New Minimum Energy Performance Standard for Air Conditioners In Ecuador

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List of Acronyms

AC	air conditioning units
ACIC	Avoided capacity investment costs
AGC	avoided generation capacity
BAU	business as usual
BID	Inter-American Development Bank
CDD	cooling degree days
CIC	Inter-Ministerial Quality Council
CNEE	National Committee of Energy Efficiency
DMEE	maximum energy-efficiency label
EC	energy consumption
EE4D	Energy Efficiency for Development Program
EER	Energy-Efficiency ratio
EQSL	Ecuadorian Quality System Law
FP	first purchases
GDP	gross domestic product
GHG	greenhouse gas
GoE	Government of Ecuador
ICM	internal combustion motor
IEA	International Energy Agency
INEN	Ecuadorian Institute of Standardization
JICA	Japanese International Cooperation Agency
KOICA	Korea International Cooperation Agency
LBNL	Lawrence Berkeley National Laboratory
LCC	life cycle cost
MPCEIP	Ministry of Production, Foreign Trade, Investments and Fisheries
MEM	Ministry of Energy and Mines
MEPS	Minimum Energy Performance Standard
MVE	Monitoring, Verification and Enforcement
PLANEE	National Plan for Energy Efficiency
PPP	purchasing power parity
PTB	German Metrology Institute

SEER	seasonal energy-efficiency ratio
SAE	Ecuadorian Accreditation Service
SDS	sustainable development scenario
SENAE	National Customs Service of Ecuador
SNEE	National System of Energy Efficiency
T&D	transmission and distribution
UEC	unit energy consumption
USAID	U.S. Agency for International Development
USD	United States dollars
WP&PL	Water Pumping & Public Lightning

EXECUTIVE SUMMARY

The electricity system in Ecuador relies heavily on hydropower. In 2022, 75% of gross electricity production came from hydroelectric plants (ARCERNNR, 2022a). Although electricity generated from hydropower has a low carbon factor, its electricity generation is highly dependent on the availability of rainfall. In the past few years, due to lack of sufficient rain to fully utilize hydropower capacity, Ecuador has not been able to satisfy electricity demand (ARCERNNR, 2022c). The Ecuadorian government is trying to solve the electricity shortage issue by activating thermal plants, increasing gas imports, and through international tenders (MEM, 2023). In addition to supply-side, demand-side solutions are also considered by the government. This study assessed the opportunities and benefits to reduce demand through improving efficiency in cooling by revising the minimum energy performance standard (MEPS) of air conditioning units (ACs) to more stringent levels.

Space cooling is the fastest-growing energy end use in buildings worldwide. According to the International Energy Agency (IEA), by the end of 2016, approximately 1.6 billion ACs were in use globally, representing approximately 11.7 TW of installed cooling capacity (IEA, 2018). In Latin America, electricity demand is expected to grow by 72% between 2021 and 2040 (IEA, 2021), with cooling electricity use expected to contribute 16% of that growth, or around 150 TWh, accounting for more than a third of all electricity end-uses growth in the buildings sector. AC use is predicted to be the second largest source of electricity demand growth for buildings by 2045, following the industrial sector (IEA, 2018; Osaka, 2023).

Similar trends are seen in Ecuador's rising use of AC and corresponding increased electricity consumption. National electricity consumption in Ecuador increased by 36% from 16.7 TWh in 2018 to 22.1 TWh in 2022. This study identified that electricity consumption from AC use climbed by 57% in Ecuador over the same 4-year period, accounting for approximately 11% of total growth in electricity consumption. Increasing AC electricity consumption became a contributor to Educator's energy shortage crisis, but it also provides a great potential to solve the problem. One feasible strategy is to update the MEPS.

The MEPS for ACs in Ecuador was first introduced in 2017 (EER 3.2W/W); since then, no new standards have been proposed in the country. Therefore, the current MEPS in Ecuador is outdated in several aspects and needs updating to better reflect the evolution of the market and align with the goals of the National Plan for Energy Efficiency (PLANEE) and Energy Efficiency Law, with Executive Decree 68, issued in 2021. The MEPS for ACs is low compared to regional and international best practices and there is no distinct standard for different equipment types or capacity distinction. This report analyzes current AC usage patterns and prospective development scenarios as the foundation for updating AC MEPS in Ecuador.

PLANEE includes lines of action under the Residential, Commercial and Public axis. These sectors represented 60% of total electricity consumption in 2022, according to data from ARCERNNR (2023b). As part of the plan to address these levels of energy and electricity consumption, the Ministry of Energy and Mines (MEM) developed regulatory mechanisms, created tax and financial initiatives, and launched initiatives to advance energy efficiency in these sectors. In coordination with INEN, MEM developed 11 energy efficiency norms since 2007 to advance energy management practices and energy- efficient construction and 23 Technical Regulations (Reglamentos Tecnicos) to ensure the prevalence of high-efficiency domestic and industrial equipment in the Ecuadorian market.

The Energy Efficiency for Development Program (EE4D) is a partnership between the U.S. Agency for International Development (USAID) and Lawrence Berkeley National Laboratory (LBNL) to advance energy efficiency in partner countries. In Ecuador, the partnership is working in collaboration with the Ministry of Production, International Commerce, Investments and Fisheries (MPCEIP), the Ministry of Energy and Mines (MEM) and the Ecuadorian Institute of Standardization (INEN) to provide technical assistance in updating current energy- efficiency regulations for ACs. The proposed update aligns with the general objectives laid out by the National Plan for Energy Efficiency and Energy Efficiency Law and with Executive Decree 68, issued in 2021.

This report provides technical assessment of a MEPS AC revision in Ecuador, and serves as the basis for stakeholder engagement as part of the regulatory development process to update the AC MEPS in Ecuador. This report can be used as guidance by policymakers in designing a well-founded, impactful MEPS program that is consistent with regional and international best practices and to highlight the energy, environmental, and economic benefits of the MEPS on users and the nation as a whole.

The methodologies used in this report include the scenario analysis of five different MEPS levels, the logistic estimation of the current AC ownership rate, and the projection of AC stock in Ecuador to 2045. The energy use analysis assesses the potential energy savings from increasing the efficiency of ACs in Ecuador and forms the basis for the energy-savings values used in the subsequent analyses and the life cycle cost (LCC) analysis.

Baseline Information key Findings

The commercial and residential sectors (the buildings sector) represented 60% of electricity consumption in Ecuador in 2022. AC household ownership rates have more than doubled in the past 9 years, as gross domestic product (GDP) per capita increased by more than 50%. More than 90% of AC users are located in the Littoral region. Residential electricity use for ACs in the Littoral region is 26% of residential electricity use (52% population). From 2015 to 2020, AC imports grew at a rate of 12% per year, almost doubling in 5 years.

Results from this study show that in 2022, approximately 470,000 of installed ACs were less efficient than the energy- efficiency regulation, indicating that 47% of ACs in Ecuador do not meet the requirements of the current regulation. The national ownership rate in 2020 was less than 10%, while in the Littoral region it reached about 17%. Even for the latter, the market is far from saturated because of the climate constraints present in the region, indicating that Ecuador may experience an acceleration of the rise in AC ownership in the upcoming years. From October to May, the Littoral region experiences a rise of electricity production from hydroelectric plants, coinciding with the peak electricity demand season revealing a somewhat strong dependence on this energy source to help cover for the peak consumption season.

The CO_2 emissions due to AC use in Ecuador between 2018 and 2022 increased about 20%, from around 0.9 to 1.1 million tons of CO_2. This represents approximately 2.5% of unconditional Nationally Determined Contributions for 2025 (Climate Resource, 2021).

Scenario Analysis Results

Five scenarios with different-efficiency levels were analyzed and compared to a baseline scenario. These efficiency levels are:

- <u>Sc 1</u>: Current MEPS enforcement: Ecuador MEPS level

- Sc 2: Proposed new MEPS: Mexico MEPS level
- Sc 3: Regional best practice: Argentina MEPS Level
- Sc 4: "A" rating from the Pan American technical standards commission, COPANT 1711 standard
- Sc 5: EU MEPS level: European Union MEPS level
- Sc 6: High Efficiency: a combination between EU MEPS levels for conventional equipment and the medium efficiency levels for inverter equipment found in Karali, et al., 2020.

The total number of ACs is projected to more than double by 2035 and more than quadruple by 2045, as AC ownership rate is projected to triple and the number of households increase by more than 50% by 2045. In the business as usual (BAU) scenario, AC electricity consumption in the residential sector is therefore projected to double by 2035 and more than quadruple by 2045, increasing from around 1 TWh in 2020 to around 2.4 TWh in 2035 and around 4.3 TWh in 2045.

For the proposed new MEPS corresponding to Sc2 defined above, estimates indicate that avoided capacity due to energy-efficiency improvements could reach 240 MW by 2035 and 460 MW by 2045. This is especially of interest for the Littoral region, because the peak load demand is satisfied with thermal power plants using fossil fuels.

Scenario 2 has lower electricity consumption than the regional best practice (Sc3) and scenario 1, reaching an approximate annual 9% reduction in electricity consumption compared to the BAU scenario.

The highest efficiency scenarios (Sc5 and Sc6) have the lowest electricity consumption of all scenarios, reaching an annual reduction in electricity consumption of 25% and 29%, respectively, compared to the BAU scenario. The purchasing price difference between a BAU scenario AC and a scenario 2-4 AC is around 50 USD, while compared to Sc5 and Sc6 AC, the price difference is 290 USD. Even though the higher efficiency scenarios (Sc5 and Sc6) have significant impacts compared to the other scenarios in terms of energy and operating cost savings and are cost effective over the long term, the high up-front cost may pose an undue burden on cash-strapped households.

MEPS Revision Benefits

Figure ES 1 presents the cumulative savings in electricity bills and the avoided investment in power capacity addition for the proposed new MEPS from 2025 to 2045. From 2024 to 2035 the cumulative energy savings in electricity bills are around 150 million USD and reach 550 million USD by 2045. Avoided investment capacity is estimated at 240 million USD in 2035 and almost doubles to reach 460 million USD in 2045. AC electricity use reduction is also shown in Figure ES 1, considering the base year as 2024. It can be seen that annual AC electricity consumption reaches a peak in 2035 at around 9%, and remains constant through the rest of the analysis period.

Figure ES 1. Summary of national impact results from 2025 to 2045 for proposed new MEPS

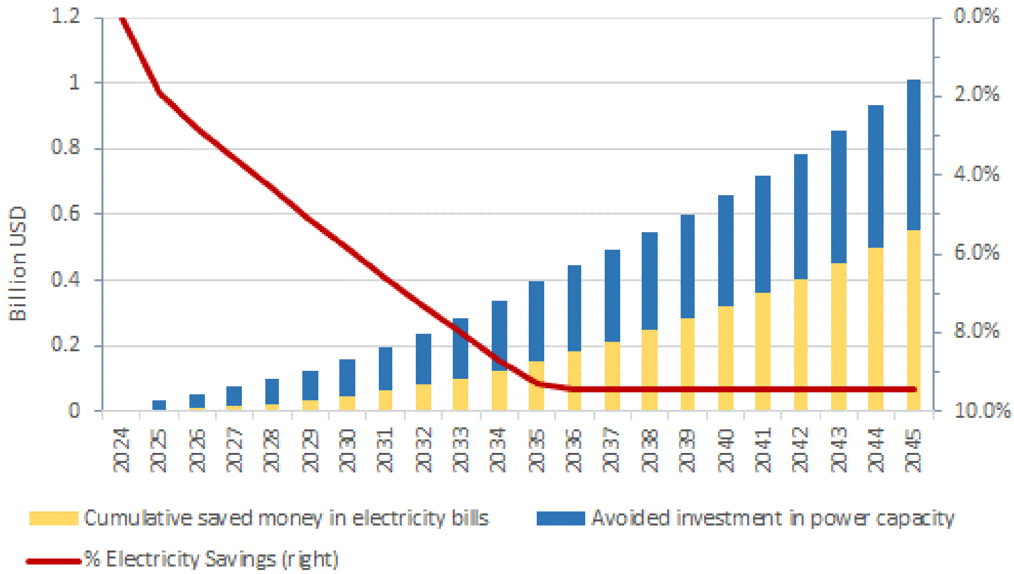


Table ES 1 summarizes the impacts associated with the adoption of higher- efficiency standards (Sc2 and Sc 6) for ACs in Ecuador. The impacts are presented for the proposed new proposed MEPS and for the resulting impacts in 2045. It is projected that with the adoption of the new proposed MEPS, savings in electricity bills and avoided investment in new power capacity would amount approximately 1 billion USD by 2045.

Table ES 1. Impacts in 2045 of the proposed Sc2 and Sc6 MEPS

	Proposed MEPS (Sc2)	**Technical Potential (Sc6)**
Annual energy savings (TWh)	0.60	1.88
Money Saved in Electricity Bills (Billion USD)	0.55	1.7
Avoided Capacity (MW)	474	1,485
Investment in Capacity Avoided (Billion USD)	0.47	1.5
Avoided Subsidies (Million USD)	24	75
Cumulative avoided CO_2 emissions (Million CO_2 Tons)	4.1	12.8
Energy- Efficiency Improvement	13%	46%
Increased Cost of Equipment (USD/AC)	$46	$287

Life Cycle Cost Analysis

The life cycle cost (LCC) analysis the trade-off between higher acquisition costs for a more efficient AC and the subsequent savings in the form of lowered electricity bills during the 10-year AC lifetime.

This study showed that all of the efficiency levels that were analysed are cost-effective for the consumers in all the Ecuadorian climatic zones, except in the Highlands region where only Sc1 was cost effective for the consumers. The most cost-effective scenario is the high efficiency level, which is equivalent to an increase of 46% in efficiency compared to the BAU scenario. Payback periods vary between 3.3 years in the Littoral region and 8.8 years in the Highlands region, depending on the size of the AC unit. For the proposed MEPS, benefits range from around $60 to $300 USD over 10 years in energy bills saving for the consumer.

RECOMMENDATIONS

Regulation:

- Based on the LCC analysis results, we recommend revising the MEPS as soon as possible to efficiency levels corresponding to either scenario 2 or 4 and propose to revise to level 5 by 2029 to facilitate market adaptation, as this level offers cost-effective economic benefits for consumers. This includes a change in the efficiency metric to the Seasonal Energy Efficiency Ratio (SEER), as this a more accurate measure of ACs efficiency than the current used measure (Energy Efficiency Ratio EER)
- Design other programs targeting the adoption of high efficiency ACs, to prepare the market for future updates to higher MEPS. Adopting higher efficiency standards for ACs (scenarios 4 and 5) is even more beneficial for the society in terms of energy savings, emissions reduction, money saved in electricity bills, and avoided investment in new power capacity.

Compliance:

- In order to increase the compliance rate of the regulation, we recommend developing a certification database to better monitor the market. This can be managed by MPCEIP with support from the Ecuadorian Accreditation Service (SAE), INEN and the National Customs Service of Ecuador (SENAE), including training to manage the certification database and related monitoring, verification and enforcement activities.
- Create guidelines for importers and retailers of AC products to understand the MEPS and the process of compliance verification.
- Work with MPCEIP, SAE, SENAE and the certifying agencies to identify possible gaps or inaccuracies in the information provided for the certification process (certificates of compliance, labels, custom declarations) from the point of manufacturing to the point of entry.

Complementary programs:

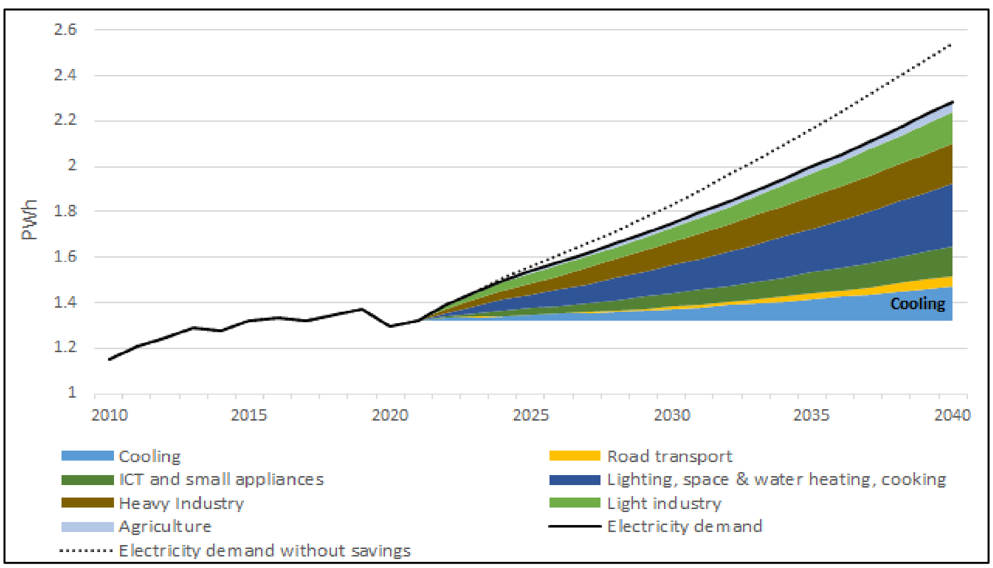
- Establish a working group with government, industry, research community and international development organizations to explore financial mechanisms to set up an energy- efficiency testing lab in-country.
- Continue the efforts to improve energy efficiency and decrease electricity consumption in the buildings sector (60% of national electricity consumption). The ongoing review of the Ecuadorian Construction Norm, undertaken by the Ministry of Urban Development and Housing, represents an opportunity to update the energy efficiency component of the code.
- Leverage ongoing efforts by international development organizations (PTB, JICA, KOICA, BID, World Bank) to explore financial mechanisms that could be created in coordination with Ecuador’s National Investment Fund for Energy Efficiency to support the implementation of initiatives such as an AC substitution program.

1. Introduction

According to the International Energy Agency (IEA), approximately 1.6 billion air conditioning units (ACs) were in use globally in 2016 globally, representing around 11.7 TW of cooling output of installed capacity (IEA, 2018). The estimations indicate that, from 1990 to 2016, electricity use for cooling tripled. This rapid growth has been influenced by the rising economies in developing countries, such as increasing income levels, increased urbanization and electrification rates, and falling prices for AC devices. As the world's temperatures rise, humid regions are predicted to make significant AC investments. Between now and 2045, the IEA projects that 10 AC units will be sold every second. By 2045, the main driver of electricity demand growth for buildings is expected to be AC use, which will rank second after the industrial sector (IEA, 2018; Osaka, 2023).

