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Long-term energy demand forecasting using LEAP software in the Santurbán paramo: The case of Berlín Santander after Covid-19

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ABSTRACT

In this study, energy demand forecasts were made for electricity and heat consumption in Berlin-Santander, in the residential sector of the economy. Three different forecast scenarios (from 2018 to 2040) were simulated in the Long-Term Alternative Energy Planning model. The first scenario, called usual trend, considered an average growth rate based on historical demand data. The second scenario was based on energy efficiency, using the energy intensity indicator agreed in the Program for the Rational and Efficient Use of Energy, a public policy guideline to promote the best use of energy resources (electric stoves, use of photovoltaic panels and other energy sources). Finally, the third scenario was the post-COVID-19 trend, based on the degree of openness of economic activity of 82% at the end of 2020, reaching 100% openness in the fourth quarter of 2021. This post-COVID-19 projection was carried out in the absence of previous similar events, accompanied by a statistical history. The results obtained in the growth forecasts are the same as those incorporated in the projection of energy demand in the national energy plan until 2050. Estimates of each of these scenarios were compared using data from a survey conducted in Berlin. The results of this study suggest a growth close to the national average. However, the composition of the energy matrix will change, so that electricity will be the most consumed form of energy, followed by LPG, natural gas, and wood.

Keywords: Electricity consumption, Energy intensity, Berlín Santander.

INTRODUCTION

In the Andes region, páramos, such as the Santurbán páramo in Colombia, play a crucial role in capturing water from the mist and supplying the lowlands. About two million people in Colombia depend on Santurbán for their freshwater needs. This dependence is especially significant for neighboring sectors, including the city of Berlín, located between 2800-4290 meters above sea level in the Department of Santander of Colombia. With a population of approximately 2,507, Berlin's economy is predominantly linked to tourism activities and agriculture.

The economic development of páramo regions is essential, but the COVID-19 pandemic has presented severe challenges over time. Significant pandemic mitigation measures in developing countries have resulted in economic repercussions, including income reductions, rising unemployment, and

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disruptions to the transportation, services, and manufacturing sectors. With regard to energy, the pandemic negatively impacted monthly electricity consumption in the residential sector, while other sectors, predominantly industrial and commercial, recorded declines, indicating an overall drop in economic activities during the initial year of the pandemic. This change in electricity consumption patterns may gradually increase energy demand, given the predominance of the residential sector in the country's electricity consumption, especially during prolonged crises (Bahmanyar et al., 2020).

Global attention has focused on projections of post-COVID-19 energy demand, with recent studies, including one by García-Rendon et al (2023), examining post-pandemic transformations in energy consumption patterns. Expected trends include the persistent impact of remote work and digital technologies on electricity demand in residential and commercial settings (Smith et al., 2021). Additionally, growing environmental awareness may drive the preference for renewable energy sources (IEA, 2022). These analyses play a crucial role in understanding the post-pandemic energy landscape, informing planning strategies, and guiding government policy.

Studies in Europe have examined the impact of the COVID-19 pandemic on electricity use, such as the comparative analysis by Bahmanyar et al. (2020), which revealed that countries with strict lockdowns experienced a reduction in electricity use in commercial and industrial sectors, while there was an increase in residential electricity consumption. Overall, electricity consumption in the first year of the pandemic reduced by 1.04% compared to rates between 2016 and 2019.

Similar studies in Latin America on electricity supply and demand forecasts exist for countries such as Ecuador (Rivera-González et al., 2019) and Mexico (Toledo et al., 2021).

In Colombia, post-COVID-19 electricity and heat demand projections have become critical areas of research. Investigations, including the UPME study, a national reference in several studies (García-Rendon et al. 2023). The anticipated changes in demand are influenced by factors such as evolving industrial processes and changes in consumer behaviors related to PROURE. This program, acting as a public policy framework, aims to encourage the rational and efficient use of energy resources by incorporating the adoption of electric cookstoves, alternative energy sources such as LPG, and sustainable energy solutions. Analyses from Colombia's Ministry of Mines and Energy provide insights into socio-economic aspects such as GDP impacting electricity and heat demand, crucial for future energy planning in the post-COVID era.

In the context of the Colombian Páramos, sustainable energy is key to economic development. However, these areas lack reliable data on energy resources and face challenges in long-term demand forecasting, making it difficult to formulate effective energy policies.

