needs, producing goods, and providing comfort (Bhattacharyya, 2019). Carbon dioxide (CO_2) emissions from fossil fuels constitute the most significant energy-related footprint (Jiang et al., 2022; Y. Wang et al., 2019), comprising 71.6 % of global emissions in 2022 (Crippa et al., 2022). The energy requirements vary depending on location, technology, and users. Given that cities differ in population, local conditions, and topography, the energy supply must align with the realities of development and progress (Bhattacharyya, 2019; Mi et al., 2020; OLADE, 2017; Robalino-López, Mena-Nieto, et al., 2014).

Ecuador's residential sector holds substantial significance, accounting for 13.2 % of the total energy demand. It represents the majority in terms of the number of users, comprising 88 % of the total users registered in the electricity system (MEER, 2016a). The research analyzes the urban residential energy demand in Ecuador's two major cities, Quito and Guayaquil, using a Bottom-up (BU) approach. This approach acknowledges societal diversity, recognizing that different groups or segments exhibit varied behaviors (Sohre & Schubert, 2022). Forty-eight variables influencing energy consumer behavior are examined based on the conceptual model developed by Araujo et al. (Araujo et al., 2021).

The study utilizes primary data to identify energy consumption drivers, employing eco-innovation as a novel management strategy to effect tangible transformations in specific sectors and contexts. Findings

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are presented in profiles based on geographical breakdowns and household monthly income levels, employing robust statistical analysis methods. Using ANOVA and the Tukey HSD post hoc test revealed significant differences between profiles, particularly marked between socioeconomic classes, as energy expenditure correlates with economic income and the ability to access consumer technologies. It facilitates the identification of true beneficiaries of energy subsidies and enables discussions on their appropriate realignment. Finally, the multiple correspondence analysis (MCA) technique is employed to discern the relationship between variables and associations that explain energy expenditure and eco-innovation related to household energy consumption.

In this context, the first analysis group comprises low-income households with monthly incomes less than or equal to $522.00 (HT1). The second group comprises households with average monthly incomes ranging from $523.00 to $1291.00 (HT2). Lastly, high-income households with monthly incomes greater than or equal to $1292.00 (HT3). As a result, HT3 households spend 2.34 times more energy than HT2 and 5.34 times more than HT1. Additionally, HT2 benefits 1.8 times more from energy subsidies than HT1, and HT3 benefits three times more than HT1. Consequently, high-income households primarily benefit from energy subsidies due to their greater access to energy sources and equipment.

The eco-innovation process, comprising four stages based on environmental awareness, has been integrated to comprehend and describe the behavior and attitude of energy consumers in the urban residential sector. These stages include i) Notion and reflection, ii) Cognitive, iii) Experimentation and action, and iv) Attitude and lifestyle. The profiles exhibit higher eco-innovation values in the initial stages, declining as complexity increases. Despite favorable concerns, notions, reflections, and knowledge, significant strides toward efficient energy consumption are still needed, underscoring the importance of environmental awareness as a driver of responsible energy consumption (Iliopoulos et al., 2021). The price of energy (PE) variable impacts all household types, indicating limited incentives for behavioral change with low energy costs.

The analysis addresses a gap in the literature concerning domestic energy consumption in urban areas, particularly in the energy context of Ecuador, where energy subsidies have been prevalent for nearly five decades. This detailed analysis seeks to identify inequities in energy consumption and subsidy distribution, informing equitable energy policies and promoting eco-innovation for sustainable practices. By examining how income levels affect energy use and subsidies, the study highlights disparities that need targeted interventions. The findings guide the design of fairer subsidy programs, ensuring benefits reach vulnerable households and preventing resource misallocation. They also support the development of eco-innovation strategies for responsible energy consumption across socioeconomic groups.

What sets our study apart is its incorporation of the Bottom-up approach and eco-innovation as a management tool. Consequently, the resulting model reveals households' diverse behavior, emphasizing the importance of comprehending consumption dynamics for effective energy planning and management (Anvari et al., 2022) tailored to each context's unique realities and specific needs. These insights are relevant for policymakers, regulators, researchers, NGOs, and the public, providing evidence to support targeted subsidies, sustainable technology adoption, and refined urban energy governance.

The research aims to address three primary research questions: (1) What disparities exist among the three household profiles (HT1, HT2, and HT3) concerning energy consumption and associated factors? (2) Are there correlations among the analyzed variables that elucidate critical concepts such as energy expenditure and eco-innovation? (3) To what extent can eco-innovation facilitate responsible household energy consumption practices?

The paper is structured as follows: Section 2 delves into the theoretical foundation of energy consumption and eco-innovation, grounded in environmental awareness. Section 3 outlines our methodology and presents the conceptual model of energy consumption behavior within the urban residential sector. Section 4 presents the findings, detailing the energy consumption characteristics of the three profiles. Section 5 synthesizes these profiles using literature-based and empirical evidence, the sensitivity analysis of transitions between profiles, and a comparison with data from neighboring countries to understand the particularities of each context. Finally, Section 6 discusses the conclusions and the implications of these findings and best practices.

2. Theoretical background

2.1. The link between urbanization and energy

The discovery and utilization of energy resources have profoundly shaped socioeconomic development (Oviedo-Salazar et al., 2015). Developing countries are distinguished by the systemic existence of an inequality gap, which conceals differences in historical processes and socioeconomic development levels (Bernal-Meza, 2016; Winchester, 2006). Furthermore, there is a spatial distribution characterized by the concentration of populations and economic activities in urban areas (Cardonoso et al., 2014).

In turn, the standards of developed countries drive developing nations toward increasingly predominant energy consumption levels (Robalino-López, García-Ramos, & Mena-Nieto, 2014). Consequently, the energy needs to be met are specific to context, location, technology, and users (Bhattacharyya, 2019). It is necessary to examine energy systems from a unique perspective, considering aspects such as i) population growth, ii) urbanization dynamics (Jebaraj & Iniyan, 2006), iii) the gap between urban and rural areas (Urban, 2009), iv) a fossil fuel-based energy matrix, v) a polluting and inefficient transportation model (CEPAL, 2018), and vi) existing energy subsidies.

The data reveals that in Latin America and the Caribbean, 82 % of the population resides in urban areas (World Bank, 2022b). In the case of Ecuador, this figure reaches 64 % (World Bank, 2022a), with Quito and Guayaquil, the two main cities, representing 32 % of the total population of the country and 33 % of the total number of households (INEC, 2010a, 2010b). Consequently, cities and the urban residential sector constitute significant energy players in social, economic, and environmental development (Tan et al., 2016). Moreover, the building sector has been identified as a key contributor to global energy consumption, accounting for 27 % of total energy use and 17 % of CO_2 emissions. It underscores the need for more effective urban energy policies that integrate both technological and behavioral strategies to mitigate energy demand growth and environmental impact (Xu, Hwang, & Lu, 2021; Xu, Lu, et al., 2021).

An appropriate study of energy systems is needed, incorporating contextual factors that enable intervention in production and consumption patterns to harmoniously coordinate economic, social, and environmental protection endeavors.

2.2. Energy consumption in households

Energy consumption is deeply intertwined with daily activities like cooking, showering, and commuting (Maréchal & Holzemer, 2015), making energy commodities indispensable for households and a significant portion of their budget (Advani et al., 2013; Jiménez & Yépez-García, 2017). Structural, cultural, social, and institutional factors shape energy usage, with households acting as both adopters and enforcers of prevailing norms and paradigms (Maréchal & Holzemer, 2015). Economic variables like income and energy prices, as well as non-economic factors such as location, household composition, and appliance availability, influence energy consumption patterns. Similarly, demographics like age, gender, education, employment, and household head's status also play a role (Jiménez & Yépez-García, 2017; Zhou & Yang, 2016).

Also, urban households generally exhibit higher energy consumption and expenses than rural ones (Jiménez & Yépez-García, 2017), with higher-income households also spending more on energy than lower-income groups (Jiménez & Yépez-García, 2017; Mi et al., 2020). Wealthier consumers typically own more appliances and vehicles and have larger households, leading to increased energy consumption and expenditure (Jiménez & Yépez-García, 2017; Keho, 2016).