Based on economic growth trends, the IEA projects Latin American electricity consumption to nearly double between 2020 and 2040 (Figure 1). Nevertheless, the IEA Sustainable Development Scenario (SDS) outlines a plan for achieving economic expansion, ensuring energy security, and reducing the impact of related greenhouse gas (GHG) emissions. In this scenario, the energy- efficiency measures account for 40% of the difference between the existing and revised paths (IEA, 2021). As shown in Figure 1, in this scenario the Latin American electricity demand is projected to grow close to 72% between 2020 and 2040. The electricity used only for cooling is projected to contribute 16% to that growth, or close to a 150- TWh increase. This represents more than a third of building sector[1] electricity consumption growth, highlighting the relevance of cooling in future electricity consumption.

Figure 1. Electricity demand growth in Latin America, 2021-2040.



Source: (IEA, 2021)

The Energy Efficiency for Development Program (EE4D), a partnership formed between the U.S. Agency for International Development (USAID) and Lawrence Berkeley National Laboratory (LBNL) to deploy technical assistance advancing energy efficiency in partner countries, is working with the Ministry of

[1] Considering cooling, lighting, space and water heating and cooking electricity consumption growth.

Production, International Commerce, Investments and Fisheries (MPCEIP , the Ministry of Energy and Mines (MEM), and the Ecuadorian Institute of Standardization (INEN) to support the update of the current energy- efficiency regulation for ACs. The proposed update aligns with the general objectives laid out by the main energy-efficiency policy instruments in Ecuador which are the National Plan for Energy Efficiency, the Energy Efficiency Law and with Executive Decree 68, issued in 2021. These policy frameworks generate the necessity of reviewing and updating all Ecuadorian norms and technical regulations to advance competitiveness, improve regulatory practices, and conform with international energy standards.

This report aims to assess the impacts of a new Minimum Energy Performance Standard (MEPS) for ACs in Ecuador. The following key elements are provided in this work:

- AC market research in Ecuador (brands, capacities, energy efficiency, and prices).
- Electricity use and related emissions analysis, and projections to 2045. Evaluate current market efficiency levels, energy use, and related emissions. Assessment of the potential electricity savings from higher MEPS.
- National impact analysis: Nationwide magnitude of efficiency impacts on energy savings, emissions reductions, and avoided peak demand.
- Life Cycle Cost (LCC) analysis: Assessing the costs and benefits of acquiring a new AC unit with higher efficiency and cost. LCC is an economic evaluation technique that determines the total cost of purchasing and operating an AC over its typical lifetime.

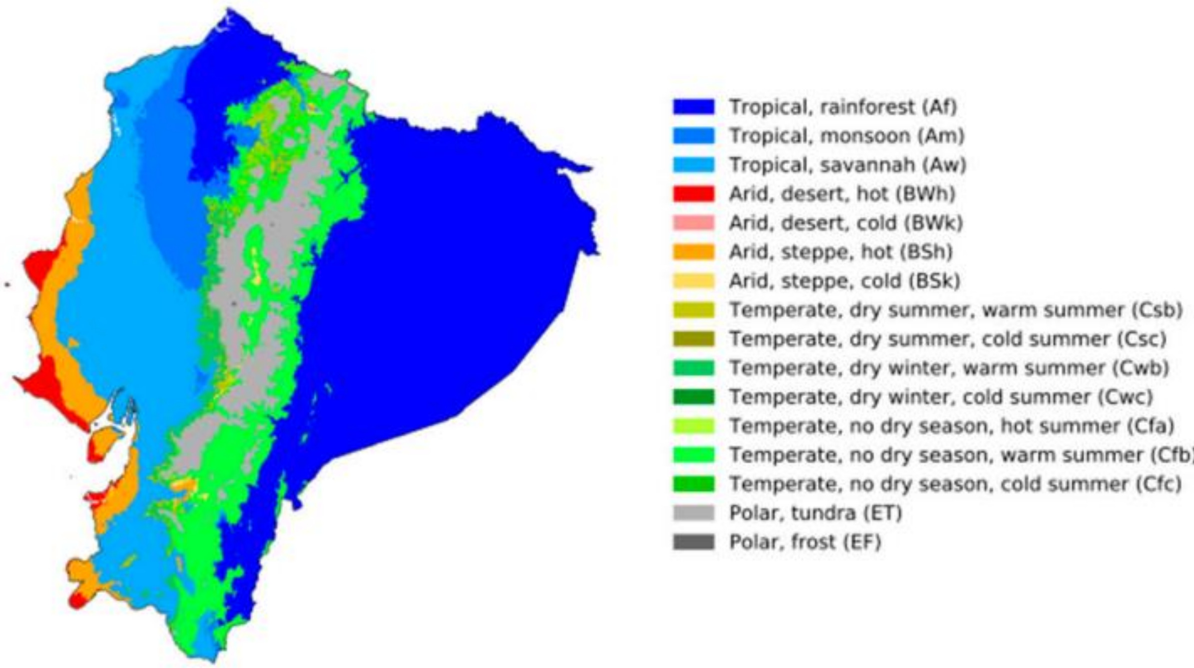
Section 2 presents general information about Ecuador, including the geography and climate; a brief introduction to the electrical system; and an estimation of the cooling energy use overview for the residential sector. Section 3 presents the AC market research sources and results as well as an energy-efficiency baseline for ACs in Ecuador. Section 4 presents the energy use and related emissions analysis along with the LCC impact results from higher MEPS. Section 5 presents an implementation plan for the proposed new MEPS. Section 6 presents conclusions and recommendations.

2. Background

2.1 Geography and climate in Ecuador

Figure 2 presents the Köppen-Geiger climate map for Ecuador (without the Galapagos islands) (Beck, et al., 2018). It shows that there is a clear division of the Ecuadorian territory between three climatic regions. The coastal region, or Littoral region, consists mainly of a variety of tropical forest, with some hot-arid areas. The center green and grey colored strip corresponds to the Inter-Andean region or Highlands and is distributed between temperate and polar climates. Finally, the area on the right in blue is the Amazon region, consisting predominantly of tropical rain forest climate in the Köppen-Geiger climate classification.

Figure 2. Köppen-Geiger climate classification map for Ecuador (1980-2016).



Source: (Beck, et al., 2018)

Table 1.Classification of Ecuadorian provinces by climatic region.

Climatic region	Province	Climate	% Pop 2020[2]
Littoral	Esmeraldas, Manabí, Santo Domingo, Los Ríos, Guayas, Santa Elena, El Oro	Tropical & Hot arid	52%
Highlands	Carchi, Imbabura, Pichincha, Cotopaxi, Tungurahua, Bolívar, Chimborazo, Cañar, Azuay, Loja	Temperate & Polar	42%
Amazon	Sucumbíos, Napo Orellana, Pastaza, Morona Santiago, Zamora Chinchipe	Tropical rain-forest	6%

Table 1 and Figure 3 present the climatic regions classification used in this work. Based on the information from Figure 2, the main climate type was considered to allocate every province in one of the three climatic categories in Table 1. As shown in Table 1, 52% of the Ecuadorian population lives in the Littoral region, and 58% of population lives in a tropical climate.

[2] Source: (INEC 2012)

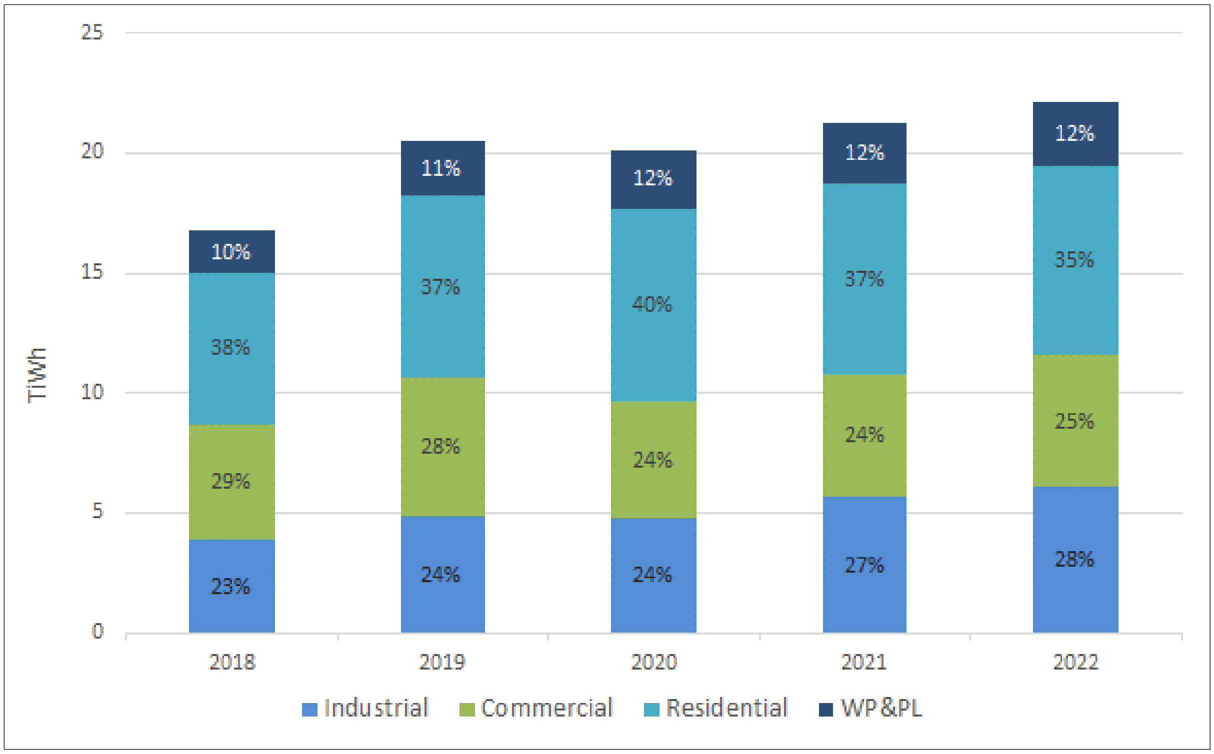
Figure 3. Map of Ecuadorian provinces by climatic region.

Source: Author preparation with online tool (Paint Maps, 2023)

2.2 Ecuadorian electricity system overview

Figure 4 presents the electricity consumption by sector in Ecuador between 2018 and 2022, showing the consumption share for the industrial, commercial, residential and Water Pumping & Public Lighting (WP&PL) sectors. The biggest electricity consumer in Ecuador is the residential sector, which represents 35% of total consumption in 2022 (ARCERNNR, 2022-2). Together, the commercial and residential sectors (the buildings sector) represented 60% in 2022. Because of this, energy- efficiency policy in the buildings sector is of special interest in a country like Ecuador. Focusing in this sector will represent high electricity savings potential, contributing to the reduction of national electricity consumption with greater impact.

Figure 4. Electricity consumption by sector in Ecuador from 2018 to 2022[3].



Source: (ARCERNNR, 2022-2)

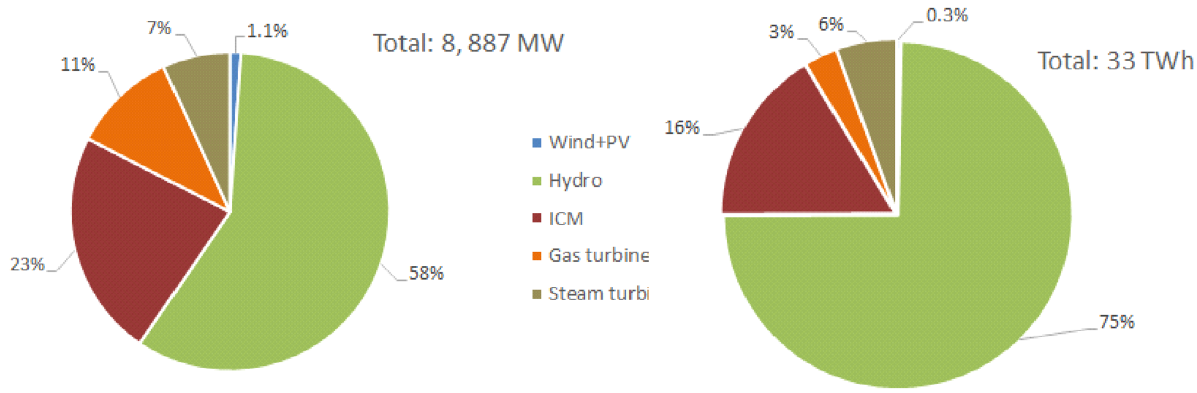
Figure 5 presents installed electricity generation capacity and gross electricity production per generation technology type for Ecuador in 2022. Nearly 60% of installed capacity was sourced from hydroelectric plants, representing 3/4 of national electricity production. In consequence, electricity in Ecuador is relatively clean, and also cheap as generation and transmission and distribution costs range between 9¢ USD and 9.2¢ USD per kWh, depending on whether it is the dry or humid season. The residential electricity tariff in Ecuador is also relatively low, at around 9¢ USD/kWh, compared to for example Uganda, where electricity is also mostly generated from hydropower and costs around 17¢ USD/kWh (UMEME, 2023).

Figure 6 presents the regional and national electricity carbon factor from 2014 to 2022. Electricity carbon factor is relatively low in Ecuador and has dramatically decreased in the last years. It went from 0.27 tons CO_2/MWh in 2018 to 0.15 tons CO_2/MWh in 2021, a decrease of almost half in 3 years, due mostly to the power additions in hydroelectric plants. The Amazon and Highlands regions have a low emission factor compared to the Littoral region, where 99% and 93% of electricity is produced with hydropower, respectively. According to data from (ARCERNNR, 2022-1) 68% of the electricity produced in the Littoral region comes from thermoelectric plants, and 26% from hydroelectric plants. But it is also a fragile system, as it is highly dependent on rain, potentially causing the increase in the need for electricity imports from neighbouring countries or, ultimately, blackouts. In 2023, the GoE estimated that during the 2023-2024 dry season (October through March), the Ecuadorian electrical system will have a shortfall of close to 460 MW In addition, the Colombian government is unable to supply electricity to Ecuador for the same climatic

[3] WP&PL: Water Pumping & Public Lightning

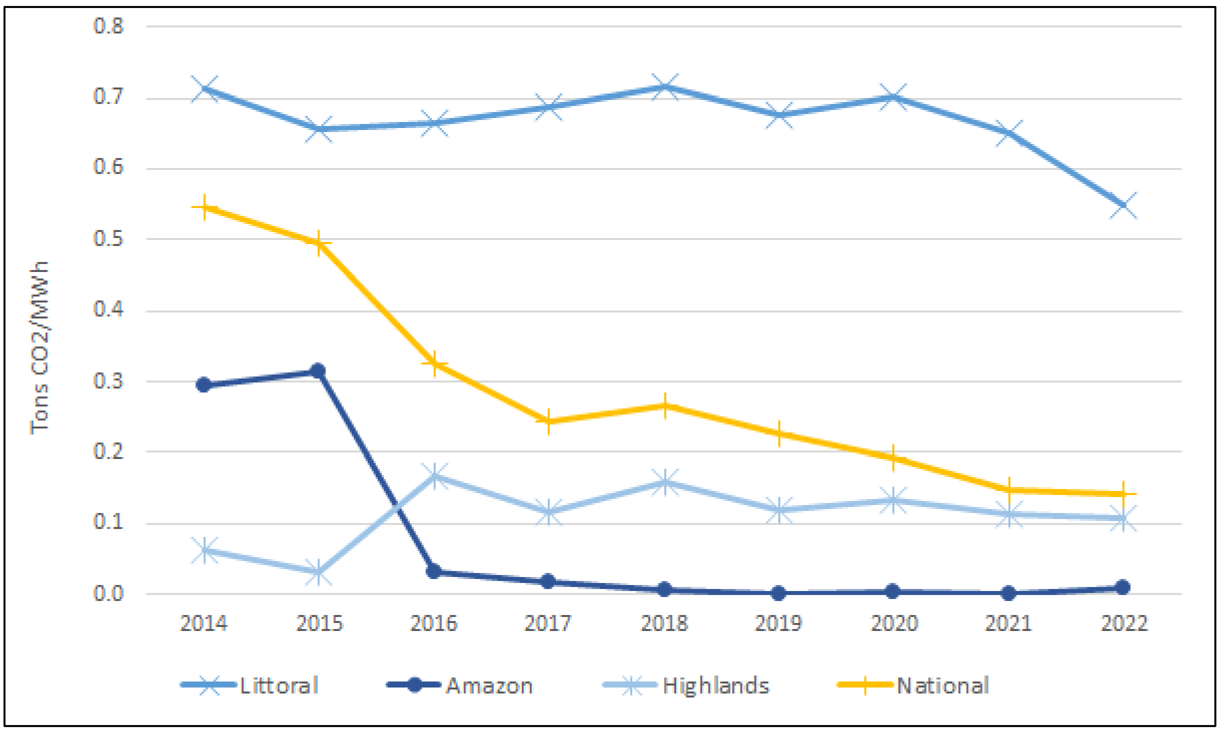
reasons. As of the writing of this work, the Ecuadorian government is trying to solve this shortage problem by activating thermal plants, increasing gas imports, and through international tenders (Orozco, 2023).

Figure 5. Left. 2022 Installed Capacity for Electricity Generation. Right. 2022 Gross Electricity Production



Source: (ARCERNNR, 2022-1)

Figure 6. Electricity emission factor in Ecuador from 2014 to 2022.