This study stands out for its groundbreaking exploration of post-COVID-19 electricity and heat demand projections in the Berlín de Santander residential sector from 2018 to 2040. Using the LEAP

model, three scenarios were simulated: a "usual trend" with average growth rates, an "energy-efficient" behavior aligned with the PROURE energy intensity index, and a post-COVID-19 trend reflecting economic openness. Despite the growing uncertainty in the forecasts, below 15%, the results indicate a growth trend similar to the national average, with a shift to electricity as the main source, followed by natural gas, wood and LPG. These findings are in line with the 2050 national energy plan, supported by comparative assessments using survey data in Berlin. The novelty of the study lies in the exploration of post-COVID-19 projections, emphasizing the impact of the PROURE program and offering valuable insights for future policymaking on the dynamics of the energy landscape. By analyzing the interplay between public policy frameworks and sustainable energy initiatives, this research not only adds a layer of uniqueness but also offers crucial insights to shape future policymaking in the ever-evolving energy landscape.

METHODOLOGY

The LEAP system, an integrated software tool, facilitates energy planning, climate change assessment, and cost analysis within a specific time frame. This involves creating alternative scenarios, each with unique information, allowing for an analysis of energy demand based on demographic and macroeconomic data for the study area (Heaps, 2019). The analysis of the total energy consumption demand is defined by Equation (1):

$$EC_i = \sum AL_i(t) x TE_i(t) \quad \text{(Eq. 1)}$$

LEAP MODEL STRUCTURE FOR BERLIN AND BENCHMARKS

In the period from 2018 to 2040, the LEAP software system analyzed the long-term energy demand forecast, incorporating historical and statistical data from 2018 as the base year. The input data covered population growth, GDP, annual and multi-year statistics of the Colombian Electricity Sector, annual consumption of electricity and natural gas, and energy intensity index, coming from public organizations such as DANE, UPME (specifically the national energy plan 2050 and PROURE) and the SUI database. The detailed description for the elaboration of scenarios in the LEAP model is provided in section 2.2, supporting the perspective until 2040.

Table 1 shows some of the parameters, benchmarks, and assumptions for 2018

Table 1. Assumptions and base values for the reference year (2018).

Parameter	Description
Population 2018	6680 people
Electricity	512467 kWh (SUI, 2022)
Heat	31867 kWh (SUI, 2022)

Urban	96.4% (SUI, 2022)
Rural	2.11% (SUI, 2022)

MAIN ASSUMPTIONS IN THE LEAP MODEL AND DESCRIPTION OF THE SCENARIOS

The first scenario, called "usual trend", considered the average growth rate of the last ten years derived from the historical data of electricity and heat demand from SUI for Berlin, with respect to heat consumption, the share is 58% firewood, 31% natural gas and 11% LPG.

The second scenario focused on energy efficiency, aligning with the energy intensity index established in the Program for the Rational and Efficient Use of Energy (PROURE). The energy intensity index, understood as the ratio of energy consumption (heat or electricity) to GDP, was used as data for the time series in LEAP. This translates into an annual increase in energy intensity of between 0.35 and 0.95 in the case of electricity demand. Alternatives identified to improve energy efficiency include upgrading cooling equipment and replacing inefficient luminaires with LEDs. Regarding heat demand, the biggest challenge is to reduce cooking losses due to the use of firewood. Initially, there is a share of heat, excluding electricity, which would be 58% firewood, 31% natural gas and 11% LPG, varying over time, reducing firewood consumption to 41% in 2025 and 20% in 2030, replacing it with LPG.

The third scenario, called the "post-COVID-19 trend", was executed in the absence of similar historical events, substantiated by statistical data. Thus, energy intensity was used as a determining factor from a socioeconomic point of view. This ratio was calculated as the ratio between historical energy consumption over GDP, established from the national energy plan until 2050, where GDP was fixed at the degree of openness of economic activity, reflecting a level of openness of 82% at the end of 2020, with the continuity of remote work and reaching 100% openness in the fourth quarter of 2021, with a minimal part of the population working remotely, only 5%. In addition, this scenario proposes improvements in heat demand efficiency with the replacement of incandescent luminaires with 60% of compact fluorescent lamps and 40% of LED by 2025; and 100% LED by 2030.