The energy price significantly influences consumption behavior, with lower energy expenses relative to household income reducing incentives to change consumption habits (Rashid et al., 2017). Higher education levels of household heads are positively associated with higher income and purchasing power, indirectly promoting greater energy consumption (Lee, 2013; Rashid et al., 2017; S. Wang et al., 2020). In wealthier households, electricity and gas expenses tend to represent a smaller percentage of the budget, while spending on transportation fuels increases (Jiménez & Yépez-García, 2017).

Cleaner products, appliances, and environmental regulations can offer competitive advantages that can reduce energy consumption (Keho, 2016). Additionally, public infrastructure plays a crucial role by limiting specific fuel options on the supply side, thus reducing dependence on particular technologies and fuels (Lee, 2013). While a technocentric approach to addressing energy consumption drivers focuses on efficiency through technical and technological innovations, it's crucial to acknowledge the significance of integrating social, cultural, behavioral, and lifestyle factors in shaping residential energy consumption (Adua, 2020).

Recent research has highlighted the importance of behavioral interventions for energy conservation. Studies indicate that nearly 80 % of variations in energy consumption are attributed to occupant behavior (Xu, Lu, et al., 2021). Consequently, behavioral intervention strategies are classified into antecedent strategies and consequence-based strategies, which include feedback and monetary incentives (Abrahamse et al., 2005). While antecedent interventions can prevent inefficient behaviors before they occur, consequence-based strategies, such as informational feedback and rewards, have shown inconsistent results, with only minimal and short-term reductions (Xu, Lu, et al., 2021). Market-based interventions that integrate feedback mechanisms and financial incentives have been proposed to enhance energy efficiency by engaging consumers, setting clear energy-saving goals, and addressing behavioral barriers that hinder the adoption of sustainable practices (Xu, Lu, et al., 2021).

Therefore, this research adopts a comprehensive perspective by considering economic, technological, and behavioral variables. This ensures a holistic understanding of energy consumers, mitigates biases, and avoids misleading conclusions.

2.3. Eco-innovation

A comprehensive approach that encompasses social, economic, and environmental dimensions is imperative to address escalating global challenges in ecological sustainability and social inequality. The OECD and the Brundtland Report recognize innovation as a fundamental driver for sustainable development and (Brundtland, 1987) underscore the need to innovate for sustainability, encompassing the creation, redesign, adaptation, and dissemination of environmentally sound technologies.

While technological innovations are pivotal, they alone cannot drive ecological and social transformation, often neglecting the intricate dynamics of production, consumption, and societal lifestyles (Pelfini et al., 2012). Hence, inclusive approaches are required, considering broader social changes and the roles of individuals, households, and organizations in energy use (Lopes & Antunes, 2022).

Addressing existing disparities within and between nations, especially in developing countries, is paramount. Innovation dynamics must prioritize social equity while generating ecological and economic benefits (Albornoz, 2013), necessitating a fundamental shift where innovations equally consider economic, ecological, and social dimensions (Boons & Lüdeke-Freund, 2013). To confront these challenges, eco-innovation has emerged as a leading management tool. While lacking a universally accepted definition, eco-innovation primarily aims to reduce negative environmental impacts through various types of innovations, extending beyond environmental considerations (Alonso-Almeida et al., 2016; Klewitz & Hansen, 2014; Kowalska, 2017).

Kemp and Pearson Field define eco-innovation as creating, assimilating, or exploiting novel products, processes, services, or management methods within organizations. These innovations mitigate environmental risks, pollution, and negative impacts of resource use, including energy consumption, while enhancing the quality of life for all (Reid & Miedzinski, 2008). They emphasize that eco-innovation is not merely a curative technology but a broad and multifaceted process (Bleischwitz et al., 2009).

Recognizing the necessity for holistic perspectives, sustainability-oriented innovations or sustainable innovations have emerged, contributing to all three dimensions of sustainable development and being sensitive to spatial, temporal, and cultural contexts (Boons & Lüdeke-Freund, 2013; Klewitz & Hansen, 2014; Kowalska, 2017; Maier et al., 2020).

De Jesus et al. (de Jesus et al., 2016) proposed that eco-innovation emphasizes technological advancements and holistic combinations as a significant and demonstrable way to achieve sustainable development results (European Commission & Directorate-General for Environment, 2013). Studies conducted in G7 countries show that eco-innovation indirectly benefits the environment and facilitates sustainable urbanization (Ahmad et al., 2021).

Transcending technological determinism, eco-innovation considers changes in norms, cultural values, and institutional structures, making it a multidimensional process (Alonso-Almeida et al., 2016). The Oslo Manual highlights the necessity of changing production methods and developing new consumption habits to effect significant system transformations (OECD, 2018).

Eco-innovation processes involve various actors, actions, activities, and impacts, encompassing the social and cultural environment (de Jesus et al., 2016). Knowledge exchange and collaborative processes are crucial (Avoyan, 2023), leading to changes in production, transformation, distribution, market approaches, and consumption patterns of technologies, products, processes, and services. This comprehensive strategy promotes the efficient and responsible use of natural resources, contributing to changes in energy consumption and production patterns, as well as their transformation, distribution, and commercialization in specific contexts.

2.4. Context of energy consumption in the urban residential sector of Ecuador

In Ecuador, petroleum derivative subsidies have been a longstanding policy since 1974. Initially, they were aimed at promoting specific industries and improving energy accessibility (Espinoza & Guayanlema, 2017). However, these subsidies have persisted for nearly 50 years, leading to inefficiencies in energy demand. In 2021, imports of petroleum derivatives in Ecuador amounted to 56,898 thousand barrels, with diesel accounting for 41.8 %, gasoline for 31.5 %, and LPG for 22.5 % (EP Petroecuador, 2022).

Analyzing the commercial prices of petroleum derivatives offers insight into the extent of liquid fuel subsidies. In 2016, a liter of gasoline in Ecuador cost $0.61, compared to $0.68 in Colombia and $0.99 in Peru. Similarly, the price per liter of diesel in Ecuador was $0.29, while it was $0.64 in Colombia and $0.88 in Peru (World Bank, 2016).

Efforts to address this inconsistency include Executive Decree 619, issued on December 26, 2018, which liberalized the price of super gasoline (Ministry of Energy and Mines, 2018). Additionally, Executive Decree 1054, dated May 19, 2020, established a monthly fuel trading system controlled by the government, implementing price fluctuation bands to ensure relative stability in the extra gasoline and diesel market (Ministry of Energy and Mines, 2020).

Ecuador has heavily subsidized LPG, making it widely used for cooking in approximately 85 % of urban homes. The country has had a robust LPG market, offering 15 kg cylinders at a fixed price of $1.60 since 2000 (Gould et al., 2020). However, the actual cost per cylinder is estimated to be $15.00 (Villavicencio & Ruiz, 2019).

In July 2007, the Ecuadorian government introduced the "dignity rate" for electricity, set at $0.04 per kWh for residential and low-consumption customers, aiming to establish a cross-subsidy. However, electricity costs have persisted at higher levels despite this initiative, reaching $0.0929 per kWh by 2022 (Ministry of Energy and Mines, 2022). Research suggests that actual electricity costs may range between $0.14 and $0.16 per kWh (Schaffitzel et al., 2019). These disparities highlight the complexity of energy subsidies and underscore the need for more accurate pricing mechanisms to ensure economic sustainability.

The National Electricity Plan for the period 2016 to 2025 emphasizes the critical role of the residential sector in the electricity system. The residential sector accounts for 88 % of total users, compared to 10 % for the commercial sector and 2 % for the industrial sector (MEER, 2016a). Given the substantial contribution of the residential sector, there has been a focus on implementing energy efficiency initiatives to enhance energy consumption patterns.

Various energy efficiency projects have targeted the residential sector: i) The RENOVA plan (2012–2016), which involved replacing high-energy consumption refrigerators with domestically manufactured efficient equipment. By 2016, 95,652 refrigerators were replaced nationwide, leading to an approximate reduction of 38,200 MWh/year of electricity (MEER, 2016b). ii) The Efficient Lighting plan (2008–2014), which deferred tariffs for high-efficiency light bulbs. Sixteen million incandescent bulbs were replaced with saving bulbs, resulting in an estimated reduction of 287,000 MWh/year (MEER, 2016b). iii) The Efficient Cooking plan (2014 - present) aimed at transitioning LPG consumption to electricity for cooking. As of December 2016, 579,637 families had benefited from this incentive (MEER, 2016b).