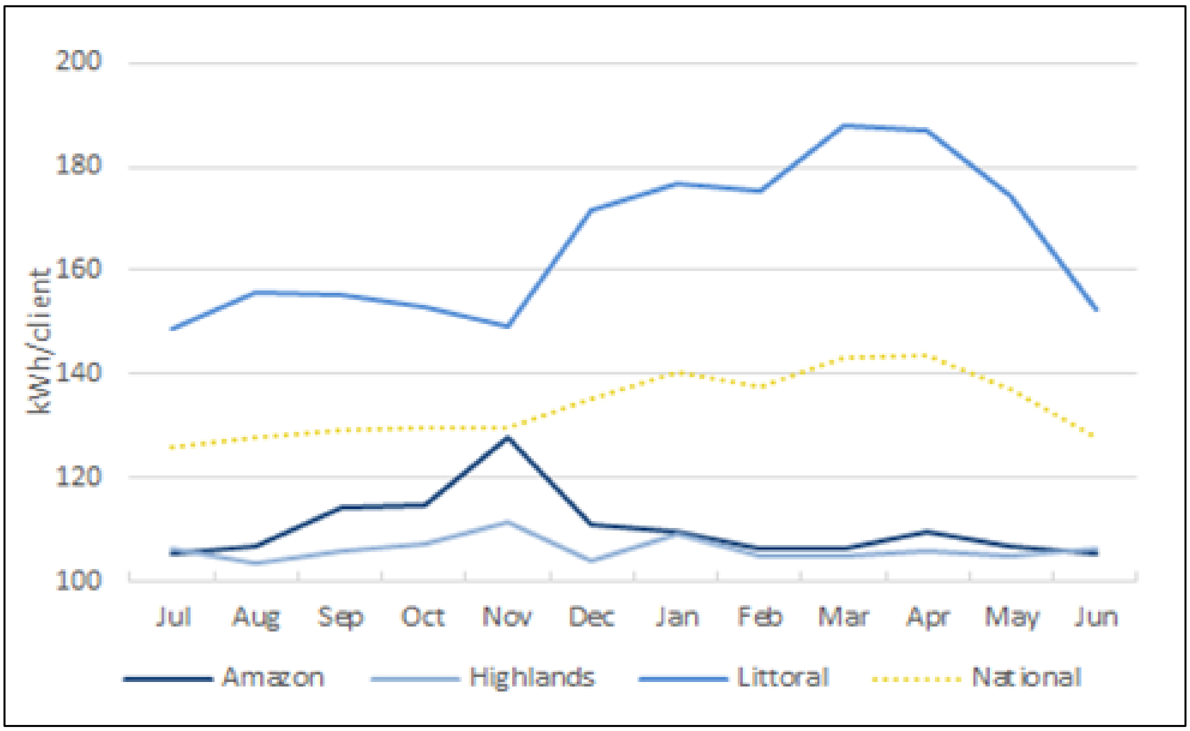


Source: National: CENACE, 2022; *Regions: Author calculation with data from* CENACE, 2021

2.3 Energy consumption and cooling

Figure 7 presents the monthly electricity consumption per customer in the residential sector at the national level and per climatic region. First evidence of the cooling electricity consumption starts with trends in electricity consumption over the year. This study sources AC sales data from ARCERNNR, 2022-2 . The Littoral region has the highest consumption per client of all three regions, ranging from 50% to 75% more. Between the months of December and May, a peak in the consumption per client is observed in the Littoral region, representing up to a 23% increase. Nationally, this phenomenon can be observed at a lower scale, with the peak representing up to 12%. The increase in electricity consumption during the hottest months in the Littoral region is caused in part by an increase in AC use. As a first approximation, defining a monthly baseline consumption would allow an estimation of the cooling load in Ecuador. The baseline electricity consumption is defined as the monthly average of electricity consumption per customer in the Highlands region; in this region it is assumed that there is no AC need, and consumption per client is somewhat stable through the year.

Figure 7. Average monthly electricity consumption per client in the residential sector in Ecuador, 2022.



Source: (ARCERNNR, 2022-2)

The baseline electricity consumption for the Littoral and Amazon regions is obtained by multiplying their respective monthly number of customers by the average of monthly electricity consumption per customer in the Highlands region. It is worth noting that by doing this, it is implied that other parameters are assumed equal in all regions (income level, appliance uptake and usage). The cooling load is then estimated by subtracting the baseline consumption to the total electricity consumption in the region, as shown in equation below:

Equation 1: $Cooling\ Load_i = E^R{}_i - BL^R{}_i = E^R{}_i - Customers^R{}_i \times BA$

The equation above presents the cooling load for the *i*-th month, where:

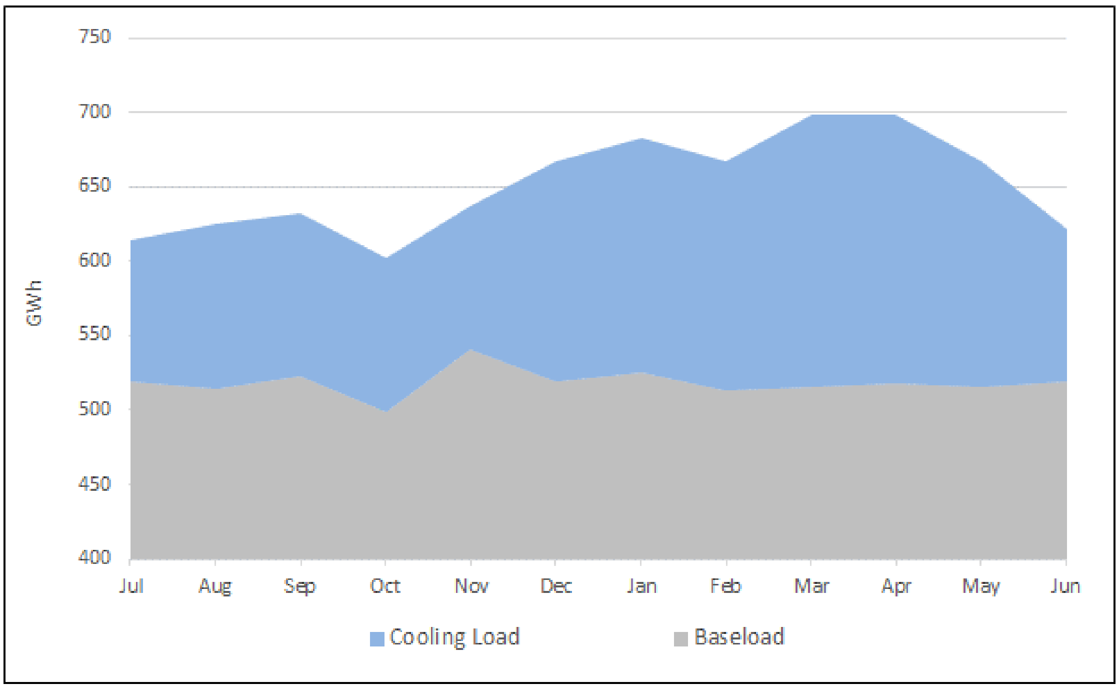
E^R is the electricity consumption in the region *R*;

BL^R is the baseline consumption in the region *R*;

and *BA* is the average of monthly electricity consumption per customer in the Highlands region.

Figure 8 shows the results of this methodology. The national baseline consumption was obtained by adding total electricity consumption from the Highlands region and the consumption baseline for the Littoral and Amazon regions. Ecuadorian cooling load in 2022 is estimated to be around 1.56 TWh. For the Littoral region, this represents on average 36% of residential electricity consumption, reaching in some months up to 45%.

Figure 8. Cooling load estimation with Top-Down methodology for the residential sector in Ecuador, 2022.



Source: Author calculations using data from (ARCERNNR, 2022-2)

2.4 Policy context

2.4.1 Overview

Ecuador has put in place an extensive legal and regulatory framework to advance energy- efficiency policies and programs. The most important and comprehensive components of this framework are the National Energy Efficiency Plan (PLANEE 2016-2035) and the Energy Efficiency Law (Gobierno de Ecuador, 2019).

The legal and regulatory framework in place in Ecuador for the uptake of EE includes:

- National Constitution (2008) - Indicates that the State will promote energy efficiency and the development of environmentally clean practices and technologies.
- Plan Nacional de EE (PLANEE 2016-2035) - presents the plan to adopt energy- efficiency policies in the transportation, industry, residential, and power sectors (Ministerio de Electricidad y Energía Renovable, 2017).
- Executive Decree 98(2017) - , ratification of the Paris agreement, outlines an unconditional goal to reduce 9% of GHG emissions for the energy, industrial, agriculture, and waste sectors and 20.9% conditional to international cooperation.
- Executive Decree 371(2018) - , adopts Agenda 2030 for Sustainable Development as public policy.
- Energy Efficiency Law (LOEE 2019) - provides a legal framework for operation of the National System of EE (SNEE); it also mandates the establishment of the National Committee of EE (CNEE), composed of public and private entities representing government, industry, and academia.
- Reglamento a Ley Orgánica de EE (2021) - develops the regulatory framework for implementation of the energy-efficiency law.
- Decree 68 (2022) - mandates alignment of national quality standards with international best practices to enhance the nation's quality system.

PLANEE includes lines of action under the Residential, Commercial and Public axis. These sectors represented 60% of total electricity consumption in 2022, according to data from ARCERNNR (2022-2). As part of the plan to address these levels of energy and electricity consumption, the Ministry of Energy and Mines (MEM) developed regulatory mechanisms, created tax and financial initiatives, and launched initiatives to advance energy efficiency in these sectors. In coordination with INEN, MEM developed 11 energy efficiency norms since 2007 to advance energy management practices and energy- efficient construction and 23 Technical Regulations (Reglamentos Tecnicos) to ensure the prevalence of high-efficiency domestic and industrial equipment in the Ecuadorian market.

One of the flagship programs under the residential, commercial and public axis was the program RENOVA for refrigerators, which consisted of substitution of inefficient units by new and energy- efficient products manufactured in Ecuador. As reported by PLANEE, during the 2012-2016 implementation period, the program achieved energy savings on the order of 38,200 MWh per year through the substitution of 95,652 refrigerators (Ministerio de Electricidad y Energía Renovable, 2017).

Another important initiative under the PLANEE line of action was the energy- efficiency program for induction cooking and electric water heating (PEC), which aimed to replace the use of liquefied petroleum gas, or propane, with electricity for cooking and heating water. Financial support for the acquisition of the induction stoves was provided by the government for 80% of the more than half a million families participating in the program (as of the end of 2016).

In 2015, Ecuador also launched the Securing EE in the Public and Residential sectors program (SECURE), which sought to increase the market share for efficient appliances through the implementation of the Maximum Energy Efficiency Label (DMEE) mechanism set up to help consumers identify equipment that consume less energy. The implementation of DMEE is carried out by MEM; participation by appliance manufacturers or importers is voluntary. In the case of AC equipment, given the lack of laboratories with the capability to conduct testing in Ecuador for this product and due to the fact that there is no local manufacturing, the program relies on the results provided by laboratories where the units originate. In all cases, the units are labeled with the maximum energy- efficiency level, which is hard to certify.

2.4.2 Regulatory framework

The main policy instrument for the issuance of norms and technical regulations is the Ecuadorian Quality System Law, which declares, as a state policy, the promotion and demonstration of quality standards as a key factor of productivity, competitiveness, and national development. This law, issued in 2007, provides the institutional framework for the organization of the National Quality System and establishes the mechanisms to ensure compliance with regulations and apply sanctions. The institutional framework consists of an Inter-Ministerial Quality Council (CIC), composed of INEN, the Ecuadorian Accreditation Service (SAE), MEM, and other ministries and coordinated by MPCEIP, which approves a National Quality Plan on a yearly basis.

The basis for the issuance of Technical Regulations (Reglamentos Tecnicos), which, unlike the Technical Norms (Normas Tecnicas) are mandatory and are determined by the relevant government agencies with technical support by INEN, include provisions from distinct legal instruments:

- Ecuador's Constitution (people's right to receive goods and services of optimal quality)
- Resolutions by the Andean Community Commission (legitimate right to issue regulations to defend the national interest but not imposing unnecessary restrictions to free trade)
- The Ecuadorian Quality System Law (which defines INEN's responsibilities in the formulation of norms and regulations and provides oversight powers to MPCEIP in the regulatory process)
- Executive Decree 68, a mandate to harmonize current regulations with international best practices to advance competitiveness and simplification of administrative procedures.

As stipulated in the Law of the Ecuadorian Quality System in its Art. 15, point a, INEN is the competent national technical body in matters of regulation, standardization, and metrology. MPCEIP is the institution in charge of approving the technical regulations that INEN develops at the direction of the relevant entities of the public administration (MEM in the case of the technical regulation for AC).

Article 22 of the Law of the Ecuadorian Quality System establishes that MPCEIP has the power to issue procedures to evaluate compliance with the technical regulations; this includes verification of compliance through the issuance of a "certification of conformity" by an entity duly accredited by SAE for that purpose before the regulated product (or service) is commercialized in Ecuador. MPCEIP, through direction of market control and surveillance, conducts inspections as part of the compliance verification process.

The SAE evaluates the technical competence, transparency, and independence of the entities dedicated to conformity assessment, ensuring that they comply with the standards established based on international practices. As of September 2021, SAE has 29 active accredited bodies in the certification area, 74 in the inspection area and 192 laboratories. Currently, there are only two laboratories accredited by SAE to conduct testing for AC equipment: LENOR and SICAL, but they don't have testing facilities in Ecuador, conducting testing in other countries.

Under this policy and regulatory framework, updating the current technical regulation for AC equipment (RTE- INEN-072-EE for ductless AC) involves the submission of a technical proposal by MEM to INEN (which is to be validated by the CNEE as the main inter-institutional body coordinating energy-efficiency policies), the implementation of technical review and public consultation processes with technical committees set up by INEN, and the eventual approval and officialization of the regulation by MPCEIP. As of 2023, a technical proposal has been submitted to INEN but no further actions have proceeded. The proposal for a new MEPS is based on a Pan American technical standards commission norm (COPANT 1711:2020), and consists in adopting the A rating in said standard as a new MEPS.

Table 2. Country comparison of AC MEPS.

Country	Efficiency metric	Standard	MEPS* (Wt/We)	Year	Source
Ecuador	EER	ISO 5151	3.20	2017	(INEN, 2017)
Colombia	EER	ISO 5151	3.00	2022	(Ministerio de Minas y Energía, 2021)
Peru	SEER	UNE-EN 15218	3.01	2018	(Ministerio de Energía y Minas, 2018)
Brazil	EER	ISO 5151	3.02	2018	(Augustus de Melo, Borges Cunha, & Santiago Suárez, 2022)
Argentina	SEER	ISO 5151	3.39	2019	(IRAM, 2019)
Mexico	SEER	AHRI 210/240	3.28	2018	(SEGOB, 2018)
Chile	EER	ISO 5151	3.20	2018	(Ministerio de Energía, 2018)
COPANT	SEER	COPANT 1711	3.6**	2017	(INEN, 2023)
China	SEER	GB 21455-2019	3.7	2020	(Karali, et al., 2020)
USA	SEER	AHRI 210/240	3.93	2023	(USDOE, 2023)
EU	SEER	EN 14825	4.60	2014	(Karali, et al., 2020)

* Showing only the lowest energy efficiency rating **Pan American technical standards commission (COPANT): value is for **A** rating.

Table 2 presents a comparison of energy- efficiency levels in selected countries/regions. Regionally, Ecuador is in the high end of minimum energy efficiency for ACs, and almost all countries except Peru use the EER metric system. Argentina represents the best regional practice, using the Seasonal Energy Efficiency Ratio (SEER) measure with the highest levels of efficiency. The United States and the European Union represent a high- efficiency AC market: they use seasonal-based metrics and have high minimum energy- efficiency requirements for ACs. These MEPS are between 30% to 45% higher than the MEPS in Ecuador. Ideally, the objective would be to bring the Ecuadorian AC MEPSto the European Union energy-efficiency levels. Such a high jump in energy efficiency is unrealistic to achieve in one step. Proposed technical assistance activities support the first step towards this longer-term goal.

3. Air conditioning market in Ecuador

This section presents the results for the Ecuadorian AC market research performed for this report. It presents information about the current AC stock, AC ownership, geographical distribution of AC usage, market share by brand, size and type, and energy- efficiency levels.

3.1 Sources of information

NATIONAL SURVEYS

This work relies heavily on the national residential surveys performed in 2011, 2012, 2019, and 2020 by INEC (2011, 2012, 2020, and 2021). Information on household equipment can be found, and specifically AC ownership. Additionally, for the years 2011, 2019, and 2020, the total number of ACs for the residential sector is also given. The 2011 survey is actually a household income survey, which includes AC ownership information. This provides a link to both pieces of information for every household in the survey to establish a distribution of AC ownership by income level (Section 4.2.1).

IMPORT DATA

Import data from the customs office was obtained through a market research company. AC units fall into the customs tariff numbers 8415.10.10[4] and 8415.82.20[5], according to the Ecuadorian Technical Regulation RTE-072 (INEN, 2017). Data cleaning was necessary as there are products that are not AC equipment that fall into those categories (i.e., motors, air compressors, fans, detached parts for ACs, and others). The inside (evaporator) and the outside (condenser) parts of the equipment were often listed separately, and needed to be identified as a unit. This was considered in the number of imported ACs estimated in this work. The import data also gives information about the brands commercialized, manufacturer name, importing company, and country of origin. Import data are available from 2015 to 2022.

RETAILERS MARKET RESEARCH

A market research analysis was performed by LBNL between February and March 2023, visiting web sites from most popular retailers in Ecuador (Mercado Libre, 2023; MARCIMEX, 2023; Artefacta, 2023; Créditos Económicos, 2023; Gran Hogar, 2023; Importadora Castro, 2023). Relevant information for this study, such as the distribution of capacities, types of AC (conventional or inverter), model number, energy-efficiency level, and associated prices, were collected. A total of 156 data points was gathered across the mentioned sites.

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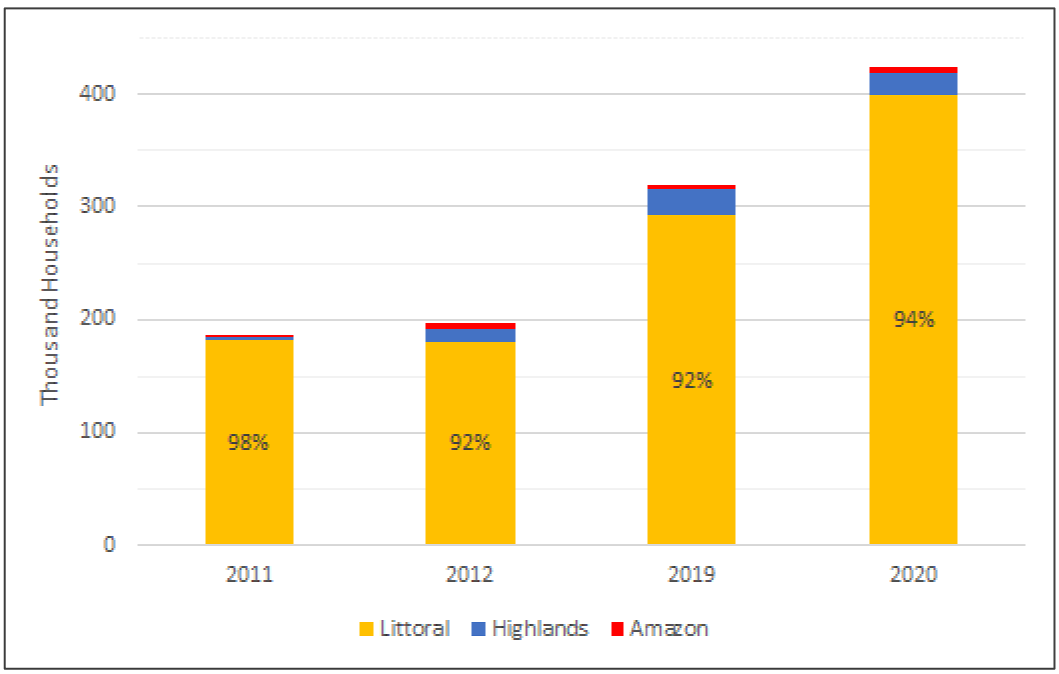
[4] "Air conditioning machines, comprising motor driven fans and elements for changing the temperature and humidity, including those machines in which the humidity cannot be separately regulated."