VALIDATION OF PROJECTED DATA THROUGH 2022

The demand forecasts for each scenario were compared using the city's annual energy demand data from a survey conducted by Becerra-Bayona (2024), which used a statistical grid to conduct tests in Berlin's residential sector and assess the final use of electricity and heat after COVID-2019. As of 2022, the average electricity consumption is 2400 GJ with an average usage of 15,213 h, and the heat consumption is 158 GJ.

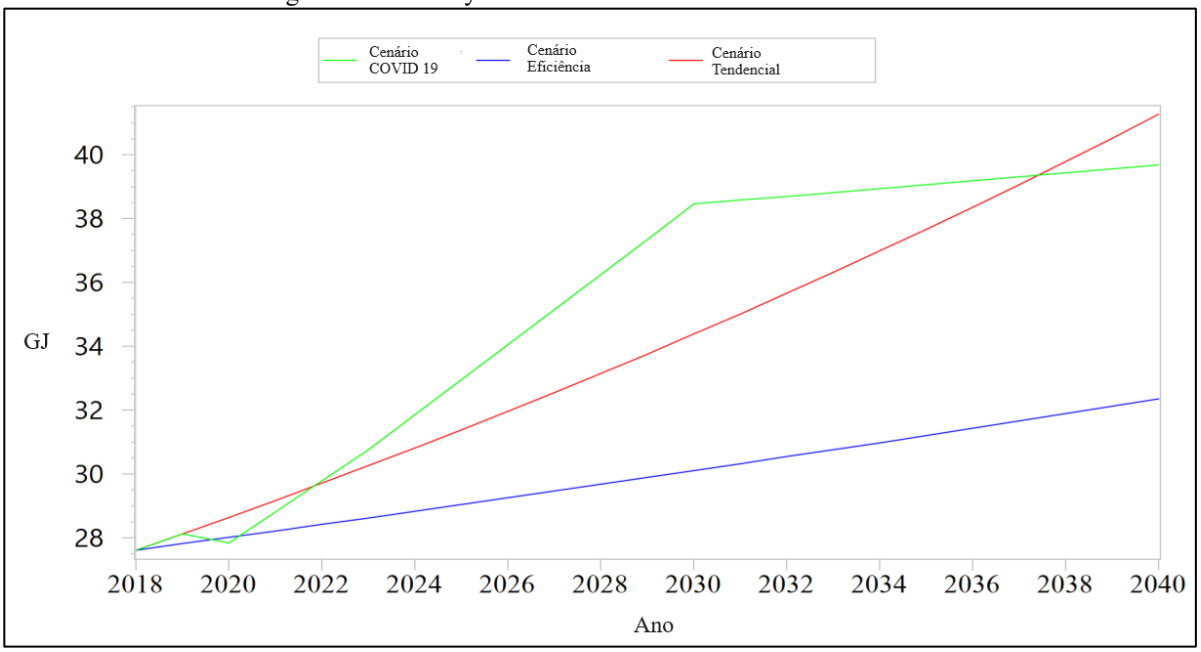
RESULTS AND ANALYSIS

This section illustrates the energy demand results for the usual trend scenario, emphasizing the importance of strategic energy planning, while energy efficiency initiatives aim to counter this trend. Finally, the post-COVID-19 scenario reflects notable changes in annual growth rates linked to GDP variations.

ELECTRICITY DEMAND FORECASTING

In Figure 1, the usual trend for electricity demand in Berlin's urban and rural sectors is evident, reaching a demand of 3368.4 GJ in 2040. The annual growth rate for both sectors is approximately 1.84%, indicating a persistent increase in residential electricity demand over the past decade. This highlights the need for strategic energy planning to cope with growing demands, requiring infrastructure expansions, adoption of efficient technologies, and implementation of policies that promote sustainability.

Figure 1. Electricity demand in Berlin's urban and rural sectors



In the energy efficiency scenario for Berlin's urban and rural areas, a distinctive approach aims to reduce electricity demand, reaching 2641.0 GJ in 2040. Applying a PROURE energy intensity index, the trajectory shows a unique pattern with annual increases ranging from approximately 0.67% initially to about 0.72% later in the forecast for both rural and urban sectors. Extrapolating these rates results in an estimated cumulative growth in electricity demand of about 21.7% for urban areas and 17% for rural areas. The strategy involves upgrading cooling equipment and replacing inefficient luminaires with LED technology, anticipating efficiency improvements of 30% to 40%, proportions similar to those obtained in