Initially aiming to build 3.5 million homes by 2018, representing an additional consumption of around 1000 MW at the national level (Purcell & Martinez, 2018), the goal was delayed until 2023 and eventually abandoned in favor of a slower, more market-dependent model (Gould et al., 2020). This demand incentive policy has been criticized as an ad hoc response to excess supply (Purcell & Martinez, 2018).

3. Methodology and data

This research aims to diagnose and characterize household behaviors related to responsible energy use in Ecuador's two major cities. The study utilizes qualitative analysis to identify contextual factors and emphasizes eco-innovation as a management strategy.

3.1. Data collection and sample size

Quantitative analysis involves primary data gathered through simple random sampling in Ecuador's two largest cities. In Quito, 620 observations were collected in October 2021, while in Guayaquil, 474 observations were gathered in August 2022, resulting in a total of 1094 observations. Both cities represent approximately 5.5 million people and 1.46 million households, accounting for over 32 % of all households (INEC, 2022). The sample size surpasses the minimum requirement of 385 households per city, calculated based on a 95 % confidence level with a 5 % margin of error. This ensures that the sample is statistically representative and significantly reduces bias in the results.

3.2. Analytical approach

The conceptual model integrates 48 endogenous and exogenous variables distributed across four categories according to Araujo et al. (2021) and following Vasseur et al. (2019) and, Ofetotse et al. (2021), namely: i) Spatial and sociodemographic characteristics (SSC), ii) Family and housing structure (FHS), iii) Infrastructure and energy consumption patterns (ICP), and iv) Eco-innovation process (EIP), as depicted in Table 1. Consequently, the research utilizes a disaggregated analysis within the Bottom-up approach, classifying households into three distinct profiles based on their energy consumption behaviors.

3.3. Applied statics and analysis of variance (ANOVA)

The analysis initially employs robust parametric statistical methods to address outliers in the sample, as they can influence point estimators and their statistical efficiency (Sottile & Frumento, 2022). Specifically, the study uses trimmed mean, winsorized mean, and one-step M-estimator techniques. Secondly, Analysis of Variance (ANOVA) is utilized to compare variances between means of different groups, verifying significant differences between city profiles and socioeconomic groups. The Tukey HSD post hoc test is also applied, enabling multiple comparisons between the various profiles based on city and income levels. At this stage, the research identifies three energy consumption profiles in the urban residential sector: i) HT1 for low-income households, ii) HT2 for households with average monthly income, and iii) HT3 for high-income households.

After thoroughly reviewing the primary data, the next step was to process and prepare the dataset systematically for deeper analysis. This involved converting numerical data into appropriate categorical formats and implementing a structured variable selection process to identify key variables relevant to the research questions.

3.4. Structured variable selection process

The theoretical model comprises 48 variables designed to categorize urban household consumers effectively (Araujo et al., 2021). Feature selection is essential for improving data analysis (Ofetotse et al., 2021). To ensure a structured approach, variable selection was conducted in three phases: (1) grouping related variables to enhance interpretability and reduce dimensionality, (2) eliminating redundant variables based on statistical contributions, and (3) excluding consumer perception and preference variables to minimize subjectivity and noise.

First, related variables were grouped based on their purpose to capture underlying dynamics, improve interpretability, and reduce dimensionality, as Ofetotse et al. (2021) suggested. This approach simplified the dataset and revealed meaningful patterns. For instance, Energy Expenses aggregate five household expenditure components: electricity, LPG, low-octane gasoline, premium gasoline, and diesel.

Second, redundant variables were removed, following Hisschemöller et al. (2022). For example, the latter was retained between the City and the District Zone for its greater granularity (27 levels vs. 2 for the City). Third, consumer perception and preference variables were excluded after a thorough review, as they are subjective and do not provide stable patterns for analysis (Abrahamse et al., 2005). This structured selection process resulted in nine key variables, enabling a robust analysis of household energy consumption patterns through Multiple Correspondence Analysis (MCA).

3.5. Multiple Correspondence Analysis (MCA)

The Multiple Correspondence Analysis (MCA) technique was employed as the main analytical tool, following Dubois et al. (2019) and Hisschemöller (2022). This method was chosen for its ability to explore complex relationships between multiple categorical variables and to reveal underlying patterns and associations within the data. In this case, 9 key variables were selected for the analysis, with the objective of identifying how they interact and influence energy consumption dynamics in the target population. By conducting this analysis, the aim was not only to identify relationships between variables but also to uncover how these associations contribute to a broader understanding of energy

Table 1
Conceptual model of energy consumption for the urban residential sector (Araujo et al., 2021).

Categories	Spatial and sociodemographic characteristics		Family and housing structure		Infrastructure and energy consumption patterns		Eco-innovation Process	
	(SSC)		(FHS)		(ICP)		(EIP)	
Endogenous variables	Na	Disaggregation into urban and rural areas	Nf	Family structure and characteristics of the head of household	Nd	Infrastructure and patterns of use of artifacts and devices	Nei	Notion and reflection
	Ng	Geographical disaggregation	Nh	Description and type of dwelling	Nv	Infrastructure and patterns of use of own vehicles		Cognitive
	Nl	Location of housing in parishes						Experimentation and action
	Ns	Income and monthly energy expenses						Attitude and lifestyle
Exogenous Variables	**PE** – Price of energy by type of fuel **TMT** – Technological and market trends **ECA** – Ecological cultural atmosphere **ELR** – Current energy laws and regulations							

consumption dynamics. Fig. 1 illustrates the methodology for understanding Ecuador's dynamics of household energy consumption.

4. Results

In Ecuador, studies on residential energy consumption primarily rely on publicly accessible data, with the latest official survey on final energy usage dating back to 2013 (CONELEC, 2013). Recent research efforts have focused on classifying residential consumers by economic status and understanding appliance usage patterns and the adoption of energy-efficient technologies (Moya et al., 2022). Additionally, studies have explored energy consumption patterns in rural households, particularly regarding LPG usage (Gould et al., 2020). These studies are instrumental in identifying factors like eco-innovation that can address environmental concerns and drive sustainable development efforts.

4.1. Applied statistics in the analytical model

4.1.1. Spatial and sociodemographic characteristics (SSC)

The study was conducted in Ecuador's major cities, Quito and Guayaquil, each characterized by distinct climates. Quito, situated in the Andes at an altitude of 2850 m, maintains an annual average temperature of 15.6 °C, with pronounced dry and wet seasons. Guayaquil, located on the Pacific coast, experiences a mean temperature of 28 °C and encounters heavy rainfall from January to April, followed by lighter rain between June and November (Guevara et al., 2021). The study's findings are presented separately for Quito and Guayaquil, with households classified into three income profiles: HT1 (income ≤ $522.00 per month), HT2 (income between $523.00 and $1291.00), and HT3 (income ≥ $1292.00 per month). The analysis focuses on variables related to monthly income and expenses by fuel type (Ns), with detailed findings outlined in Table 2.