[5] "Air conditioning machines incorporating a refrigerating unit but without a valve for reversal of the cooling-heat cycle (excluding of a kind used for persons in motor vehicles, and self-contained or "split-system" window or wall air conditioning machines)"

3.2 Current AC market in Ecuador

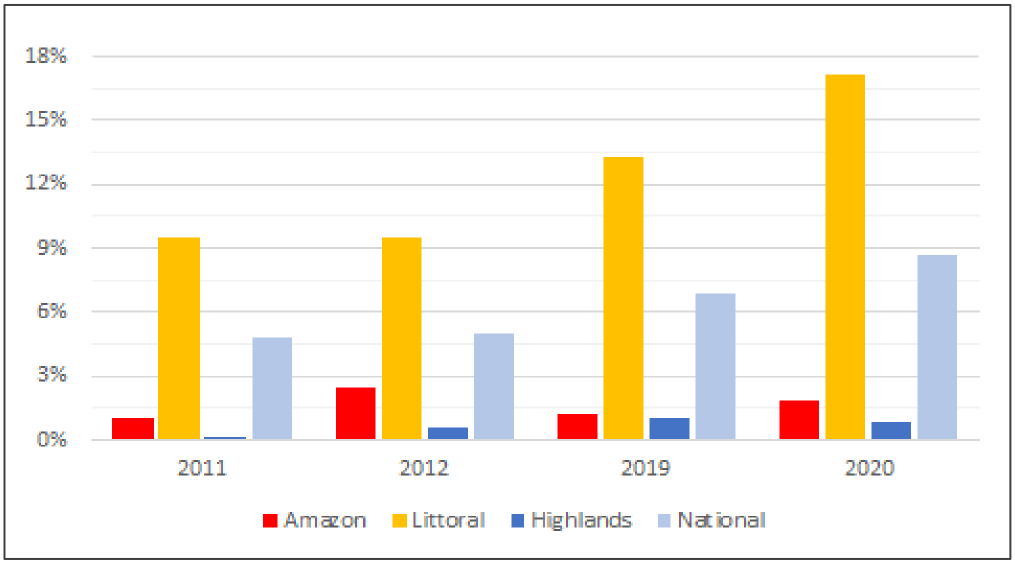
AC ownership in the residential sector is obtained directly from the national surveys for the years 2011, 2012, 2019, and 2020. Figure 9 shows the number of households owning at least one AC device categorized into climatic zones. Over the 9 -year time frame for which data were available, AC household ownership rates have more than doubled. Percentages indicated in this figure correspond to the share of households owning an AC unit in the Littoral region, implying that more than 90% of AC users are located in the Littoral region, which is the hottest climate zone in the country. Figure 10 shows the AC ownership rate for the different climate zones and at the national level. The highest AC ownership rate is seen in the Littoral, where it has gone from around 9.5% to approximately 17%, increasing by more than 80% in 9 years. Correspondingly, the national AC ownership rate has also seen an increase, but remains relatively low, below 9% in 2020, because only 52% of Ecuadorian households are in the Littoral region. Figure 9 and Figure 10 show that the AC energy consumption in Ecuador focuses in the Littoral region, where the majority of the Ecuadorian population lives and where most of ACs are located. The figures also show the rapid growth of AC users in the last 9 years, which has more than doubled.

Figure 9. Number of households owning an AC unit in Ecuador by climatic zone in Ecuador.



Source : INEC, 2011; INEC, 2012; INEC, 2020; INEC, 2021

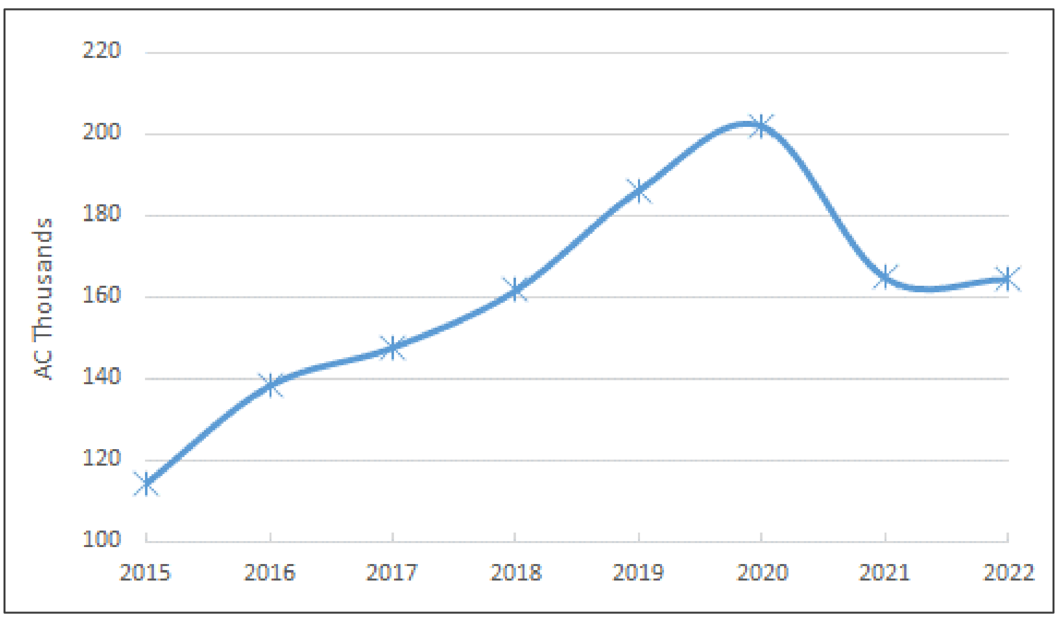
Figure 10. AC ownership rate for the residential sector in Ecuador.



Source : INEC, 2011; INEC, 2012; INEC, 2020; INEC, 2021

Figure 11 shows the total number of imported ACs. From 2015 to 2020, AC imports grew at a rate of 12% per year, almost doubling in 5 years. Due to the COVID crisis, the inertia of import growth was interrupted, and imports dropped dramatically in 2021 and 2022 to 2018 levels.

Figure 11. AC imports from 2015 to 2022



The AC stock (total number of AC units) in the residential sector was gathered from the national surveys, for the years 2019 and 2020. As ACs are used in both the residential and commercial sectors, to estimate AC stock, it was assumed (as in McNeil & Diaz, 2019) that the distribution of AC ownership between the residential and commercial sectors is 70% and 30%, respectively.

Figure 12. AC stock in Ecuador from 2011 to 2023

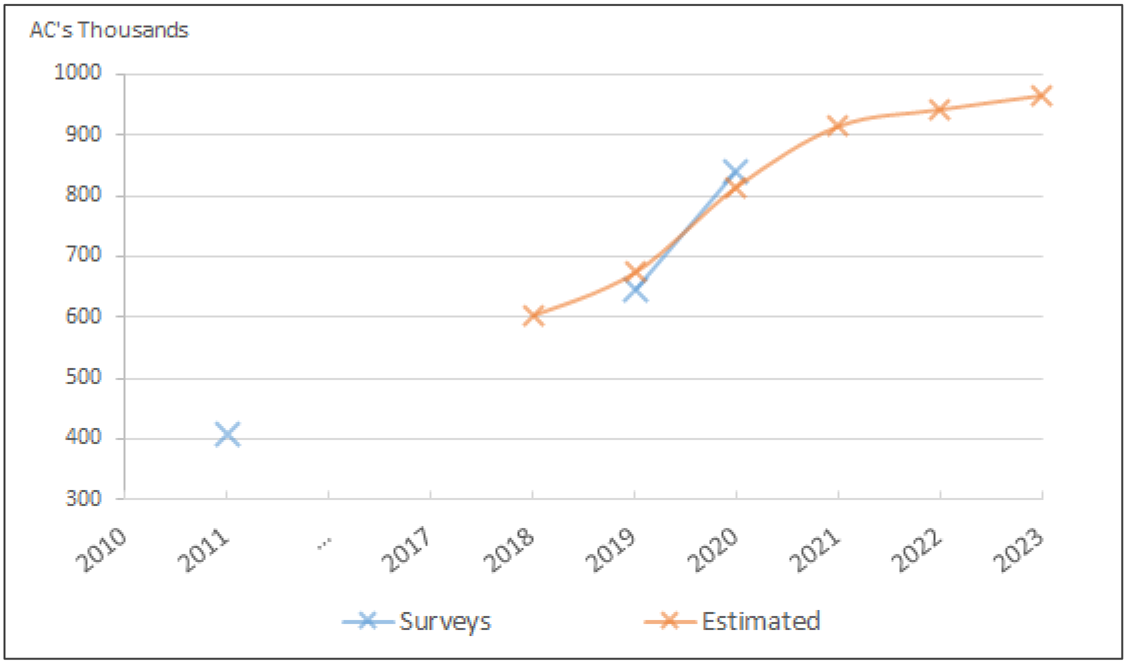


Figure 12 shows the total AC stock in Ecuador. The data was collected from the national surveys and a 70% residential market share was considered (blue). AC stock estimations are presented in orange. These preliminary estimations were made using a stock turnover model considering a constant 15% renewal rate and combining data from surveys (AC stock) and yearly AC sales/imports[6]. This is a different and simpler stock accounting model than the one presented in Section 4.2.4. As AC stock data is available only for 2019 and 2020, this methodology was used here extrapolate the AC stock in Ecuador for the more recent years. Surveys indicate that, between 2011 and 2021, AC stock more than doubled in size. Estimations indicate that between 2018 and 2023, AC stock increased by 60%. Between 2019 and 2020 the increase rate is significantly higher (21%) than other years. This is caused by an also higher increase rate in AC imports (15%) in 2019. This effect is seen until 2020, as imports from a year account for the following year AC stock. As for the information from surveys, it somewhat correlates with the estimated values, registering a higher increase of 30%. Between 2021 and 2023, the AC stock curve flattens as imports decrease dramatically (see Figure 11).

As seen in Figure 10, the national ownership rate is below 10% and, in the Littoral, it reaches around 17%. Even for the Littoral, 17% is far from being a saturated market, as (Mcneil and Letschert, 2007) have demonstrated that AC ownership rate is correlated to income and climatic conditions and theoretically it could reach the United States levels (88%) (EIA, 2020). This suggests that AC ownership could see an accelerated increase in the coming years in Ecuador.

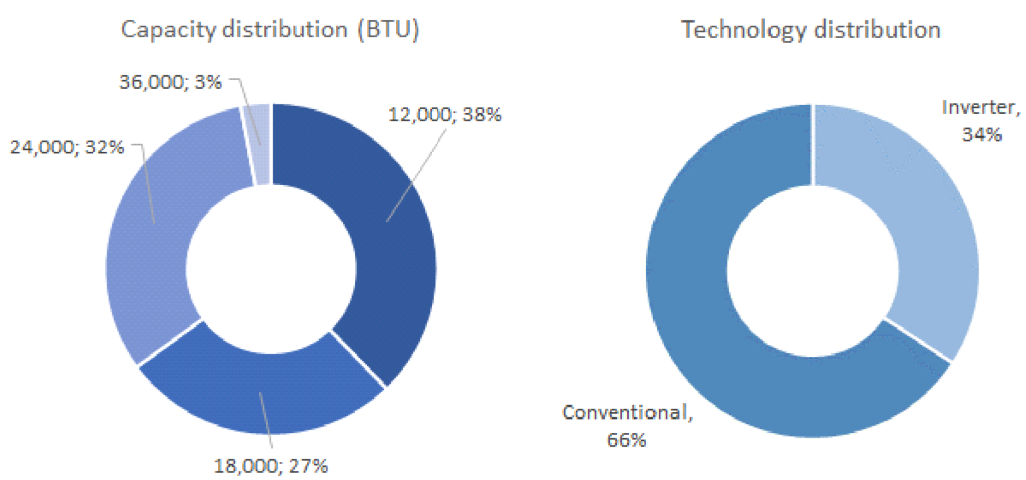
[6] There is no production of AC equipment in Ecuador. Here, yearly imports are assumed to be equivalent to yearly sales.

3.3 Energy efficiency and AC market in Ecuador

Table 3 presents the 11 predominant brands identified by the online market study. TCL, Midea, and RCA are the most common brands, with 30%, 19%, and 16% market shares, respectively. Eighty percent of the market share is dominated by Chinese brands, with the other 20% made up of non-Chinese brands—despite the fact that 95% of ACs are manufactured in China (based on the shipment port form in the import data). Energy- efficiency data were obtained by searching in owner's manuals, technical manuals, efficiency labels, or directly from the retailer's website. However, it was not always possible to find. Table 3 displays known energy-efficiency levels for conventional equipment, representing 55% of the total market share. Only conventional equipment is shown in Table 3, since inverter models generally meet the current Ecuadorian regulation of 3.2 W/W (INEN, 2017). The table presents general averages across all capacities within the brand, categorized into Chinese brands and non-Chinese brands. As can be seen, average energy- efficiency levels for Chinese brands (3.08 W/W, representing 59% of Chinese market share) are significantly lower compared to other brands (3.23 W/W. representing 40% of other brands market share), and the weighted average is below the 3.2 W/W level as stated by the Ecuadorian regulation (INEN, 2017). Furthermore, the weighted average across *all* brands with available data does not attain the minimum levels required.

Since energy- efficiency data were missing for many AC models, energy efficiencies for Chinese brands and for non-Chinese brands were grouped into two main categories, the portion of models with no data was assigned the weighted average efficiency of the other models in that group (see table 3). The resulting EER per appliance can be found in Table 22 Table 22. Energy-efficiency baseline for AC equipment by brand, type and capacity, EER (Wt/We).in the Annex section. Based on the data collected, we estimate the number of ACs on the Ecuadorian market and in the stock of ACs installed that do not comply with the current Ecuadorian MEPS. In 2022, approximately 470,000 installed ACs were below the energy-efficiency regulation, representing 47% of the total AC stock. Assuming that all inverter ACs meet the standard, this implies that 67% of all conventional ACs in 2022 fail to meet it. In other words, nearly half of the Ecuadorian AC stock fails to meet the current energy- efficiency regulation, and more than two thirds of conventional ACs fail (see table 3).

Figure 13. Cooling capacity and technology type distributions for the AC market in Ecuador



As can be seen in Figure 13, the most common cooling capacity for ACs sold in Ecuador is 12,000 BTU, representing approximately 38%, followed by 24,000 BTU, with about a third of the market. Units of 18,000 BTU have about a 27% share; units of 36,000 BTU have a 3% share. Roughly a third of units are inverters and two thirds are conventional ACs.

Table 3. Energy- efficiency levels and market share by brand for conventional equipment in Ecuador

	Brand	EER level (W/W)	Market Share	
Chinese Brands	TCL	2.97	30%	80%
	Midea		19%	
	RCA	3.24	16%	
	Hisense		9%	
	Chigo		5%	
	Innovair	2.89	1%	
	Weighted Average	3.08		
Other brands	LG		9%	20%
	Samsung	3.21	4%	
	Electrolux		3%	
	Mabe	3.28	3%	
	Panasonic	3.21	1%	
	Weighted Average	3.24		
	Weighted Average	**3.10**		

* Weighted averages are based on the total number of ACs by type and brand

4. AC energy consumption and related CO_2 emissions in Ecuador

4.1 Current energy consumption and GHG emissions

In order to calculate the average unit energy consumption (UEC) of ACs in Ecuador and model the impact of energy- efficiency regulations, the market is divided into the segments described in Figure 14. Figure 14 diagrams the process of disaggregating the total AC stock into the number of ACs by brand, type, and capacity. The distributions shown in blue were obtained from data sources presented in Section 3. Detailed information can be found in the Annex in Table 20.

The difference between AC technology types lies in the response to seasonal climate variations. These variations, depict the fluctuating demands of a cooling season. During periods of heightened heat and less extreme cooling needs, such as transitional periods within the season, the functioning of inverter ACs compared to conventional ones becomes relevant. Conventional ACs, often referred to as Fixed Speed (FS), operate at full capacity when turned on, shutting off once the desired temperature is reached, and restarting the cycle when the thermostat triggers it. In contrast, inverter ACs possess the ability to modulate their operating capacity. Consequently, during non-peak cooling periods, conventional ACs run at maximum capacity, whereas inverter ACs function at a fraction of their maximum capacity, showcasing their lower energy consumption and adaptability. For this reason, the SEER energy efficiency measure, which incorporates seasonal variations, proves to be a more realistic energy efficiency metric for air conditioning compared to the EER. With the SEER measure, the responses to seasonal climatic variations between the two technology types are modelled more accurately, revealing a greater disparity in efficiency between inverters and conventional ACs than what is observed with the EER measure. From now on, the SEER measure is going to be used and the following equation was used to convert from EER units to SEER units (Karali, et al., 2020):

Equation 2: $SEER = 1.012 \times EER$

The annual UEC for cooling can be modelled as a log-linear function of the energy- efficiency grade as used in (Karali, et al., 2020). As in the mentioned paper they work with a different energy efficiency measure than in the present work, the idea is taken using data gathered from (Letschert, et al.,2023) and an online tool (AFUE Calculator, 2023). This data relates the SEER rating of ACs and the UEC. The UEC obtained from (Letschert, et al.,2023) were scaled for the annual hours (1,095 hours) of AC operation in Ecuador as in Porras, Arnaldo, Soriano, & Ramirez (2023). The UEC is estimated by the following equation:

Equation 3: $UEC = (-0.0744 \times ln(SEER) + 0.2784) \times CC$

In this equation, SEER is expressed in (BTU/h) /W, and CC is the cooling capacity in BTU/h. The SEER per appliance can be found in Table 21 (see Annex). Equation 3 corresponds to the UEC of AC appliances in the Littoral and Amazon region. For the Highlands region, as the climate maximum (defined later in Section 4.2.1) is a third of the climate max in the Littoral region, the UEC in the Highlands region is estimated as a third of the UEC in the Littoral region. Total electricity consumption (EC) related to cooling use is obtained by multiplying the number of ACs (by brand, type, capacity, and region) with its respective UEC, that is:

Equation 4: $EC = \sum_{b,t,c,r} \#AC_{btcr} \times UEC_{btcr}$

Where *EC* is the total AC electricity consumption and $\#AC$ is the number of ACs. The subscripts *b, t, c,* and *r* represent the brand, type, capacity, and region, respectively.