For HT1 households, LPG and electricity expenses constitute 3.9 % of their monthly income in Quito and 3.6 % in Guayaquil, where vehicle ownership is uncommon. In Quito, HT2 households with a monthly income of $910.00 allocate 5.3 % to energy consumption due to vehicle ownership, while in Guayaquil, they spend 3.7 % of their monthly income on energy without vehicle ownership. HT3 households, with a monthly income of $1880.00, allocate 4.7 % of their income in Quito and 5.5 % in Guayaquil to monthly energy expenditure. These households primarily consume Extra Gasoline for their vehicles, with Super Gasoline and Diesel being less significant. In summary, LPG and

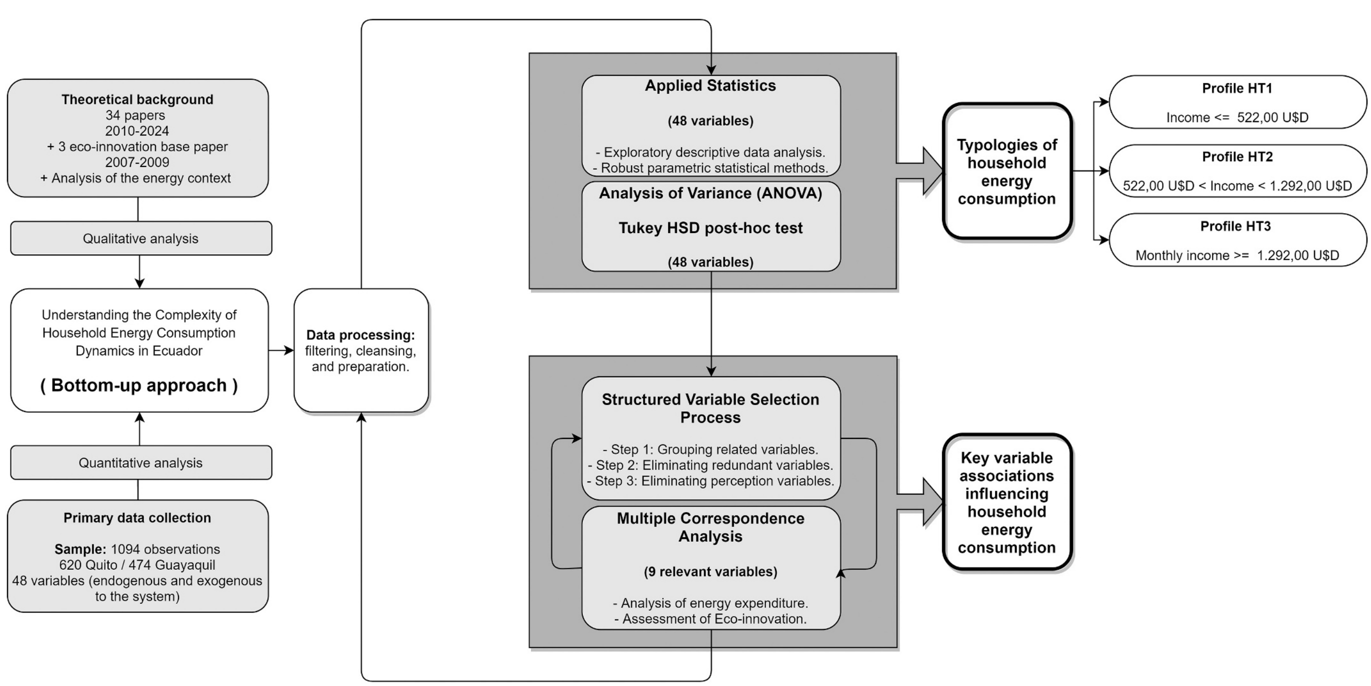


Fig. 1. Research methodology.

Table 2
Monthly income and expenses related to energy consumption.

		HT1		HT2		HT3	
		Quito	Guayaquil	Quito	Guayaquil	Quito	Guayaquil
Average monthly income [U$D]		$480.00		$910.00		$1.880.00	
Average monthly expenses [U$D]	LPG	$3.50	$2.00	$3.50	$3.50	$7.50	$3.50
	Electricity	$15.00	$15.00	$15.00	$30.00	$30.00	$30.00
	Gasoline Extra/Ecopaís	$0.00	$0.00	$30.00	$0.00	$50.00	$70.00
	Gasoline Super	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	Diesel	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Average monthly energy expenses [U$D]		$18.50	$17.50	$48.50	$33.50	$87.50	$103.50

electricity are essential for households in Ecuador, regardless of income level, while liquid fuels are not. The results indicate that LPG consumption remains relatively stable across different income groups, whereas higher-income households spend more on transportation fuels. As income increases, the proportion of expenses allocated to electricity and gas gradually decreases (Guevara et al., 2021).

4.1.2. *Family and housing structure (FHS) and infrastructure and household energy consumption patterns (ICP)*

Table 3 presents data on household heads' age, gender, education,

Table 3
Characteristics of family and housing structure and household energy consumption patterns.

		HT1		HT2		HT3	
		Quito	Guayaquil	Quito	Guayaquil	Quito	Guayaquil
Household head age		45 to 54 years	35 to 44 years	45 to 54 years	25 to 34 years	45 to 54 years	35 to 44 years
Household head gender		Male 59.1 %	Male 55.8 %	Male 67.9 %	Male 57.2 %	Male 65.8 %	Male 78.8 %
Household head education		Secondary 52.5 %	Secondary 71.5 %	Secondary 47.0 %	Secondary 75.0 %	Fourth level 50.9 %	Third level 51.5 %
Household members		4	3	4	4	3	4
Family structure (age groups)		1 child/youth 3 adults	1 child/youth 2 adults	1 child/youth 3 adults	1 child/youth 3 adults	3 adults	1 child/youth 3 adults 2 children/youth 2 adults
Description of habitual residence %		Single family Household 69.7 %	Single family Household 89.1 %	Single family Household 67.0 %	Single family Household 85.2 %	Single family Household 52.7 % Apartment building 3 or more units 27.2 %	Single family Household 66.6 % Multifamily house 22.2 %
Square meters of construction %		< 100 m2 61.9 %	< 100 m2 72.1 %	100 to 150 m2 48.6 %	100 to 150 m2 51.8 %	100 to 150 m2 34.2 % 150 to 200 m2 30.7 %	100 to 150 m2 61.1 %
Type of fuel or energy used for cooking %		Gas 93.4 %	Gas 88.9 %	Gas 85.5 %	Gas 81.4 %	Gas 71.9 %	Gas 84.8 %
Water heating technology for taking a shower %		Electric shower 72.4 %	Electric shower 63.6 %	Electric shower 60.6 %	Electric shower 64.5 %	Gas water heater 50.9 % Electric shower 36.0 %	Gas water heater 39.4 % Electric heaters 33.3 %
Availability of APPLIANCES (WHITE LINE)	Domestic kitchen	1	1	1	1	1	1
	Shower	1	1	1	2	2	2
	Microwave oven	1	–	1	–	1	1
	Refrigerator / fridge	1	1	1	1	1	1
	Washer / dryer / dishwasher	1	1	1	1	1	2
	Heater / air conditioner	–	–	–	–	–	1
	Coffee / tea maker / blender	1	1	1	1	2	1
	Clothes iron / Dryer and/or hair iron	1	–	2	1	2	2
Availability of ELECTRONIC DEVICES (BROWN LINE)	TVs / screens	1	1	2	1	2	2
	Video players / video game / consoles	–	–	–	–	–	–
	Sound players	1	–	1	–	1	1
	Smartphones / tablets	3	2	3	3	3	4
	PC / computer / laptop	1	–	2	1	2	2
Availability and main type of own vehicle %		–	–	Small / medium gasoline car 58.6 %	–	Small / medium gasoline car 64.9 %	Small / medium gasoline car 87.9 %

household size, family structure, residence type, and usage patterns of appliances, electronic devices, and vehicles. Household heads generally fall within the age range of 35 to 54 years, with males being predominant. Education levels vary: HT1 and HT2 households typically have completed secondary school, while HT3 households often hold higher academic degrees. Higher-income households tend to attain higher education levels, indirectly influencing energy consumption. On average, households comprise around four members, encompassing adults and children. HT1 households usually inhabit single-family homes under 100 m2, whereas HT2 and HT3 households often occupy detached or attached single-family homes ranging from 100 to 150 m2. Single-family residences are prevalent, with housing construction areas expanding with academic achievements and income levels.

In HT1 households, LPG is the predominant cooking fuel, used in 90 % of cases, while electric stoves are less common. Electric showers serve as the primary water heating technology in HT1 and HT2 households, while HT3 households exhibit a variety of technologies. In Quito, gas water heaters are the most prevalent (50.9 %), followed by electric showers (36 %) and electric water heaters (11.4 %). In Guayaquil, gas and electric water heaters are equally distributed, at 39.4 % and 33.3 %, respectively, with solar panels being notably used at 18.2 %. Each household is equipped with one kitchen and one refrigerator, with the number of showers and appliances increasing with income. Televisions, smartphones, and computers are widespread in all household types and correlate with income levels. These differences arise from climate variations, technology accessibility, market reception, and initial investment requirements.

HT1 households do not own vehicles. In Quito, HT2 households possess one vehicle, while in Guayaquil, they do not. HT3 households in both cities typically own one vehicle, mainly small or medium-sized gasoline cars. This trend aligns with the analysis of monthly expenses, as vehicle owners incur direct liquid fuel costs. Consumption of "Super" gasoline and diesel is minimal in this demographic. Higher-income households tend to have more appliances, electronic devices, and vehicles, with property ownership associated with increased energy consumption.

4.1.3. Eco-innovation process based on the notion of environmental awareness (EIP)

Four stages of eco-innovation processes were proposed based on environmental awareness within the urban residential sector: i) Notion and reflection, ii) Cognitive, iii) Experimentation and action, and iv) Attitude and lifestyle. A 4-point scale was utilized to assess 12 statements: 1) Total disagreement = Not acceptable, 2) Little disagreement = Acceptable, 3) Little agreement = Notable, and 4) Total agreement = Outstanding.

The Notion and reflection stage (2 statements) involves fundamental energy consumption concepts. The Cognitive stage (4 statements) deepens understanding and knowledge. The Experimentation and action stage (4 statements) relates to responsible energy consumption behaviors. The Attitude and lifestyle stage (2 statements) promotes responsible environmental behaviors. Table 4 displays the assessments of these stages by household type and city.

Evaluation reveals lower notion and knowledge scores in HT1 households in Guayaquil, with marginal differences observed in HT2 and HT3 across cities. Interestingly, as household income increases, awareness of energy consumption also rises. Quito receives higher ratings in all household types for the experimentation and action stage. Two statements, Ac (3) = "My household participated in at least one of the efficient uses of energy programs promoted by the Government (Efficient Cooking Program or Renova Refrigerator Plan)" and Ac (4) = "In my household, we use some alternative or innovative technology that promotes efficient energy consumption such as sensors, household automation," exhibit notably low scores, indicating limited participation in government energy efficiency programs and the utilization of innovative energy-saving technologies.

Attitude and lifestyle scores remain consistent across cities and household types. Scores decline as the complexity of energy consumption thoughts and behaviors increases. Despite positive awareness and knowledge, substantial strides in efficient energy consumption are still necessary. The study highlights the role of environmental awareness as a driver for responsible energy use (Iliopoulos et al., 2021) and emphasizes the significance of knowledge-sharing and collaborative processes (Avoyan, 2023). Achieving fundamental transformations necessitates diverse approaches centered on sustainable environmental and social management rather than relying solely on technological determinism and economic incentives.

4.1.4. Exogenous variables to the system "Household of the urban residential sector"

Exogenous variables are categorized as follows: i) Price of energy by fuel type (PE), ii) Technological and market trends (TMT), iii) Ecological cultural atmosphere (ECA), and iv) Current energy laws and regulations (ELR). Findings reveal divergent energy perceptions in both cities. Guayaquil prioritizes the economic aspect (PE), whereas Quito emphasizes "Hydroelectric" and "Energy sources" linked to (TMT).

In addressing Ecuador's energy sector challenges, "The inefficient use of energy" prevails in Quito, linked to (ECA). In Guayaquil's HT1 and HT2 households, "Current energy subsidies" are prominent, representing PE. In HT3, "The lack of access to quality energy services" and "The high cost of energy-efficient technology" emerge, both tied to TMT. Household motivation primarily centers on "Economy in energy consumption" (PE), with "Environmental conservation" gaining significance in Guayaquil's HT2 and Quito's HT3 (ECA).

Regarding barriers hindering more energy-efficient actions, both HT1 and HT2 households nationwide identify "Lack of economic resources" as a critical challenge, along with the necessity for "Greater availability of energy-efficient equipment/technology," corresponding to PE and TMT. In Quito, HT3 households express a need for "More knowledge" and "Greater availability of energy-efficient equipment/technology," reflecting ECA and TMT. Conversely, Guayaquil highlights "Increased awareness" and "Financial resources," emphasizing PE and ECA. Table 5 summarizes results for exogenous variables by question, city, and household type.

The analysis reveals that the Price of energy (PE) variable predominates in Ecuadorian households, with people showing a strong inclination toward discount and incentive programs (Shippee, 1980). Only Quito's HT3 households are partially inclined toward the Ecological Cultural Atmosphere (ECA). Consequently, the Energy Price (PE) factor significantly influences household energy consumption, garnering substantial consumer interest and influence over sector management. Notably, when energy expenses remain low relative to income, there is

Table 4
Eco-innovation process on household energy consumption.

		HT1		HT2		HT3	
		Quito	Guayaquil	Quito	Guayaquil	Quito	Guayaquil
Eco-innovation stages/phases	Notion and reflection	3.30	2.63	3.24	3.14	3.52	3.41
	Cognitive	3.21	2.77	3.17	3.14	3.32	3.36
	Experimentation and action	2.64	2.56	2.72	2.86	2.77	2.47
	Attitude and lifestyle	2.72	2.73	2.64	2.99	2.70	2.58

Table 5
Synthesis of the exogenous variables to the system by question, city, and type of household.

Valued questions	HT1		HT2		HT3		Reaction per question
	Quito	Guayaquil	Quito	Guayaquil	Quito	Guayaquil	
What is the first image or word that comes to mind when you think of the energy sector?	TMT	PE	TMT	PE	TMT	PE	**PE TMT**
Which of the following is the main problem that Ecuador's energy sector should solve?	RCT	PE	RCT	PE	RCT	TMT	**RCT**
What drives you to take steps towards efficient energy consumption?	PE	PE	PE	RCT	RCT	PE	**PE**
What needs to be added for you to carry out more actions of good energy use?	PE	TMT	PE	PE	RCT	PE RCT	**PE**
Reaction by city and type of household	**PE**	**PE**	**PE**	**PE**	**RCT**	**PE**	**PE**

little motivation for behavioral change (Rashid et al., 2017), underscoring how energy subsidies promote inefficiency in Ecuadorian household energy behavior.

Ecological Cultural Atmosphere (ECA) and Technological and Market Trends (TMT) hold considerable sway over energy sector management, although consumer interest is notably lower. It is highlighted that for consumers, greater competitiveness in energy services and products generally translates into energy savings, operational efficiency, and greater visibility of how they use energy (Zhou & Yang, 2016). Research indicates users' limited enthusiasm for new household technologies, particularly in older adult households (55 years or older) (Iliopoulos et al., 2021). Strategies must be devised to enhance consumer acceptance to harness the potential of ECA and TMT in residential energy management.

Conversely, current Energy Laws and Regulations (ELR) must pique the audience's interest. Ecuador has implemented the Energy Efficiency Program (PEC) since 2014, aiming to transition three million LPG stoves to induction cooktops nationwide (Martínez-Gómez et al., 2017). This initiative anticipates a 29 % energy savings and a 69 % reduction in GHG emissions by 2030 in the residential sector (P. Castro et al., 2019). However, significant legal changes could catalyze a transformative shift in energy behavior management. The success of such programs hinges on the interplay of exogenous and endogenous variables.

4.2. Energy consumption profiles in ecuadorian households: ANOVA analysis

A one-factor ANOVA was conducted to compare energy consumption between Quito and Guayaquil, resulting in $F(1) = 0.1698$, $p > 0.05$, suggesting no significant differences between the two cities. In essence, Ecuador enjoys a mild climate throughout the year. Another one-factor ANOVA was conducted to evaluate energy consumption across three household types, revealing a significant difference, $F(2) < 2.e\text{-}16$, $p < 0.05$.

In essence, while there are notable variations among socioeconomic classes, no significant differences were observed between the cities. The Tukey HSD post hoc test allows multiple comparisons between the three household profiles, showing a $p < 0$, indicating statistically significant differences between the HT1-HT2, HT1-HT3, and HT3-HT2 group pairs. The analysis delineates three energy consumption household profiles (HT1, HT2, and HT3) within the country.

The results suggest that households typically consist of four individuals, predominantly three adults and one child/youth. The heads of these households are mostly male, aged between 35 and 54. These families predominantly live in single-family homes, whether detached or attached, and universally use LPG for cooking and electricity for various purposes. Additionally, HT2 and HT3 households utilize liquid fuels for their vehicles. Common household appliances include kitchens, showers, refrigerators, irons, washing machines, televisions, and smartphones.