Table 4. UEC results for the BAU scenario (kWh/year).

Capacity (BTU)	Conventional	Inverter
12,000	1,101	863
18,000	1,688	1,355
24,000	2,257	1,756
36,000	3,342	2,788

Figure 14. Diagram for the disaggregation methodology for the total number of ACs.

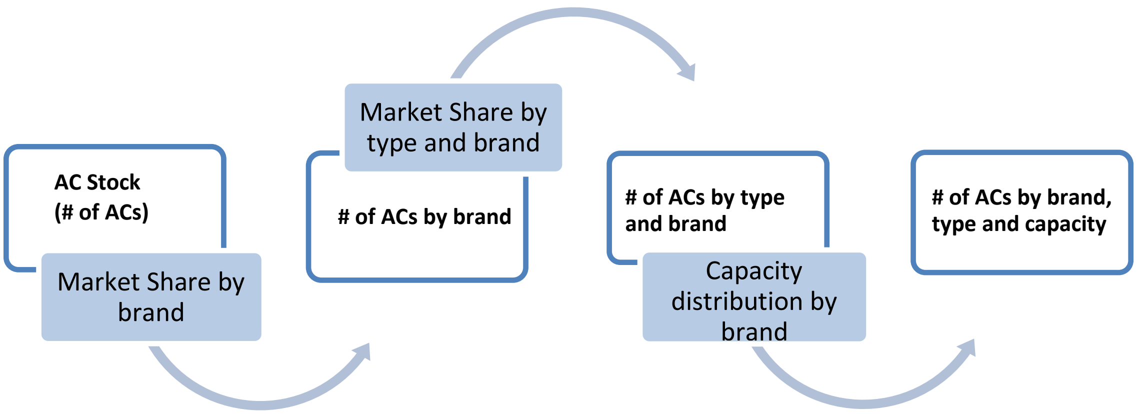


Figure 15 shows the results for electricity consumption estimation due to AC use in Ecuador from 2018 to 2022. The results are based on the AC stock presented in Figure 12. In 2022, electricity consumption due to AC use in Ecuador was estimated to be around 1.63 TWh. For the residential sector, this would be equivalent to 1.14 TWh of electricity consumption, representing around 15% of national residential electricity use in that same year. Residential electricity use only in the Littoral region reaches approximately 26%, representing a large share of the highest electricity consumption sector in the country.

Figure 15. AC electricity use and related CO_2 emissions in Ecuador from 2018 to 2022

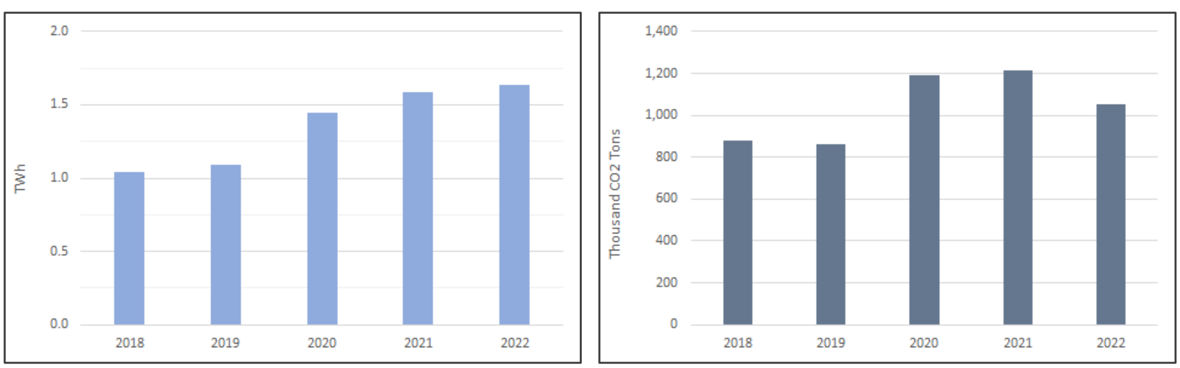
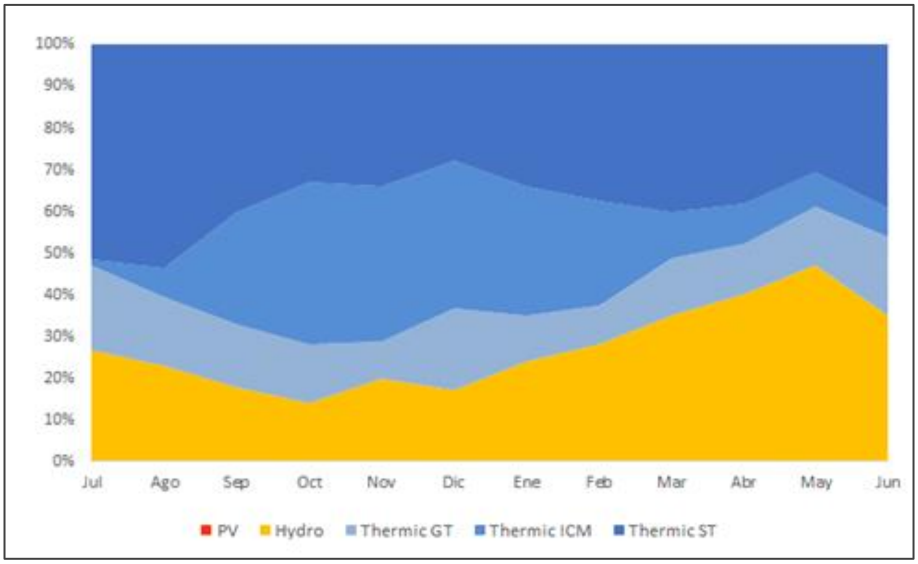


Figure 16 shows the monthly generation technology share of gross electricity production in the Littoral region in 2022. Where PV, ICM, GT, and ST are acronyms for photovoltaic, internal combustion motor, gas turbine and steam turbine, respectively. As can be seen, between the months of December and May, there is an increase of electricity production from hydroelectric plants. This shows that the peak electricity consumption coincides with the season when hydroelectric power has the most activity revealing a somewhat strong dependence on this energy source to help cover for the peak consumption season. However, thermoelectric plants still represented more than half of the electricity production during 2022. These thermoelectric plants are mostly fired by natural gas and biogas (43% combined) and fuel oil (44%). For this reason, it is important to distinguish between electricity generation within the different climatic regions. An electricity carbon factor for each climatic region was calculated following the methodology used in CENACE, 2022. The results for the littoral region are shown in Table 4. As can be seen, the national electricity carbon factor remains relatively low, whereas the carbon factor in the Littoral region is 3.5 times higher.

Figure 16. Monthly generation technology share of gross electricity production in the Littoral region, 2022.



Source: (ARCERNNR, 2022-1)

Table 5. Electricity carbon factor results and transmission and distribution (T&D) losses by climatic region in Ecuador, 2022

Climatic Region	Carbon Factor* (Tons CO_2/MWh)	T&D losses
Littoral	0.522	16.7%
Amazon	0.007	6.9%
Highlands	0.113	6.9%
National	0.143	13.3%

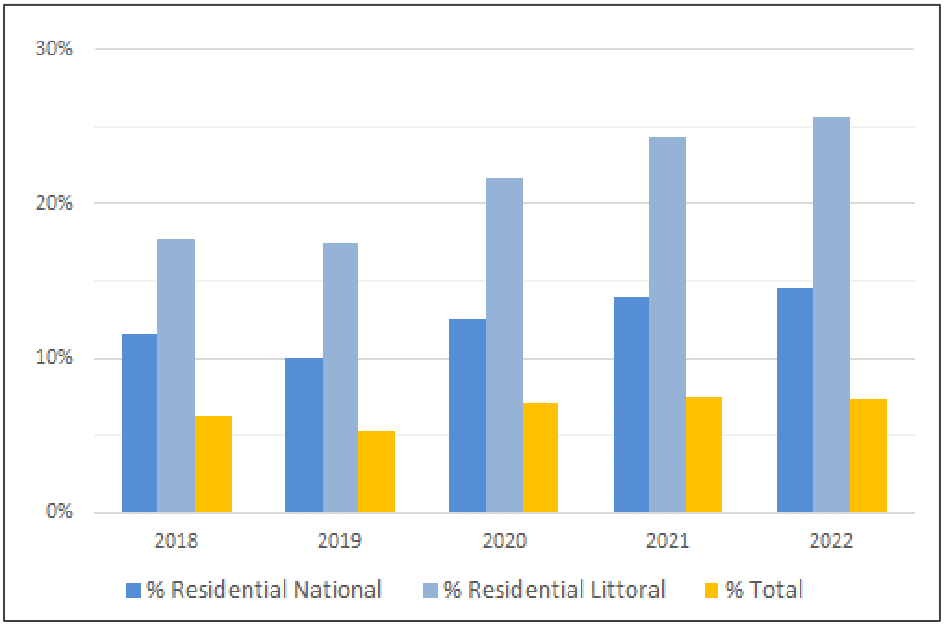
*Source: *Author calculations with data from* (ARCERNNR, 2022-1; CENACE, 2022)

When calculating CO_2 emissions from electricity use, T&D losses must be considered, especially in a country like Ecuador where total losses amount up to 26% in some cases (ARCERNNR, 2023). According to data from (ARCERNNR, 2022-2), more than 99% of electricity in the Littoral region is sold by the CNEL company. Therefore, T&D losses for the Littoral region are assumed to be the same as at the CNEL company. The Amazon and Highlands regions are assumed to have the same T&D loss rate as the energy efficiency company. Values were taken from (ARCERNNR, 2023) and are shown in Table 4.

Figure 15 shows the CO_2 emissions due to AC use in Ecuador between 2018 and 2022. Despite a 13% decrease in emissions between 2021 and 2022, estimations indicate that between 2018 and 2022 emissions had an increase of around 20%.

Figure 17 shows the evolution in time of the electricity from AC use share compared to the total national residential sector, to the residential sector in the Littoral region, and to the total national electricity consumption. From 2018 to 2022, the share of electricity consumption from AC use compared to the residential electricity use in the Littoral region grew from 18% to 26%, a 45% increase. Compared to the national residential sector electricity consumption, a growth of 26% is observed, going from 12% in 2018 to 15% in 2022. In 2022 AC electricity use represented 7% of national electricity consumption, highlighting the important part that electricity consumption from AC represents in the residential sector, especially in the Littoral region.

Figure 17. Share of AC electricity use compared to residential, residential Littoral, and total national electricity consumption.



4.2 Forecast and energy analysis methods

4.2.1 Diffusion model

LBNL developed a Policy Analysis Modeling System (PAMS, 2007), a tool combining a bottom-up approach and econometric models based on climate variables and household income. This allows the assessment of a new MEPS and the quantification of its impacts in the residential sector from a consumer perspective. This methodology has been widely used in similar studies and by different actors, by government agencies as in Chile (Ministerio de Energía, 2017), international organizations such as the UNEP for Latin America and the Caribbean, and by academic researchers for the city of Guayaquil, Ecuador (Porras, Arnaldo, Soriano, & Ramirez, 2023), and in the rest of the world (Hitchin, Pout, & Riviere, 2013) (Li, Fei, Zhang, & Qin, 2019). Specifically, this methodology relates income level and a climate variable with AC household ownership through a logistic function as shown by (Mcneil and Letschert, 2007). As the climate variable, the climate maximum $CMax(CDD)$ is considered and represents the maximum saturation level. The climate maximum is calculated as a function of the cooling degree days (CDD)[7]. The AC household

[7] $CMax(CDD)=0.994-1.17\times\exp(-0.00298\times CDD)$ (McNeil, Letschert and Van Buskirk 2007)

ownership or diffusion of ACs in the residential sector as a function of income (*I*) is described by the following equation:

Equation 5: $Diff(I) = \frac{CMax}{1+\gamma e^{-\beta I}}$

Were $Diff$ is the AC ownership, I is monthly income, and β and γ are the parameters to calculate for each climatic region.

The data source to perform the logistic regression comes from the national survey of household income and expenses from 2011-2012 (INEC, 2011). This was used because it is the only data source available that allows to link AC ownership and income level in Ecuador. The data allows for analysing the three climatic regions separately, even though more than 94% of ACs are located in the Littoral region. The data are grouped by income, into $50 USD increment groups. Then, the AC ownership is calculated within each of the groups. Groups with zero income or zero ownership are excluded; only incomes lower than $10,000 USD per month are considered. The data shows that 95% of households have a monthly income of $2,000 USD or less. The regression model must reflect this, and accord more importance to those data points. Therefore, a logistic regression was performed using a weighted least squares methodology and the solver tool in Excel software following the relationship established in Equation 4 . The weights considered were the total number of households for each income group.

Figure 18 presents the logistic regression results for each climatic region. Compared to the Amazon and Littoral regions, the Highlands region has a very small amount of CDD, resulting in a low response from AC ownership to income. As expected, the Littoral region has the fastest saturation, attaining it at an income of around 4,000 USD/month compared to around 6,000-8,000 USD/month in the other regions. Table 5 presents the input coefficients for Equation 3 for the different climatic regions, as well as previous diffusion models found in the literature. Analysis shows that the coefficient of determination (R^2) for the Littoral region is higher than in the other two regions, which is expected because of the number of data points found in each of the regions. Due to the symmetry of the curve, the inflection point is where AC ownership gets to 50%, and where the speed in which the rate of change in AC ownership reaches its maximum and starts to decrease. It is the middle point of the curve, giving a sense of the position in the curve given an income value. Currently, Ecuador is at an income level of around a thousand USD per capita per month. That is, the country is just at the beginning of the exponential growth in AC ownership.

Figure 18. AC diffusion model by climatic region in Ecuador

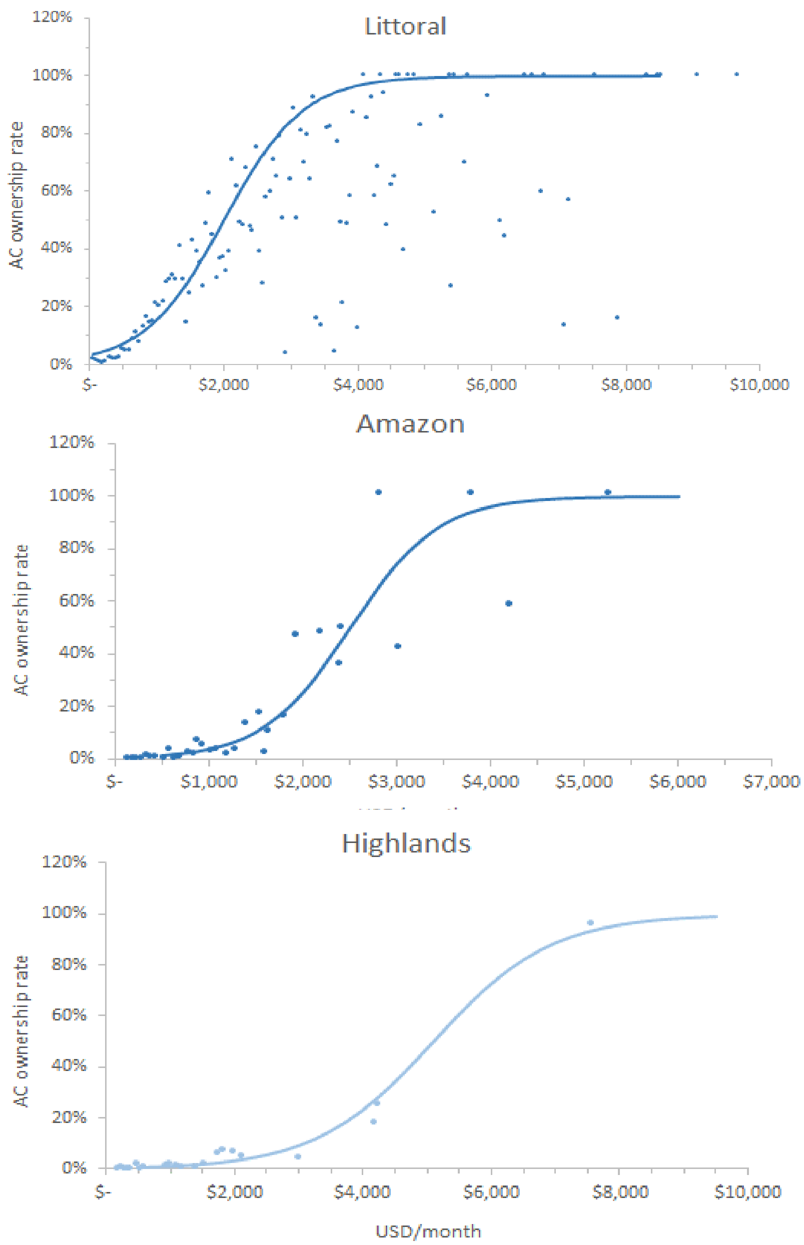
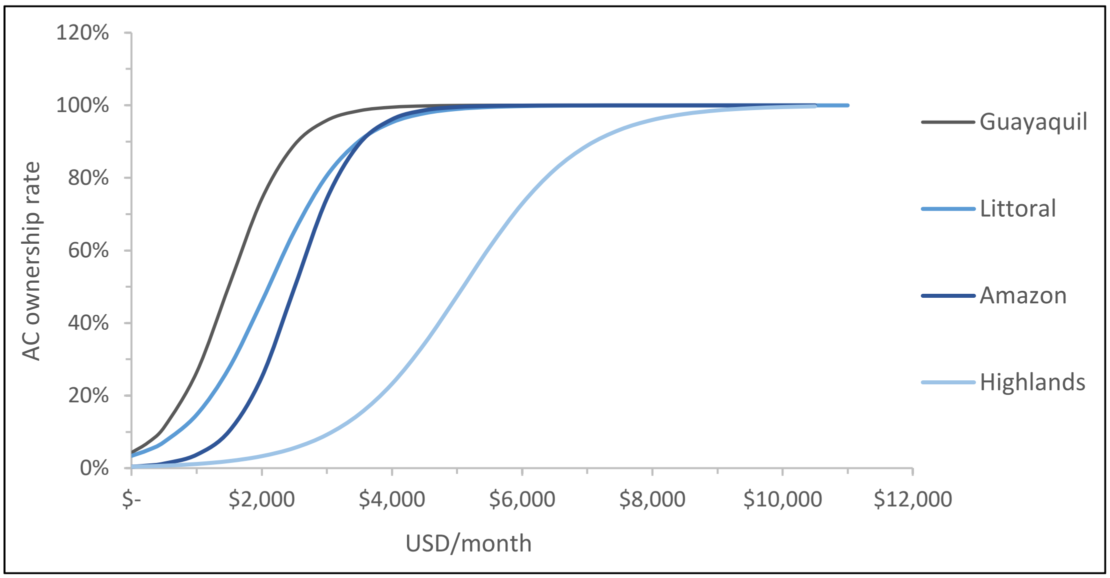


Table 6. Comparison of AC diffusion models.