Fig. 2 presents boxplots illustrating household energy consumption expenses across the three profiles. These plots visualize the median, means represented with crosses, and outliers.

The analysis revealed that spatial and sociodemographic characteristics (SSC) significantly influence energy consumption, particularly in urban households and those with higher incomes, leading to greater energy usage and greenhouse gas emissions (Advani et al., 2013; Keho, 2016). Family and Housing Structure (FHS) and Household Infrastructure and Energy Consumption Patterns (ICP) also impact energy consumption. The educational level of the household head is positively correlated with income, indirectly contributing to higher energy consumption (Lee, 2013; Rashid et al., 2017; S. Wang et al., 2020). Understanding households' structure, characteristics, and energy usage patterns is crucial for effective urban planning and management (Ren et al., 2016). However, despite efforts toward energy efficiency, the Eco-innovation Process (EIP) has not shown significant results.

4.3. Key variable associations in household energy consumption: MCA insights

Nine relevant variables were used to apply the multiple correspondence analysis (MCA) technique and identify key associations influencing household energy consumption (Hisschemöller et al., 2022). Fig. 3 illustrates these relationships.

One association suggests that households with higher incomes tend to have greater purchasing power, leading to the ownership of more appliances, electronic devices, and larger homes (measured in square meters) (Jiménez & Yépez-García, 2017; Keho, 2016). These variables, associated with higher incomes, are correlated with increased expenditure and energy consumption. Vehicle ownership is excluded from this group since not all households have one; however, the analysis indicates that it influences higher energy expenditure and consumption, as observed in Eqs. (1) and (2).

$$\textit{Energy consumption} \sim \textit{Energy expenditure} \tag{1}$$

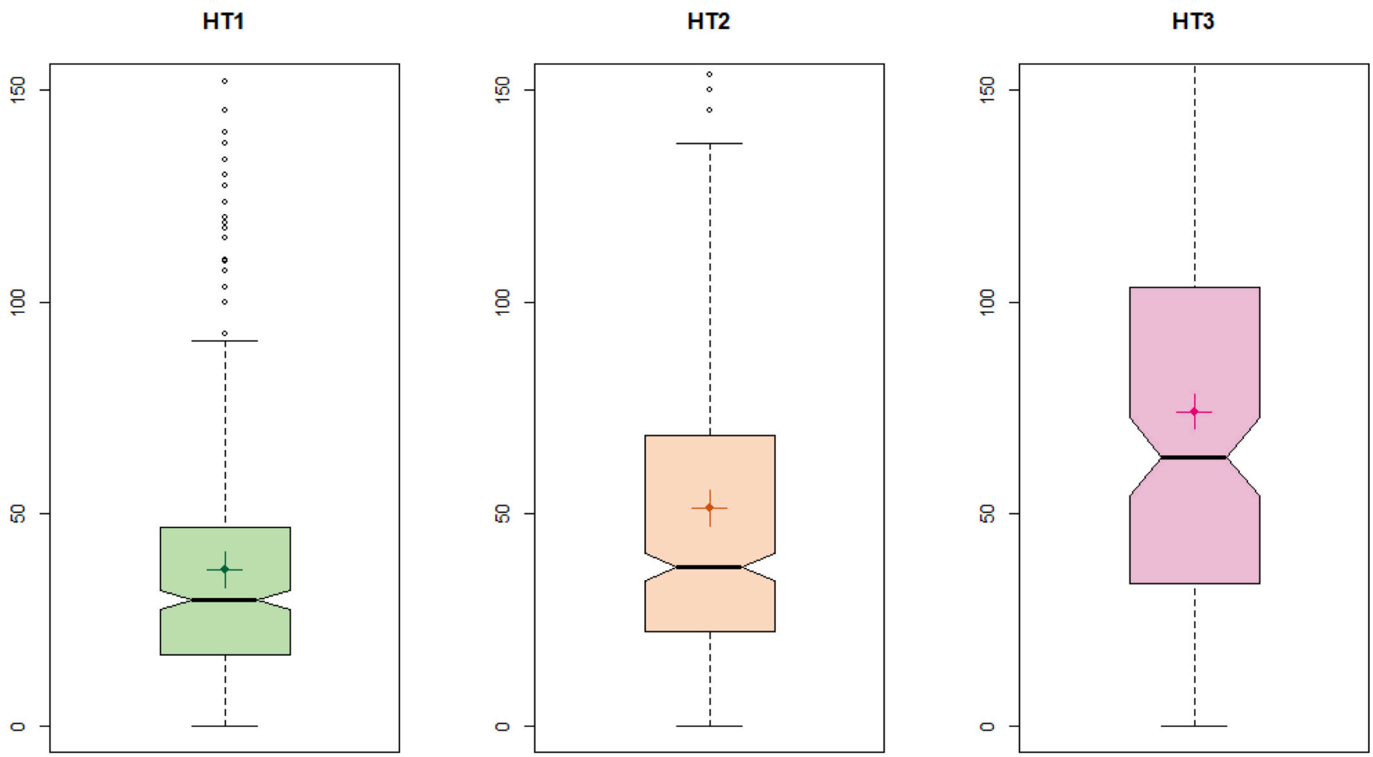


Fig. 2. Household energy consumption expenses across profiles (HT1, HT2, and HT3).

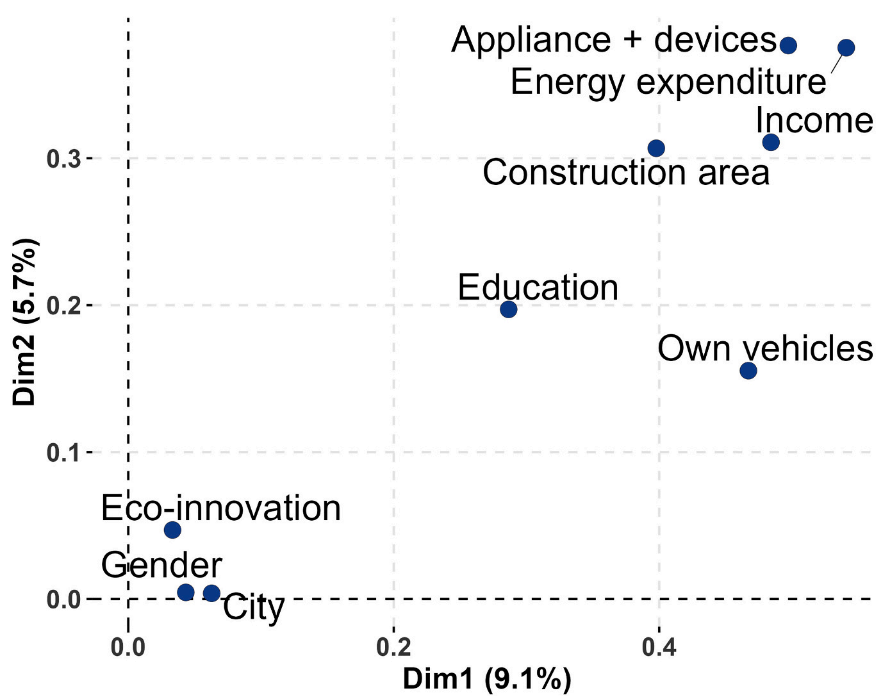


Fig. 3. Relationships among variables using the Multiple Correspondence Analysis (MCA) technique.

$$Energy\ expenditure = f\,(Income, Ownership\ of\ assets, Household\ size) \quad (2)$$

The variable of the head of the household's level of education, also excluded from the group, correlates positively with an increase in household income, which also serves as an indirect driver of higher energy consumption (Rashid et al., 2017; S. Wang et al., 2020). Nevertheless, it constitutes a variable of significant interest, as augmenting awareness of energy consumption may enhance the probability that consumers translate potential actions into actual behaviors (Camara et al., 2018; Henryson et al., 2000).

The grouping of variables composed of city, gender of the head of the household, and eco-innovation is distant in terms of explaining energy consumption. The understanding should encompass that within the extensive concept of eco-innovation, various strategies are applicable. These include alterations in production patterns, alongside the acceptance and integration of technologies, products, processes, services, market approaches, and organizational structures, all aimed at mitigating the impact of economic activities and daily practices on the environment (Araujo et al., 2021; Araujo-Vizuete & Robalino-López, 2023). These tactics can include comprehensive and strict environmental regulations (Gonzalez-Torres et al., 2023; Keho, 2016), improved energy knowledge (Camara et al., 2018; Henryson et al., 2000), and sustainability-oriented technological changes (Amendola et al., 2024; Boardman, 2004; Camara et al., 2018; Gonzalez-Torres et al., 2023).

5. Discussion

5.1. Impact of subsidy removal

Table 6 outlines three urban residential energy consumption typologies, including energy consumption and greenhouse gas emissions per household member. It also estimates the potential impact of removing subsidies on electricity, LPG, and gasoline. Assuming a cost of $0.0929/KWh for electricity compared to the commercial price of $0.04/KWh (Ministry of Energy and Mines, 2022), monthly electricity expenses would increase by 230.2 %.

Similarly, using the 2013–2022 average international price of $2.83/gal for gasoline (U.S Energy Information Administration, 2022), compared to the 2019 commercial price of $1.75/gal (Ministry of Energy and Mines, 2020), monthly gasoline expenses would rise by 161.7 %. As for LPG, with the actual cost per domestic cylinder at $15.00 (Villavicencio & Ruiz, 2019) and the retail price at $1.60 (Gould et al., 2020), monthly LPG expenses would substantially increase by 937.5 %.

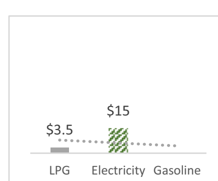
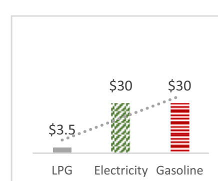
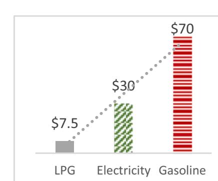
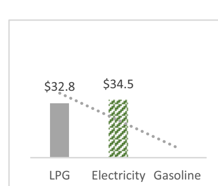
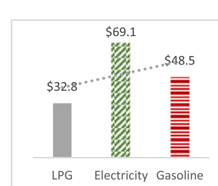
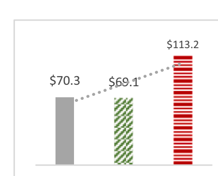
Lower-income households mainly use electric showers, while higher-income ones prefer gas water heaters and advanced technologies. Limited finances may prevent lower-income households from investing in efficient equipment like induction hobs or solar panels. HT2 households benefit 1.8 times more from energy subsidies than HT1, and HT3 benefits three times more. Consequently, high-income households are primary subsidy beneficiaries. Results show significant carbon footprint variations among income groups, with HT3 emitting five times more than HT1 and 1.9 times more than HT2.

The subsidy reforms in Ecuador, although unpopular and sparking significant protests in October 2019 and June 2022, face consumer skepticism regarding government intentions and the allocation of budget savings in the event of subsidy elimination. Despite this resistance, substantial efforts have been underway since 2019 to reduce support for liquid fossil fuels (Ministry of Energy and Mines, 2022). However, protective measures for the most vulnerable segments of society remain crucial, necessitating specific programs, gradual price increases, strengthening of state-owned enterprises, and the adoption of non-politicized price-setting mechanisms (FMI, 2022). Moreover, liberalized energy market policies have provided consumers with more options (Faiers et al., 2007).

Energy should be taxed like any other consumer product, with the final price reflecting its societal and environmental impacts (FMI, 2022). Subsidizing energy ultimately leads to fiscal inefficiency, resource depletion, pollution, and reduced incentives to invest in cleaner alternatives. While market forces and technology play pivotal roles in driving energy use transformation, it's essential to recognize that they alone cannot instigate broader societal changes (Pelfini et al., 2012).

Research indicates that guilt over excessive consumption can support strict energy policies and intentions to adopt more conservative behavior. Conversely, behavior change and responsible energy usage are less likely when individuals don't perceive themselves as responsible for energy overuse (Shippee, 1980). Lower-income households are more inclined to engage in energy-saving initiatives, likely due to their awareness of economic challenges (Iliopoulos et al., 2021). Consequently, strategies are needed to foster environmental awareness behaviors and reshape group attitudes toward energy. The model facilitates opportunities for end-users to embrace impactful practices, including demand response programs, time-of-use tariffs, energy efficiency challenges, adopting cleaner home technologies, and active participation in energy community initiatives (Lopes & Antunes, 2022).

Table 6
Typologies of household energy consumption, indicators, and estimation of subsidies.

Average monthly values	HT1	HT2	HT3
Income [U$D]	$480.00	$910.00	$1880.00
Energy expenses [U$D]			
$\frac{\text{Energy expenses [U\$D]}}{\text{Income [U\$D]}}$	$\frac{\$18.50}{\$480.00} = 3.8\%$	$\frac{\$63.50}{\$910.00} = 7.0\%$	$\frac{\$107.50}{\$1,880.00} = 5.7\%$
Energy consumption [kWh]	483 [kWh]	1244 [kWh]	2407 [kWh]
Monthly energy consumption per household member [kWh per capita]	120.75 [kWh per capita]	311 [kWh per capita]	601.75 [kWh per capita]
Average monthly emission of greenhouse gases [Kg CO2eq]	123.2 [Kg CO2eq]	325.4 [Kg CO2eq]	615.5 [Kg CO2eq]
Average monthly emission of greenhouse gases per household member [Kg CO2eq per capita]	30.8 [Kg CO2eq per capita]	81.4 [Kg CO2eq per capita]	153.9 [Kg CO2eq per capita]
Energy expenses without subsidies [U$D]			
$\frac{\text{Energy expenses without subsidies [U\$D]}}{\text{Income [U\$D]}}$	$\frac{\$67.30}{\$480.00} = 14.0\%$	$\frac{\$150.40}{\$910.00} = 16.5\%$	$\frac{\$252.60}{\$1,880.00} = 13.4\%$
Monthly subsidized value [U$D]	$48.84	$86.88	$145.06

Understanding consumers' habits and multidimensional nature is crucial to identifying potential barriers and enabling fundamental changes (Maréchal & Holzemer, 2015).

5.2. Sensitivity analysis: How income growth transforms energy consumption and emissions

A sensitivity analysis was conducted in terms of percentage variations, using the variable Income due to its direct relationship with energy consumption and emissions. This analysis quantifies how income increases impact these factors and models the transition from one consumption profile to another. Accordingly, the percentage increase in Income required for a household to shift from one energy consumption profile to another (HT1 → HT2 → HT3) was calculated. This allows us to estimate how energy consumption and emissions change during each transition. The analysis followed three key steps: i) Define the threshold values for the variable Income, with HT1: $480, HT2: $910, and HT3: $1880.

ii) Calculate the percentage variation in income between profiles using Eq. (3):

$$\textit{Percentage variation} = \left(\frac{\textit{New Value} - \textit{Initial Value}}{\textit{Initial Value}}\right) \times 100 \tag{3}$$

iii) Assess the impact on energy consumption and emissions, as shown in Table 7.

The results indicate that the most significant relative increase in energy consumption and emissions occurs during the HT1 → HT2 transition, with sharper growth rates compared to HT2 → HT3. This suggests that lower-income households experience a more substantial proportional impact on their energy consumption and emissions as their Income rises, reflecting a more pronounced shift in consumption habits and technologies.

Furthermore, the data reveal that the relationship between Income growth and the increase in energy consumption and emissions is not linear. That is, a percentage increase in income does not result in a directly proportional rise in energy consumption and emissions. This suggests the influence of additional factors, such as changes in consumption patterns, energy efficiency, and access to more advanced technologies as income levels increase.

5.3. Energy consumption patterns in ecuador and neighboring countries

Energy needs vary depending on location, technology, and users (Bhattacharyya, 2019). Therefore, analyzing the energy context from a localized perspective is essential, as it highlights the significant differences among developing countries and within each of them (Winchester, 2006). Currently, energy demand in these countries is growing at a faster rate than in developed nations, with a marked preference for liquid fossil fuels in some cases (Bhattacharyya, 2019).