Location	CDD (°C)[8]	$CMax$	β	$ln\ (\gamma)$	R^2	Inflection point (USD/month)
Littoral region	2,748	0.994	1.69×10^{-3}	3.347	0.81	1, 980
Amazon region	2,400	0.989	2.16×10^{-3}	5.403	0.78	2, 507
Highlands region	178	0.320	1.09×10^{-3}	5.569	0.59	5, 096
Guayaquil (Porras, Arnaldo, Soriano, & Ramirez, 2023)	2,748	0.994	2.08×10^{-3}	3.10	0.59	1, 490

Figure 19. Comparison of AC diffusion models.



4.2.2 Population, households and GDP forecasts

A population forecast by province in Ecuador from 2010 to 2045 made by the national planning and development secretary (INEC, 2012) was used as the base for estimating the number of households. According to data from (INEC, 2011; INEC, 2020; INEC, 2021), from 2010 to 2020, household size decreased at a rate of 0.73% per year. This was used to calculate future household size, and, with population, the future number of households. In the same period, the number of ACs per household (only considering

[8] CDD for the Littoral region was taken as in (Porras Carrión 2020). CDD for the other regions was obtained using an online tool, considering a base temperature of 18.5°C (Degree Days 2023). For the Amazon region an average of available values between 2020 and 2022 from three weather stations was taken (Coca/francisco, EC (76.99W,0.46S); Lago Agrio, EC (76.87W,0.09N); Pastaza / Rio Amazonas, EC (78.06W,1.51S)). For the sierra region an average of available values between 2020 and 2022 from three weather stations was taken (Nuevo Aeropuerto Internacional Mariscal Sucre, EC (78.35W,0.12S); Cuenca / Mariscal Lamar, EC (78.98W,2.89S); Riobamba/chimbor, EC (78.66W,1.65S))

households that have at least one AC) remained nearly constant in all three regions. The number of ACs per household for each climatic region is taken as the average of the levels in 2010, 2019, and 2020.

The input for the diffusion model, the household income, is modeled by the gross domestic product (GDP) per capita. The GDP per capita, in purchasing power parity (PPP) constant 2010 USD, is used and is forecasted to 2045. During the whole analysis period, the GDP per capita was considered to grow at a rate of 2.8% per year as used in official Ecuadorian projections (BCE, 2007-2022). The PPP coefficient is the 2021 International Monetary Fund coefficient, and an average GDP deflator from 2010-2020 from the World Bank was taken (see Table 6). Climatic region disaggregation is obtained through a constant GDP share, equal to the average share between 2016 and 2020.

Table 7. Variables used for the GDP and households forecast.

Variable name	Region	Value	Units
Household-size decrease rate	National	0.73%	%/year
GDP deflator	National	1.0083	USD 2010/USD
PPP coefficient	National	1.942	USD PPP/USD
ACs per household	Littoral	1.5	#AC/Household
	Amazon	1.2	
	Highlands	1.2	
GDP Share	Littoral	47.2%	
	Amazon	3.8%	
	Highlands	48.9%	
Electricity Tariff	Littoral	0.089	USD/kWh
	Amazon	0.077	
	Highlands	0.087	

4.2.3 Baseline energy consumption and scenario building

With the results from sections 4.2.1 and 4.2.2, it is possible to project to 2045 the ownership rate based on the projected GDP per capita. For each region, the number of ACs in the residential sector is obtained using the following equation:

Equation 6: $\#AC^i = \%\ Ownership^i \times \#HH^i \times \left(\frac{\#AC}{HH}\right)^i$

Where *i* is the region, $\#HH^i$ is the number of households in region *i*, and $\left(\frac{\#AC}{HH}\right)^i$ is the number of ACs per household in the region *i*, values can be found in Table 6. As suggested by McNeil & Diaz (2019), the residential sector in Ecuador represents 70% of the market share of mini-split systems under 36,000 BTU/h in Ecuador. The small commercial sector has the remaining 30% share, a necessary condition to obtain the total number of ACs in Ecuador. Once the total number of ACs is obtained, the methodology described in Section 4.1 and Figure 14 can be used to disaggregate the number of ACs by brand, type, and capacity for each climatic region. Finally, energy consumption and CO_2 emissions can be obtained, shown in Section 4.1

All scenarios described below use the same number of AC projections based on GDP growth scenario mentioned in section 4.2.2. Scenarios assume 1,095 hours of yearly AC use in the Littoral and the Amazon regions (Porras Carrión, 2020), and 350 hours for the Highlands region (a third of the other regions). From 2022 onwards, the electricity carbon factor was taken as in Table 4.

- ***BAU:***

The baseline scenario or *"Business as Usual"* BAU scenario, considers the energy-efficiency levels described in Table 21 of the Annex, a product of the assumptions made in Section 3.3, that is, no efficiency improvement in the absence of new MEPS nor a better enforcement of regulations.

- ***SC 1: CURRENT NORM ENFORCEMENT:***

This study shows that a significant portion of the AC market in Ecuador is not at the energy- efficiency level required by the current norm (3.2 Wt/We EER). For this scenario, it is considered that the energy efficiency for all new ACs is at least at the norm requirements. The energy efficiency of the portion of equipment that is currently below the norm requirement is set to the minimum level of the current standard.

- ***SC 2: PROPOSED NEW MEPS:***

The new MEPS proposed and analyzed here requires various new elements to consider in the new regulation. First is the change of energy- efficiency metric. Second, is the introduction of stepped MEPS according to the capacity of the equipment. Third, is the introduction of a MEPS for each type of AC (conventional or inverter).

The new MEPS proposal adopts the current energy- efficiency requirements in Mexico. Even though the higher efficiency scenarios (Sc4 and Sc5) are a step ahead compared to the other scenarios in terms of energy efficiency, they are too expensive for the Ecuadorian households to adopt. This makes it a good compromise between the BAU scenario and higher efficiency standards, adding different dimensions to regulate the market. This standard regulates the energy efficiency of conventional equipment and inverters separately, based on the capacity of the equipment. Additionally, a different measure of energy efficiency is used instead of the ERR measure. SEER considers a set of different climatic conditions during the testing, whereas the EER considers only one climatic condition. As a result, SEER is a more realistic measure of the energy efficiency of a mini-split system. Table 7 presents the new energy performance standard proposed for Ecuador. It is considered that the energy efficiency for all new ACs sold is at least at the norm requirements. The energy efficiency of all equipment that in the baseline is below the norm requirement is set to the minimum level presented in Table 7.

Three additional scenarios for other levels of MEPS are explored. Table 8 and Table 9 present the energy efficiency and UEC definitions used for every scenario.

- **Sc 3: Regional best practice:** Argentina MEPS level (IRAM, 2019)
- **Sc 4: Regional standardization commission:** MEPS level is the "A" rating from the Pan American technical standards commission, COPANT 1711 standard (INEN, 2023).
- **Sc 5: EU MEPS level:** European Union MEPS level

- **Sc 6: High efficiency:** Is a mix between EU MEPS levels for conventional equipment and the medium efficiency levels for inverter equipment found in (Karali, et al., 2020)

Table 8. Proposed new mini-split system MEPS for Ecuador (scenario 2).

BTU/h	Conventional SEER W_t/W_e (BTU/We)	Inverter SEER W_t/W_e (BTU/We)
Less than 14, 000 More than 14, 000 Up to 20, 000	3.40 (11.6)	4.68 (16)
More than 20, 000 Up to 36, 000	3.37 (11.5)	4.39 (15)
More than 36, 000 Up to 65, 000	3.34 (11.4)	4.1 (14)

Source: (SEGOB, 2018) (SEGOB, 2016)

Table 9. Energy- efficiency scenario definitions for new AC MEPS, SEER (W/W).

	Capacity (BTU/h)	BAU	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Conventional	12,000	3.24	3.24	3.40	3.39	3.60	4.60	4.60
	18,000	3.17	3.24	3.40	3.39	3.60	4.60	4.60
	24,000	3.16	3.24	3.37	3.39	3.60	4.60	4.60
	36,000	3.20	3.24	3.34	3.39	3.60	4.60	4.60
Inverter	12,000	4.13	3.32	4.69	3.39	3.60	4.60	5.90
	18,000	3.95	3.32	4.69	3.39	3.60	4.60	5.90
	24,000	4.06	3.32	4.40	3.39	3.60	4.60	5.53
	36,000	3.83	3.32	4.10	3.39	3.60	4.60	5.15

Table 10. Maximum acceptable UEC for new AC MEPS scenarios, (kWh/year).

	Capacity (BTU/h)	BAU	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6
Conventional	12,000	1,101	1,101	1,049	1,052	990	775	775
	18,000	1,688	1,651	1,573	1,577	1,485	1,163	1,163
	24,000	2,257	2,201	2,115	2,102	1,980	1,549	1,549
	36,000	3,342	3,300	3,199	3,153	2,969	2,324	2,324
Inverter	12,000	910	1,073	760	1,052	990	775	604
	18,000	1,355	1,609	1,140	1,577	1,485	1,163	907
	24,000	1,756	2,145	1,621	2,102	1,980	1,549	1,289
	36,000	2,788	3,217	2,605	3,153	2,969	2,324	2,075

In Table 10, the UEC in the BAU scenario reflects what the current AC efficiency AC looks like. UEC for scenarios 1 through 6 are the maximum acceptable consumption based on the values from Table 9 using Equation 3. It can be noted that some values from Table 10 corresponding to the analysed scenarios are higher compared to the BAU scenario. For example, scenarios 3 and 4 have a higher energy consumption for a 12, 000 BTU inverter AC. That means that the scenario will have no effect on that particular size and type of AC, because the market is on average already more efficient than the minimum standard.

4.2.4 Sales accounting model

The objective of this section is to determine the number of AC units that are entering households every year based on the methodology proposed by McNeil, Letschert, & Van Buskirk (2007). This methodology consideration has two parts in order to account for total AC sales in one year. First it considers the first purchases: new AC owners derived from the AC ownership increase. First purchases are dictated by the diffusion model and the GDP projection. First purchases (FP) are defined as follows:

Equation 7: $FP^{y} = \#AC^{y} - \#AC^{y-1}$

That is, FP in year *y* equals the number of ACs in year *y* minus the number of ACs in the previous year.

The second part of the methodology focuses on estimating the number of ACs that are replaced every year. For this, McNeil, Letschert, & Van Buskirk (2007) assign a replacement probability based on a probability distribution considering the age of the equipment and other constant variables. Equation 8 uses an accumulated normal distribution as the replacement probability.

Equation 8: $P_r(\alpha) = \sum_{\alpha=0}^{\alpha} \frac{1}{D_{age}\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\alpha-\alpha_0}{D_{age}}\right)^2}$

Where, α is the age of the AC, α_0 is the average lifetime for an AC, taken as 12 years. And, D_{age} the mean deviation of replacement ages taken as 2 years (McNeil, Letschert, & Van Buskirk, 2007). AC replacements for the year *y* are described by the following equation:

Equation 9: $REP^{y} = \sum_{\alpha=1}^{A} \#AC^{y-1}(\alpha) \times P_r(\alpha)$

Where $\#AC^{y-1}(\alpha)$ is the number of ACs of age α in year *y-1*. Finally, the total AC sales for year *y* are obtained adding equations 7 and 9:

Equation 10: $Sales^{y} = FP^{y} + REP^{y}$

4.2.5 Peak load analysis

Energy savings from new MEPS for ACs will also avoid a certain level of capacity demand from the electricity grid. A part of this reduced demand will happen during peak hours in the hot season, and the rest will occur throughout the rest of the year. This is important because it not only relieves pressure on the electrical system in the short term, but also will avoid the construction of new capacity in the medium and long terms. This is of special interest for the Littoral region, because the peak load demand is satisfied with thermic power plants using fossil fuels, as shown in Figure 16.

Following the methodology proposed by Letschert, Agarwal, de la Rue du Can, & Park (2023), it is assumed that half of AC use occurs during the day and the other half in the evening and at night. All AC use in the commercial sector (30%) is assumed to coincide with the peak load during the day. Accordingly, a 65% coincidence factor is determined between AC use and peak demand. Additionally, ACs are turning on and off constantly and are not all running simultaneously. During peak times it is assumed that 60% of ACs are running simultaneously. Letschert, Agarwal, de la Rue du Can, & Park (2023) offer a voided generation capacity (AGC) is given by the following equation:

Equation 11: $AGC = \frac{Energy\ Saved}{1-T\&D} \times \frac{1}{8760} \times \frac{PCF \times SF}{U \times K}$

Where the energy saved is the difference between the electricity consumption in the BAU scenario and the electricity consumption in a new MEPS scenario.; *T&D* is the regional transmission and distribution loss factor: *PCF* is the peak coincidence factor determined to be 65%, *SF* is the simultaneity factor assumed to be 60%; *U* is the percentage of time ACs are used in a year, in this case $U = \frac{1095}{8760} = 12.5\%$; and *K* is the peak load electricity generation plant factor, calculated regionally using capacity installed and electricity production data from (ARCERNNR, 2022-1).

Once the AGC is obtained, it can be used to estimate the avoided capacity investment costs (ACIC). As shown previously, peak load demand in the Littoral region is satisfied by thermic power plants. With data from (ARCERNNR, 2022-1), it was possible to calculate the share by technology type of energy produced only with thermal power plants. In 2022 in the Littoral region, 32% of electricity was produced using Internal Combustion Motors (ICM), 21% with gas turbines and 47% with steam turbines, all powered with natural gas, diesel, fuel oil, and crude oil (percentages relative to total thermal power plant production). Only an investment cost for ICM specific for Ecuador could be found (ARCERNNR, 2021). For the other generation technology types, reference values for Chile were taken (CNE, 2023) and can be seen in Table 10.

Table 11. Investment costs for thermic generation technology.

Technology	Investment Cost (USD/kW)	Electricity Generation Share[9]
Internal Combustion Motor	1, 254	32%
Steam Turbine	791	47%
Gas Turbine	1, 048	21%
Weighted Average	**986**	

Source: (ARCERNNR, 2021; CNE, 2023; ARCERNNR, 2022-1)

4.2.6 Consumer economics

The online retailer market research collected for this study is used to perform a regression analysis to obtain AC prices according to the criteria in Table 11. However, the data gathered does not have the level of detail of prices by efficiency required to describe all scenarios individually. For this reason, scenarios were grouped into three efficiency levels. The low- efficiency level corresponding to ACs that are below the current regulation (Scenario 1); the medium- efficiency level corresponding to ACs with efficiencies above the current regulation but below higher- efficiency standards (Scenarios 2, 3 and 4); and high- efficiency level corresponding to the United States and European Union efficiency levels (Scenarios 5 and 6). Additionally, capacities are sorted into three categories: 12, 18, and 24 and above, all in kbtu/h. This methodology establishes a baseline price corresponding to the current efficiency standard, as shown in Table 11.

Table 12. AC prices used for the LCC analysis, USD.

Scenario	>> **Efficiency**	**12,000**	**18,000**	**24,000 and above**
-	Baseline	\$373	\$495	\$628
Sc1	Low- Efficiency <3.2 SEER	\$325	\$447	\$580
Sc2, Sc3 & Sc4	Medium- Efficiency 3.2< . <4.6 SEER	\$420	\$541	\$675
Sc5 & Sc6	High- Efficiency >4.6 SEER	\$660	\$782	\$915

Table 13 presents the UEC for AC appliances used for the LCC analysis. They were obtained by applying Equation 3 to the respective energy- efficiency levels and capacities. The low- efficiency ratings correspond to the average of AC equipment that is below 3.3 W/W SEER.

Based on the information in Table 12 and Table 13, a LCC assessment was performed for the three climatic regions. The average electrical residential tariff of 2022 was used as the electricity tariff for this analysis (Table 6). As mentioned in (Porras Carrión, 2020) and by the central bank of Ecuador, for the Ecuadorian residential sector a 6% discount rate is a proper value.

[9] Only for the Littoral region. Share relative to the total thermal power plants production.

Table 13. UEC considered for the LCC analysis, kWh/year.

	SEER (W/W)	12,000	18,000	24,000 and above
Baseline	3.24	1,206	1,809	2,412
Low- Efficiency <3.3 SEER	3.12-2.97-3.01	1,228	1,911	2,522
Medium- Efficiency 3.3< <4.6 SEER	3.4	1,152	1,728	2,304
High- Efficiency >4.6 SEER	4.6	882	1,323	1,764

4.3 New MEPS, energy savings, and GHG emissions reduction

4.3.1 National Impacts

Figure 20 shows the forecasted results for the residential cooling electricity consumption projection to 2045, as well as other parameters used in the forecast. The total number of ACs is projected to more than double by 2035 and quadruple by 2045, as AC ownership rate is projected to triple and the number of households is expected to increase by more than 50% by 2045. As a result, cooling electricity consumption in the residential sector in Ecuador is projected to more than double by 2035 and more than quadruple by 2045, increasing from 1TWh in 2020 to 2.3 TWh in 2035 and 4.3TWh in 2045.

Figure 20. Residential cooling electricity consumption projection.