An analysis of Ecuador's energy demand reveals its uniqueness compared to neighboring Colombia and Peru. Ecuador is characterized by high fossil fuel consumption in transportation and cooking. This trend is primarily driven by fuel subsidies, which encourage the use of conventional energy sources (M. Castro, 2011).

Table 7
Percentage variation in Income, Energy Consumption, and CO_2 Emissions across profiles.

Transition	Income Increase	Energy Consumption Variation	CO2 Emissions Variation
HT1 → HT2	+89.58 %	+157.56 %	+164.12 %
HT2 → HT3	+106.59 %	+93.49 %	+89.15 %
HT1 → HT3	+291.67 %	+398.34 %	+399.59 %

To provide context, in 2023, Colombia's GDP per capita was approximately $20,600, Peru's $16,900, and Ecuador's $16,000. In terms of urbanization, 83 % of Colombia's population resides in urban areas, compared to 79 % in Peru and 65 % in Ecuador (World Bank, 2022b). This underscores the significance of the urban residential sector in total energy demand, as it accounts for a large number of users and a substantial share of consumption.

Energy subsidies in Ecuador contribute to inefficiencies, as reflected in per capita CO2 emissions from fossil fuel combustion. In 2023, Ecuador recorded 2.5 metric tons of CO2 per capita, followed by Colombia with 1.9 and Peru with 1.7 (World Bank, 2022a), despite Colombia and Peru having more industrialized economies.

While Ecuador faces challenges transitioning to a more efficient and sustainable energy system, its historical reliance on subsidies has shaped its consumption patterns. In contrast, Colombia and Peru are also working to enhance energy efficiency and reduce dependence on fossil fuels, albeit with unique strategies and challenges.

Comparing these consumption patterns offers valuable insights. Promoting clean technologies, raising awareness of energy efficiency, and implementing policies that encourage energy diversification are key strategies for mitigating the risks of overreliance on a single energy source.

In summary, understanding the dynamics of energy consumption in Ecuador and its neighboring countries allows for the identification of key factors influencing demand and its environmental effects. The reliance on subsidies, differences in urbanization levels, and variations in household income generate distinct consumption patterns, highlighting the need for strategies tailored to each specific context.

However, this study's findings extend beyond national borders and can be applied to other countries with similar energy subsidy structures, income distributions, and transition challenges. The methodology employed not only provides a flexible and replicable tool for analyzing the impact of subsidies in diverse socio-economic settings but also enables the assessment of equity in energy access, resource efficiency, and environmental impact mitigation. Its applicability extends to various developing economies facing comparable challenges, offering a valuable model for policy formulation in different contexts.

Beyond the Ecuadorian case, this study contributes to the global debate on energy sustainability. The gradual phasing out of subsidies, combined with the adoption of more efficient technologies and awareness strategies for responsible consumption, emerges as a key approach to strengthening the sector's sustainability. Additionally, regional cooperation and the exchange of best practices can not only accelerate the transition toward more resilient energy systems in Latin America but also serve as a reference for other nations undergoing energy transformation.

6. Conclusions and policy implications

In a country like Ecuador, where energy subsidies have been a constant for decades and are regarded as acquired rights, the transition to a more efficient and sustainable energy system represents both a challenge and a unique opportunity. The gradual elimination of subsidies can not only free up significant fiscal resources but also catalyze a profound change in the population's energy consumption habits. To achieve this change, it is essential to involve all sectors of society and promote effective communication as a key success factor. Consequently, it is crucial to educate the public about the benefits of political reforms and how these can lead to a more equitable and sustainable energy system. This process also includes the implementation of favorable tariffs, specific taxes, and regulatory frameworks that incentivize the adoption of efficient technologies.

In this context, developing innovative strategies to disseminate energy knowledge is fundamental. In Ecuador, energy efficiency education must be integrated into educational institutions so that its impact extends to households and other organizations (Berchin et al., 2018), since greater energy knowledge increases the likelihood that consumers will take concrete actions to save energy (Camara et al., 2018). Moreover, feedback mechanisms should be established for both energy production and distribution companies and consumers. This would allow companies to understand consumption patterns better (Faruqui et al., 2010) and, in turn, help users know how and how much energy they use, as information about their current consumption can promote energy savings (Camara et al., 2018; Ueno et al., 2006).

It is also essential in Ecuador to develop communication strategies that inform the public about the real costs of electricity and the inequity generated by subsidies (Salehi-Isfahani et al., 2015). These campaigns should be extensive and supported by the media, authorities, academics, business leaders, and public figures (Camara et al., 2018). Furthermore, behavioral interventions, such as the Household Energy Saving Option (HESO), can be powerful tools for changing residential energy consumption. These interventions must be designed to provide attainable goals and systematic feedback, thereby fostering more sustainable consumption patterns (Xu, Hwang, & Lu, 2021; Xu, Lu, et al., 2021).

The measurement and monitoring of the energy system are essential to generate changes in behavior, which implies developing adequate data collection techniques, analytical methods, and simulation models that allow for evaluating impacts and formulating relevant metrics (Hong et al., 2016). Consequently, the segmentation analysis conducted in this study enables the design of differentiated strategies according to consumer profiles. In high-income households, access to information that helps them choose efficient technologies and adopt concrete actions within their environment should be promoted. In contrast, low-income households require policies that facilitate the transition to cleaner and more efficient technologies, promoting the gradual abandonment of obsolete and polluting equipment.

We've enriched our analysis with unique contextual elements by employing a Bottom-up analytical approach and integrating the eco-innovation concept into our energy consumption characterization model for urban residential areas. These include family composition, infrastructure, technology, habits, behaviors, and cultural aspects of our case study. This approach illuminates how households internalize reflections, thoughts, knowledge, behaviors, and lifestyles concerning energy consumption. Consequently, our study offers valuable insights into specific consumer behaviors, laying the groundwork for effective strategies to achieve meaningful and enduring transformations. In this regard, eco-innovation plays a crucial role among various factors, enabling us to view responsible energy consumption not only as an instrumental concept but also as a socio-cultural and structural consideration.

Analyzing the model's endogenous and exogenous variables, as proposed by Araujo et al. (2021), establishes typologies within the urban residential sector. This approach allows us to identify distinct energy behaviors across segments (HT1, HT2, and HT3), underscoring the sector's inherent heterogeneity. For instance, HT3 households exhibit a 1.7-fold higher energy expenditure than HT2 households and a substantial 5.8-fold increase compared to HT1 households. Notably, HT1 households do not directly consume fossil fuels for mobility. Similarly, HT3 households emit 1.9 times more greenhouse gases than HT2 households and a staggering 5 times more than HT1 households. Consequently, the analysis reveals that HT3 households benefit 1.8 times more from energy subsidies than HT2 households and 3 times more than HT1 households. Therefore, high-income households are the primary beneficiaries of energy subsidies. Given these disparities, it becomes imperative to devise energy consumption management strategies prioritizing equity within the country's urban residential sector.

The analysis highlights that despite significant awareness, reflections, and knowledge about energy consumption, additional factors are crucial to promote responsible and efficient actions consistently. Several barriers hinder more efficient household practices, including: i) The country's energy costs incentivize inefficiency in energy consumption, ii) Users lack awareness of their energy consumption profiles, making it challenging to alter established routines and habits, iii) Limited interest in the centralized energy market, iv) Widespread distrust in government programs and policies, and v) Higher costs associated with acquiring efficient equipment. In summary, achieving significant changes in household energy consumption patterns within the country requires a coordinated approach that encompasses economic, ecological, social, commercial, technological, political, and cultural dimensions.

Ecuador should take advantage of national blackouts—lasting up to 14 h per day due to a severe energy crisis—to raise awareness about responsible energy consumption, strengthen consumer consciousness regarding electricity scarcity, and improve household energy savings. It is important to note that energy management cannot be addressed solely from a techno-centric approach; a holistic strategy that integrates economic, social, environmental, political, technological, educational, and cultural dimensions is crucial. Strengthening regulatory frameworks, improving energy literacy, and promoting sustainable technological advances will be key to achieving a more efficient and equitable energy system. The combination of financial incentives, behavioral interventions, and well-coordinated policy alignment will be essential to transform the country's energy landscape.

CRediT authorship contribution statement

Gabriela Araujo-Vizuete: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Andrés Robalino-López:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ángel Mena-Nieto:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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