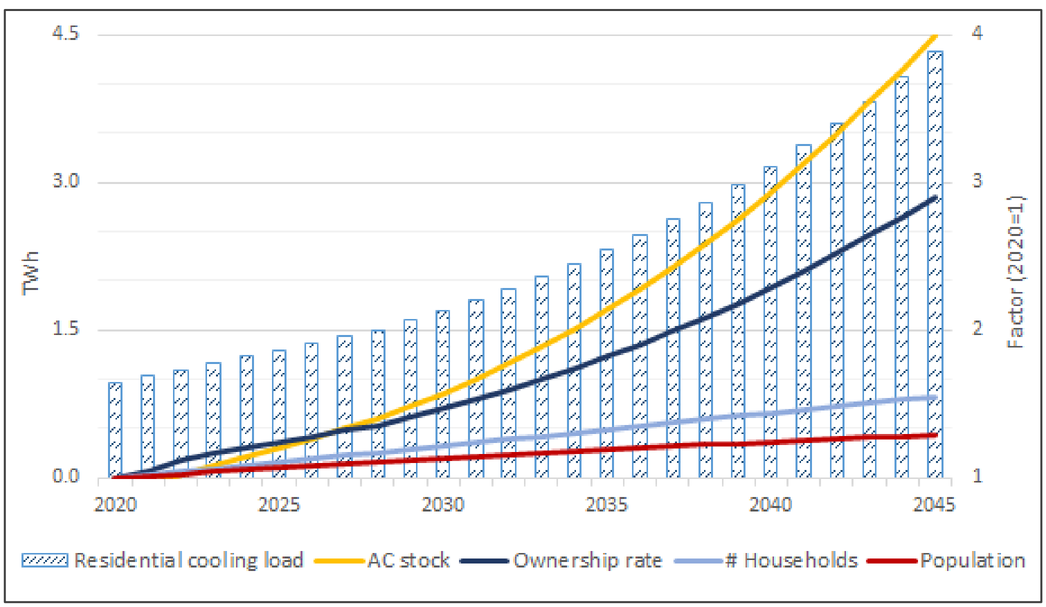


Figure 21 presents the projected energy consumption due to cooling from 2018 to 2045, for the new proposed MEPS compared to the BAU scenario. It shows the contribution in energy consumption reduction by type of AC. As shown, despite inverter ACs representing 34% of the market share, they represent approximately 57% in energy savings. It is estimated that, by 2035, the new proposed MEPS will lead to an annual 9% reduction in electricity consumption compared to the BAU scenario. Figure 22 presents AC electricity consumption under the different explored MEPS. The proposed MEPS have a lower electricity consumption than the regional best practice. It can be seen that the higher- efficiency scenarios (Sc4 and Sc5) are a step ahead compared to the proposed MEPS scenario, making it a good compromise between the BAU scenario and higher- efficiency standards, preparing the grounds for a posterior regulation update.

Figure 21. Projected cooling electricity consumption for the BAU and proposed new MEPS scenarios.

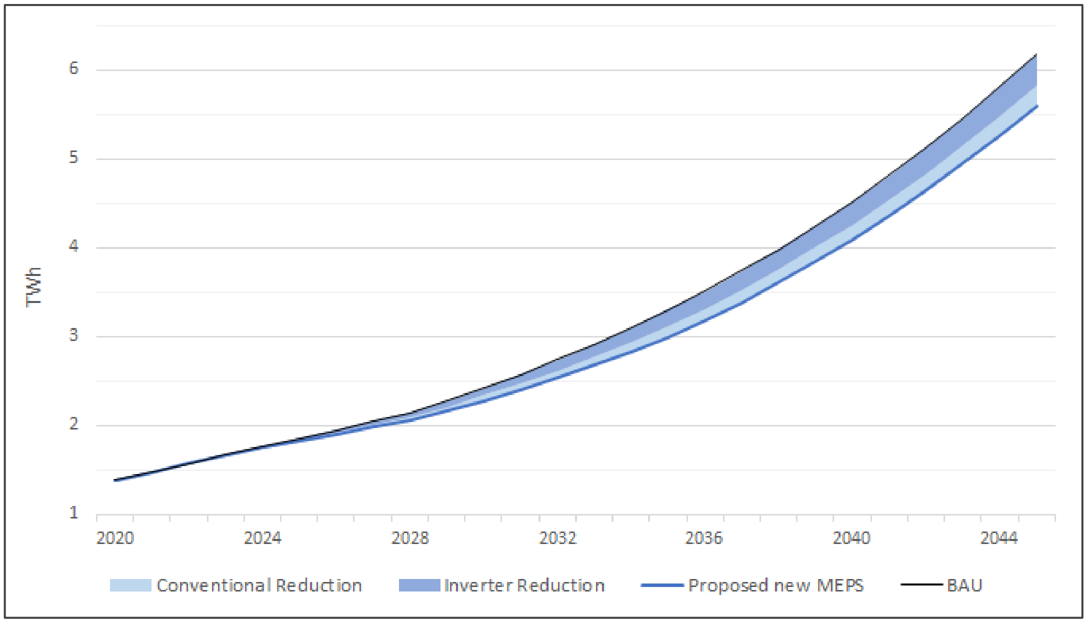
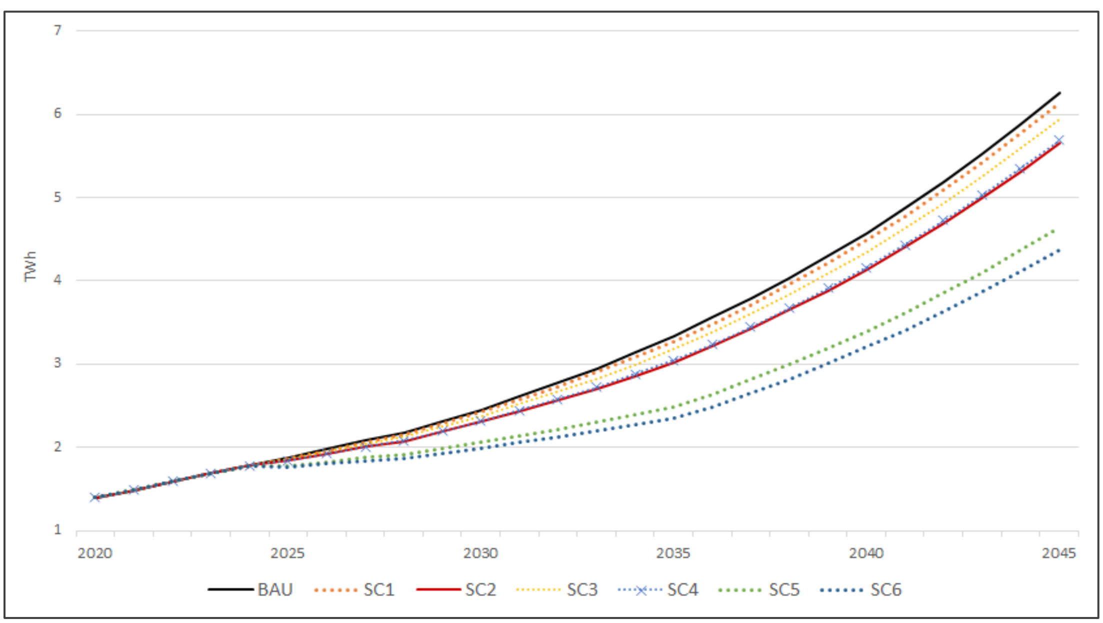


Figure 22. Projected cooling electricity consumption under the different scenarios, 2020-2045



The following tables (Table 13 through Table 18) present the results regarding energy savings, capacity reduction, and related monetary savings, as well as cumulative avoided CO_2 emissions. Results are presented in 2035 and 2045 for every MEPS scenario and by type of AC.

Figure 23 shows the projected UEC for the different MEPS scenarios compared to the baseline scenario. It also shows the time for all old and less efficient ACs to be replaced, happening around 2035. Percentage reduction in the UEC is shown for 2035. New proposed MEPS have a UEC reduction of around 9%. The highest UEC reduction corresponds to the high- efficiency scenario, registering a 30% reduction.

Figure 23. Projected UEC for the baseline and new MEPS scenarios.

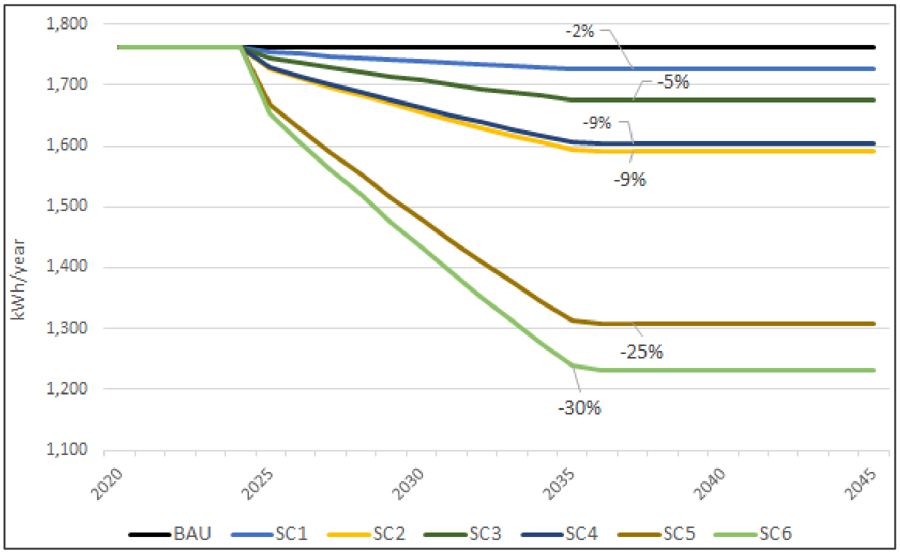


Table 14. Annual energy savings under the different MEPS in 2035 and 2045, GWh.

MEPS	Conventional		Inverter		Total	
	2035	2045	2035	2045	2035	2045
Sc1	64	122	-	-	64	122
Sc2	**121**	**230**	**195**	**369**	**316**	**599**
Sc3	134	255	26	50	160	305
Sc4	236	447	60	113	296	560
Sc5	650	1,234	198	376	848	1,610
Sc6	650	1,234	338	642	988	1,876

Table 15. Cumulative saved money in electricity bills under the different MEPS in 2035 and 2045, Million USD.

MEPS	Conventional		Inverter		Total	
	2035	2045	2035	2045	2035	2045
Sc1	32	115	-	-	32	115
Sc2	**60**	**217**	**96**	**348**	**156**	**565**
Sc3	66	240	13	47	79	287
Sc4	116	421	29	107	145	528
Sc5	320	1,162	98	354	418	1,516
Sc6	320	1,162	166	605	486	1,767

Table 16. Cumulative avoided subsidies under the different MEPS in 2035 and 2045, Million USD.

MEPS	Conventional		Inverter		Total	
	2035	2045	2035	2045	2035	2045
Sc1	1.4	4.9	-	-	1.4	4.9
Sc2	**2.5**	**9.2**	**4.1**	**14.9**	**6.6**	**24.1**
Sc3	2.8	10.2	0.6	2.0	3.4	12.2
Sc4	5.0	18.0	1.3	4.6	6.3	22.6
Sc5	13.7	49.6	4.2	15.1	17.9	64.7
Sc6	13.7	49.6	7.1	25.8	20.8	75.4

Table 17. Capacity addition avoided under the different MEPS in 2035 and 2045, MW.

MEPS	Conventional		Inverter		Total	
	2035	2045	2035	2045	2035	2045
Sc1	51	97	-	-	51	97
Sc2	**96**	**182**	**154**	**292**	**250**	**474**
Sc3	106	202	21	40	127	242
Sc4	187	354	47	90	234	444
Sc5	515	977	157	298	672	1,275
Sc6	515	977	268	508	783	1,485

Table 18. Investments in capacity avoided under the different MEPS in 2035 and 2045, Million USD.

MEPS	Conventional		Inverter		Total	
	2035	2045	2035	2045	2035	2045
Sc1	50	96	-	-	50	96
Sc2	**95**	**180**	**152**	**289**	**247**	**469**
Sc3	105	199	21	39	126	238
Sc4	184	349	47	89	231	438
Sc5	508	964	155	294	663	1,258
Sc6	508	964	264	501	772	1,465

Table 19. Cumulative CO_2 emissions reduction under the different MEPS in 2035 and 2045, Million CO_2 Tons.

MEPS	Conventional		Inverter		Total	
	2035	2045	2035	2045	2035	2045
Sc1	0.2	0.8	-	-	0.2	0.8
Sc2	**0.4**	**1.6**	**0.7**	**2.5**	**1.1**	**4.1**
Sc3	0.5	1.7	0.1	0.3	0.6	2.0
Sc4	0.8	3.1	0.2	0.8	1.0	3.9
Sc5	2.3	8.4	0.7	2.6	3.0	11.0
Sc6	2.3	8.4	1.2	4.4	3.5	12.8

These results show that, for the new proposed MEPS, the total electricity savings would amount to 0.6 TWh in 2045, resulting in a capacity reduction of 474 MW equivalent to an investment of 469 million USD. Consumer financial savings from electricity bill reduction would amount to approximately 565 million USD, with subsidies amounting to 24 million USD by 2045. Cumulative CO_2 emissions avoided through 2045 are estimated to be 4 million tons. It should be highlighted that the new proposed MEPS and Scenario 4, which corresponds to the COPANT norm, have very similar overall results. The distribution of the impacts by equipment type creates a difference in the two scenarios. While conventional AC equipment accounts for 80% of all impacts in Scenario 4, it only accounts for 40% in the new proposed MEPS.

The technical achievable potential represented here by Scenario 6 shows that the total electricity savings is 1.9 TWh, resulting in a capacity reduction of 1.5 GW, equivalent to an investment of 1,400 million USD. Consumer financial savings due to reduced electricity bills amounts to 1,700 million USD, and subsidies amount to 75 million USD. Cumulative CO_2 emissions avoided through 2045 are estimated to be around 13 million tons.

4.3.2 Life cycle cost analysis

Table 19 presents the average LCC reduction results for the different climatic regions. Reductions are compared to the base case and averages were obtained by weighting with the respective market share for every capacity as in Figure 13. Detailed results for every AC capacity in every climatic region can be seen in the Annex (Table 23 through Table 25). As mentioned previously, efficiency levels shown in Table 19 are only indicative and correspond to the efficiency scenarios as in Table 11.

Values for the low- efficiency case appear as negative; they indicate that the LCC is higher compared to the base case, and therefore the base case is cost effective compared to the lower- efficiency case. Only the low- efficiency case for the Highlands region was not cost effective. The highest profits are found in the Littoral region for the high- efficiency scenario for large capacities, estimated at more than 1,800 USD. Profits from proposed new MEPS in the Littoral region are, on average, approximately 200 USD, ranging from 130 to 300 USD. Payback periods for the Amazon and Littoral regions are 5.5 years for the new proposed MEPS and 8 years for the Highlands region, both below the average lifespan of a typical AC.

Table 20. Size-average LCC results for different climatic regions.

	LCC Scenario	LCC reduction (USD)	Payback Period (years)
Littoral	Low Efficiency	-$193.4	6.6
	Medium Efficiency	$214.8	5.4
	High Efficiency	$1278.2	5.5
Amazon	Low Efficiency	-$163.2	5.9
	Medium Efficiency	$182.1	5.7
	High Efficiency	$1082.5	5.8
Highlands	Low Efficiency	-$31.4	10+
	Medium Efficiency	$39.5	7.9
	High Efficiency	$228.9	8.0

Figure 24. Ten-year LCC results for the Highlands region in Ecuador.

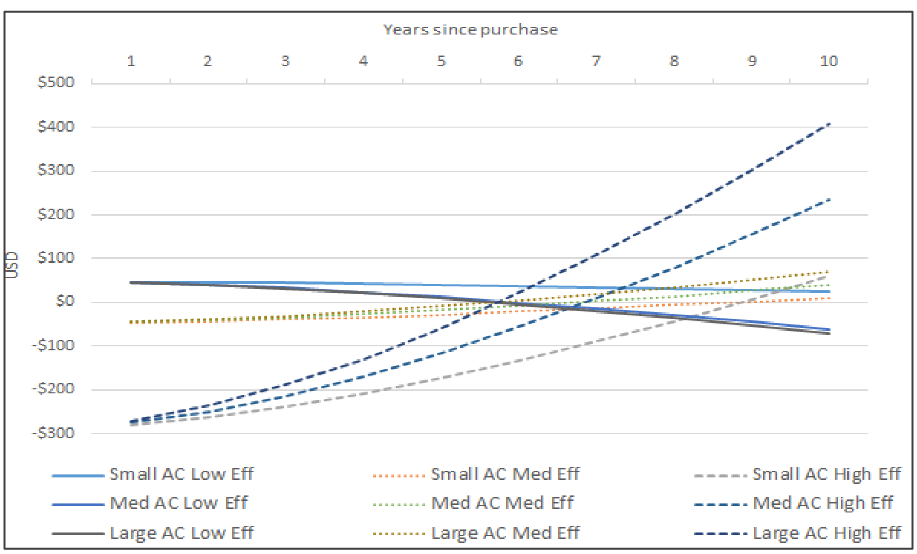


Figure 24 presents the 10-year life cycle cost for AC use in the Highlands region. As shown, payback periods are quite long, ranging between 6 and 9 years. The small AC in the low- efficiency scenario is not cost effective, and other cases are barely profitable. Generally speaking, the big losers in an updated MEPS scenario are low-intensity users. Assuming that the standard causes an increase in price, people living in the Highlands regions are the ones seeing the fewest benefits, or even none at all. Assuming that all households in the Highlands region will not benefit from AC MEPS, this would affect approximately 9,000 homes, representing around 0.2% of all households in Ecuador. This population is low and is the least likely to own an AC unit due to weather conditions. Additionally, retail price-based incremental cost tends to be overestimated, since the imposition of a standard provides the economies of scale and competitive pressure to lower prices.

5. Implementation plan

5.1 Stakeholder engagement

LBNL conducted missions to Ecuador in September 2022 and February-March 2023 to engage with the key agencies of the country's energy and regulatory space and introduce the project supported by USAID to update the technical regulation for ACs and develop a regulatory action plan. In addition to connecting with MEM, MPCEIP, INEN, SAE and ARCERNNR to get buy-in for the implementation of the initial phase of activities, LBNL engaged with HVAC industry representatives and members of the research community based in Guayaquil to get information about the market dynamics and implementation challenges of the current regulation (Reglamento Tecnico)[10] for ACs in Ecuador. Engagement with key regulatory agencies was reinforced with the participation of LBNL in the conference "Talks about Energy Efficiency in Industry, Construction and Sustainable Public Procurement," which was organized by SAE in conjunction with the German Metrology Institute (PTB).

As a result of these outreach activities, a "cooling summit" was held in collaboration with Ecuador's Ministry of Production, Investment, Foreign Trade and Fisheries and the LBNL team on November 15th, 2023 in Quito, Ecuador. This activity gathered government, industry and academia and informed the Ministry of Energy and Mines on the energy savings resulting from revised energy efficiency standards in Ecuador to regional best practice levels for AC. This activity also provided inputs to INEN and the Geological and Energy Research Institute (IIGE) to develop the analysis necessary to inform standard revisions and provide recommendations on the steps needed to set standard regulations.

The process of implementation of an updated technical regulation for ACs will involve increased coordination with government agencies and collaboration with other entities that eventually could be part of the technical working groups that need to be set up by INEN as part of the public consultation process to approve the updated regulation.

5.2 Administrative capacity

The Ecuadorian Quality System Law (EQSL) lays out the general framework for monitoring, verification

10 Reglamentos Tecnicos define the characteristics of products and their related production processes that need to be met to ensure security, health, preservation of the environment and consumer protection agains fraudulent practices.

and enforcement for all products (manufactured in-country or imported) that are subject to Reglamentos Tecnicos. As part of this framework, the legal and regulatory framework that Ecuador has developed over the years to advance energy efficiency, notably since the publication of the PLANEE in 2016, has created a solid institutional network with well-defined attributions and powers to implement energy-efficiency programs and manage regulatory processes. The technical teams at MEM, MPCEIP, INEN, and SAE, which are part of the CNEE, work in close coordination to review and improve regulations as part of their mandate to improve the country's quality system and comply with the objectives of the PLANEE and LOEE, in addition to updating the National Quality Plan, which includes the guidelines to improve products and services.

Ecuador has been working with international development organizations (mainly Germany's PTB) to improve its technical capabilities and infrastructure to enforce standards as part of the objectives of the Ecuadorian Quality System, which is defined as the series of processes, procedures, and public agencies responsible for the execution of the principles and mechanisms supporting quality and compliance evaluation. In this regard, as part of a bilateral cooperation agreement between Ecuador and Germany, PTB is helping government agencies implement training and infrastructure development to improve the country's quality-assurance infrastructure system. Exploration by LBNL of potential collaborations and synergies could help in capacity building efforts.

The institutional framework charged with implementation of standards has been in place since 2007. The GoE has recognized the need to advance capacity-building efforts in this area to fulfil the objectives of the National Quality Plan, which is updated every other year

In terms of funding, the energy-efficiency National Fund established in 2014 provides the opportunity to present a proposal to develop a capacity-building program to support implementation of energy-efficiency standards, including building codes. INEN will play a key role in this process, but the actual directives and proposals are set by MEM, and MPCEIP is the agency that ultimately signs off on the reglamentos approval.

5.3 Monitoring, verification, and enforcement

Article 57 of EQSL gives MPCEIP powers to ensure compliance with the requirements and evaluation of conformity procedures included in the Reglamentos Tecnicos on behalf of the Ecuadorian state. Article 31 of the same legislation stipulates that prior to the commercialization of national or imported products that are subject to Reglamentos Tecnicos, compliance must be demonstrated through the presentation by the manufacturer or importer of a certificate of conformity issued by a certifying agency duly accredited by SAE.

In the specific case of AC equipment, the importer must submit a customs declaration to the National Customs Service of Ecuador (SENAE) with a certificate of conformity with the current regulation (RTE-072-1R), issued by a certifying agency from the point of origin of the product. The certificate is validated by INEN as part of the process to obtain approval for the importation and commercialization of the product.

The current Reglamento Tecnico for ACs adopts the requirements established in the Ecuadorian Technical Norm NTE INEN 2495. These requirements include the labelling of the product to provide information about model, brand, energy- efficiency level, cooling capacity, and categories of equipment classification based on their energy- efficiency level. The review procedures conducted at the point of entry by SENAE includes ensuring that these labelling requirements are met as part of the approval process.

According to the procedures for evaluation of conformity with RTE-072-1R covering AC, the certifying agencies, laboratories, and other entities that issue certificates of conformity based on erroneous information or that deliberately manipulate the testing data will face administrative, civil, penal, or fiscal sanctions.

Even though monitoring, verification, and enforcement of the Reglamentos Tecnicos is outlined in the EQSL and the corresponding regulation for each product or service, the procedures and regulations are not given for ductless AC equipment. The control is based predominantly on documentary evidence at the point of entry, rather than continuing surveillance of the market (frequent inspections conducted at the point of sale of the products) , verification (random testing of energy-efficiency levels to ensure that products are compliant), and enforcement (penalties applied to non-compliant importers). The lack of testing facilities for AC equipment in the country is a serious limitation for conducting actual sampling and testing to verify compliance of products already in the market.

Additionally, the information provided by the importer to the SENAE is compiled into a list that does not serve as a certification database, as it is not used for review characteristics of new AC products entering the market. This is a gap in the process that can be addressed by developing an actual certification database that could be operated by SENAE and MPCEIP with improved capacity to manage this function.

The lack of an in-country lab to serve as a testing facility for ACs, the absence of a full-fledged certification database, and the emphasis on documentary evidence required at the point of entry by SENAE to support MVE processes constitute serious barriers to ensuring full compliance with the current Reglamento Tecnico for AC. The recent free- trade agreement between Ecuador and China may facilitate the penetration of more AC units with energy- efficient levels that are below the MEPS included in the current Reglamentos Tecnicos.

Due to the limitations of enforcement capacity related to the importation of AC equipment, more and better information on market conditions is necessary to develop a comprehensive strategy. Elements of this strategy include updating the current MEPS; providing guidelines to importers and retailers to understand the MEPS; developing an actual certification database (modelled after best practices at the regional level); increasing institutional capacity to carry out MVC functions; working with SAE, SENAE and the certifying agencies to identify gaps in the information provided for the certification process from the point of manufacturing to the point of entry of the products; and exploring different financing options to set up a testing lab for AC equipment in Ecuador.

6. Conclusions and recommendations

The general conclusion for the analysis presented here is that the proposed new MEPS for the Ecuadorian AC market, as well as the other explored MEPS, are technically and economically viable. The impacts reach different aspects of the Ecuadorian economical structure.

RECOMMENDATIONS:

Regulation

• Based on the LCC analysis results, we recommend revising the MEPS as soon as possible to efficiency levels corresponding to either scenario 2 or 4 and propose to revise to level 5 by 2029 to facilitate market adaptation, as this level offers cost-effective benefits for consumers. This includes a change in the efficiency metric to the Seasonal Energy Efficiency Ratio (SEER), as this a more accurate measure of ACs efficiency than the current used measure (Energy Efficiency Ratio EER)

  - Nationwide: By 2035, electricity consumption from AC use will be reduced by approximately 9% annually. In 2045, total electricity savings reach approximately 0.6 TWh, equivalent to 4 million CO_2 tons. Avoided subsidies amount to 23 million USD.
  - Electrical sector: By 2045, 460 MW of power demand could be avoided, equivalent to an investment of 520 million USD in thermic power plants.
  - Consumers: Depending on the capacity of the AC equipment, consumers will save between $130 and $300 USD in cooling costs over the 10-year lifetime of the appliance. At the national level, user savings in electricity bills amount to 550 million USD in 2045.

- The analysis also shows that adopting higher efficiency standards for ACs (scenarios 5 and 6) is even more beneficial for the society in terms of energy and capacity savings, emissions avoided, and the positive cost-benefit of purchasing higher- efficiency AC equipment. Therefore, it is recommended to design other programs targeting the adoption of high- efficiency ACs, to allow the market to prepare for future updates to higher MEPS.
  - For example, introducing an efficient AC appliances subsidies program, similar to the one already existing for efficient cooking (PEC), or encouraging the production of energy-efficient ACs in the country, either by local or international manufacturers. MEM is currently implementing an AC substitution pilot program in the Galapagos, which can be used, through in-site metering, as evidence of the economic and environmental benefits associated with the use of more efficient AC equipment. An expanded version of this program, targeting more populated geographic areas of the country where the use of AC is very high, could be presented as a project to be funded by the newly created National Investment Fund for Energy Efficiency.

Compliance

- Paired with the adoption of an updated MEPS for AC , the GoE could expand significantly its capacity-building efforts to strengthen MVE capabilities as part of a strategy to enhance the quality infrastructure for energy efficiency. This strategy would include the following:
  - Develop an actual certification database that would be managed by MPCEIP with support from SAE, INEN and SENAE.
  - Train teams from MPCEIP, SAE, INEN and SENAE and other relevant agencies to manage the certification database and related MVE activities.
  - Create guidelines for importers and retailers of AC products to understand the MEPS and the process of compliance verification.
  - Work with MPCEIP, SAE, SENAE, and the certifying agencies to identify possible gaps or inaccuracies in the information provided for the certification process (certificates of compliance, labels, custom declarations) from the point of manufacturing to the point of entry.

    - Establish a working group with government, industry, the research community, and international development organizations to explore financial mechanisms to set up a testing lab in-country.
- The buildings sector in Ecuador is of special interest because it represents approximately 60% of electricity consumption in the country. It is recommended to continue the efforts to improve energy efficiency and decrease electricity consumption in the buildings sector. The ongoing review of the Ecuadorian Construction Norm, undertaken by the Ministry of Urban Development and Housing, represents an opportunity to update the energy- efficiency component of the code and to build institutional capacity at the national and sub-national levels to ensure enforcement of the updated regulation. This aligns with the current plan of the GoE to create a SAE certification for energy management professionals as a strategy to develop a new labor market around energy efficiency.
- Leverage ongoing efforts by international development organizations (PTB, JICA, KOICA, BID, World Bank) to explore financial mechanisms that could be created in coordination with Ecuador's National Investment Fund for Energy Efficiency to support the implementation of initiatives such as an AC substitution program or a training program to build up regulatory MVE capacity. This financial mechanism could potentially support the development of an in-country testing lab for AC equipment.
- Related to the above, it is recommended to create a "cooling community of practice" in Ecuador, with strong participation by government agencies, industry, the research community, and civil society organizations. This will ensure continuing interaction and possible collaboration between stakeholders interested in addressing the cooling challenge in the country.

Ecuador has developed a policy, regulatory, and institutional framework that constitutes an enabling environment for the advancement of energy- efficiency programs and projects, such as the update of AC MEPS and implementation of building codes. The political transitions happening in Ecuador in the next two years (special elections in 2023 and regular elections in 2025) may impact the pace of EE projects, but key agencies such as MEM, MPCEIP, INEN and SAE have clear mandates under the energy-efficiency law and the Ecuadorian Quality System Law and have technical teams that have worked in the regulatory space across different administrations.

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ANNEX

Table 21. Ecuadorian AC market configuration.

Brand	Market Share	Inverter	Conventional	Capacity Distribution (BTU)			
				12,000	18,000	24,000	36,000
TCL	30%	36%	64%	38%	28%	31%	3%
Midea	19%	43%	57%	29%	43%	29%	-
RCA	16%	-	100%	33%	25%	33%	8%
LG	9%	82%	18%	41%	12%	47%	-
Hisense	9%	22%	78%	33%	33%	33%	-
Chigo	6%	22%	78%	33%	33%	33%	-
Samsung	4%	43%	57%	71%	14%	14%	-
Electrolux	3%	36%	64%	100%	-	-	-
Mabe	3%	38%	62%	54%	-	46%	-
Innovair	1%	33%	67%	-	-	33%	67%
Panasonic	1%	67%	33%	33%	33%	33%	-

Table 22. Energy-efficiency baseline for AC equipment by brand, type and capacity, EER (Wt/We).

	Conventional				Inverter			
Capacity (BTU)	12,000	18,000	24,000	36,000	12,000	18,000	24,000	36,000
TCL	3.16	2.75	2.94	2.97	3.24	3.26	3.24	-
Midea	3.08	3.08	3.08	3.08	3.22	3.22	3.22	-
RCA	3.24	3.24	3.24	3.24	3.22	3.22	3.22	-
LG	3.31	3.31	3.31	3.31	5.59	4.68	5.86	-
Hisense	3.08	3.08	3.08	3.08	3.22	3.22	3.22	-
Chigo	3.08	3.08	3.08	3.08	3.22	3.22	3.22	-
Samsung	3.21	3.21	3.21	3.20	4.33	4.33	4.33	-
Electrolux	3.13	3.13	3.13	3.13	3.20	4.33	4.33	-
Mabe	3.30	3.35	3.25	3.34	5.86	5.86	5.86	-
Innovair	2.87	2.84	2.97	2.90	3.22	3.22	3.22	-
Panasonic	3.50	3.15	2.97	3.21	6.57	4.33	4.33	-

Table 23. LCC results for the Littoral region.

Capacity (BTU/h)	LCC Scenario	LCC reduction (USD)	Payback Period (years)
12,000	Low Efficiency	-$23.7	9.7
	Medium Efficiency	$129.4	6.4
	High Efficiency	$767.0	6.4
18,000	Low Efficiency	-$283.3	5.1
	Medium Efficiency	$217.4	5.5
	High Efficiency	$1,293.0	5.6
24,000 and above	Low Efficiency	-$308.5	4.3
	Medium Efficiency	$305.5	4.2
	High Efficiency	$1,820.9	4.3

Table 24. LCC results for the amazon region.

Capacity (BTU/h)	LCC Scenario	LCC reduction (USD)	Payback Period (years)
12,000	Low Efficiency	-$14.7	9.4
	Medium Efficiency	$107.4	5.7
	High Efficiency	$635.3	5.8
18,000	Low Efficiency	-$241.8	4.6
	Medium Efficiency	$184.4	4.7
	High Efficiency	$1,096.4	4.8
24,000 and above	Low Efficiency	-$263.9	3.1
	Medium Efficiency	$261.5	3.1
	High Efficiency	$1,557.5	3.2

Table 25. LCC results for the Highlands region.

Capacity (BTU/h)	LCC Scenario	LCC reduction (USD)	Payback Period (years)
12,000	Low Efficiency	$24.5	-
	Medium Efficiency	$11.4	9.7
	High Efficiency	$60.5	9.8
18,000	Low Efficiency	-$61.0	6.0
	Medium Efficiency	$40.4	6.7
	High Efficiency	$234.1	6.9
24,000 and above	Low Efficiency	-$69.3	6.8
	Medium Efficiency	$69.4	6.7
	High Efficiency	$407.8	6.8

INDEX DECOMPOSITION ANALYSIS OF AC ENERGY USE IN ECUADOR

This analysis is performed only for the residential sector. The IDA is a methodology that allows to allocate the contributions of certain factors to an observed change in a variable. In this case, the variable to be analysed is the AC electricity consumption (*EC*), changing from years y_0 and y, as in equation below:

$$\Delta EC = EC^{y_0} - EC^{y}$$

The base year here is 2020, and the year of change is 2040. For any given scenario and year, the AC electricity consumption can be expressed as:

$$EC = \sum_i EC_i = \underbrace{UEC_i}_{Intensity} \times \underbrace{MS_i}_{\substack{Market\\Configuration}} \times \underbrace{Pop}_{Activity} \times \underbrace{\frac{HH}{Pop}}_{Social} \times \underbrace{\%Own}_{Structure} \times \underbrace{\frac{\#AC}{HH}}_{Comfort} \tag{1}$$

Where:

- *i* denotes the type of the AC (Conventional or Inverter)
- UEC_i : Is the intensity factor and is directly related to the efficiency of the AC.
- MS_i : Is the market share of conventional and inverter AC, it is a measure of efficient equipment market penetration.
- *Pop* : Total Population, it is a measure for the activity factor.
- $\frac{HH}{Pop}$: Is the household size, it is a measure for social habits and traditions.
- *%Own*: Is the ownership rate and it is a measure for the activity structure factor.
- $\frac{\#AC}{HH}$: Is the number of ACs per household, it is a measure of the comfort level within households.

The IDA allows quantification of the impacts of factors from equation 1. In an additive form this can be written as:

$$\Delta EC = \sum_i \Delta EC_{int_i} + \Delta EC_{mc_i} + \Delta EC_{act} + \Delta EC_{soc} + \Delta EC_{str} + \Delta EC_{cmf} \tag{2}$$

Where ΔEC_j is the additive impact of factor *j*. The LMDI-I approach was used to solve equation 2. The full methodology description can be found in (Ang, 2015). Every impact factor *j*, is obtained through the identities shown in Table 25.

Table 26. LMDI-I decomposition factors for AC electricity use.

Name	Symbol	Equation	Variable
Intensity	ΔEC_{int_i}	$\sum_i L({EC_i}^{y_0}; {EC_i}^{y}) \times ln\left(\frac{{UEC_i}^{y}}{{UEC_i}^{y_0}}\right)$	AC efficiency
Activity	ΔEC_{act}	$\sum_i L({EC_i}^{y_0}; {EC_i}^{y}) \times ln\left(\frac{Pop^{y}}{Pop^{y_0}}\right)$	Population
Social habits	ΔEC_{soc}	$\sum_i L({EC_i}^{y_0}; {EC_i}^{y}) \times ln\left(\frac{HH\ size^{y}}{HH\ size^{y_0}}\right)$	Household size
Activity structure	ΔEC_{str}	$\sum_i L({EC_i}^{y_0}; {EC_i}^{y}) \times ln\left(\frac{\%Own^{y}}{\%Own^{y_0}}\right)$	AC Ownership

In this case, the market configuration and the comfort factor in equations 11 and 12 remain constant through the analysis period; therefore, its impacts to the electricity consumption change are 0. Consequently, Table 25 only shows non-zero impact factors.

Results

Figure 24 shows the IDA results for the AC electricity consumption change from 2020 to 2040. Values seen in Figure 24 correspond to the contributions in the energy change that each impact factor had during the analysis period. The structural component of the model, the ownership rate, is found to be the biggest driver for AC electricity consumption. The efficiency components of the model corresponding to the UEC of conventional and inverter units, is found to help decrease electricity consumption. Together, they are similar in size as the household size component, and slightly smaller than the population component. Meaning that the proposed efficiency change will negate the effect of the household size on the change in energy consumption, and almost that of the population. The change in ownership rate is found to be, by far, the largest contributor in electricity consumption for ACs. The main reason for this is that the ownership rate is projected to experience the fastest growing rate in the following 25 to 30 years, due to its logistic behaviour.

Figure 25. Index decomposition analysis results, energy change 2020-2040.