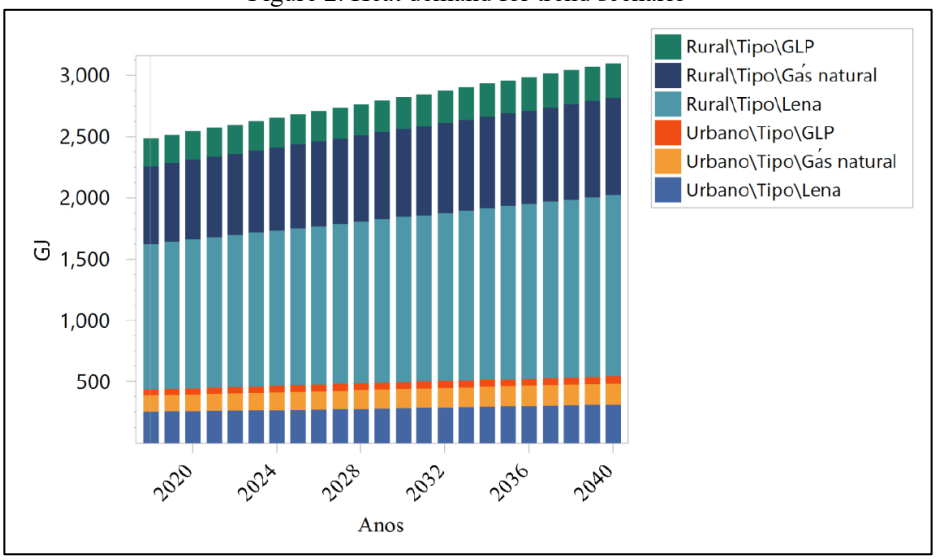
research such as Shahzad et al. (2016). In addition, these innovations aim to significantly reduce energy consumption, promoting a more sustainable and environmentally conscious approach in Berlin.

The post-COVID-19 trend scenario for electricity demand shows significant dynamics, reaching 3008.8 GJ in 2040. In 2020, negative growth rates, reflecting the immediate impact of the pandemic, led to a reduction of approximately -6.9% in electricity demand in both urban and rural areas due to the closure of tourism y agriculture activities, which had a high impact on the city of Berlin due to the lack of tourists in wool pandemic, which led a large part of the population to migrate to other areas of the country. However, in 2021, there was a resilient resurgence with a growth rate of around 3.7%, aligning with the post-pandemic recovery. The calculated average growth rate, derived from annual comparisons, indicates a stable metric, averaging approximately 3% through 2022, signifying the early phases of recovery and the anticipated trend. This is in line with UPME's national projections (2022), which predict annual growth ranging between 2.21% and 3.38% for the period from 2022 to 2036. By examining the cumulative growth rates through 2030 and 2040, a comprehensive understanding of Berlin's electricity demand trajectory emerges. This highlights the importance of implementing adaptive strategies in the face of unprecedented events, while also promoting sustainability in the energy sector.

HEAT DEMAND FORECASTING

In the Berlin trend scenario (Figure 2), the assessment of heat consumption reveals insights, projecting 3,096.1 GJ in 2040. A growth rate of 23.7% in demand for the urban area and 28.6% for the rural area stands out. According to UPME (2020), in the urban area, there was a 64.62% increase in natural gas consumption, a 2.52% decrease in firewood consumption, and a 92.05% increase in propane gas consumption. In the rural area, there was a decrease of 4.5% in the consumption of firewood, an increase of 32.96% in the consumption of natural gas and an increase of 84.95% in the consumption of propane gas.

Figure 2. Heat demand for trend scenario



In the efficiency scenario represented in Figure 3, the projected annual demand for 2040 is 3,096.1 GJ. In the urban area, this demand experienced an increase of 23.7% between 2018 and 2040. According to the guidelines of the "National Energy Plan 2020 and 2050" (UPME, 2020), the consumption of propane gas increased by 64% by 2025, while the consumption of natural gas increased by 4.88%, and the consumption of firewood decreased by 34.3%. For 2030, it is projected that the consumption of propane gas will increase by 69%, that of firewood will decrease by 28%, being replaced by the use of propane gas, and the consumption of natural gas will increase by 11.24%.

In rural areas, the consumption growth rate is 28.6%. It is estimated that propane gas consumption will increase by 67%, firewood by 37.3%, and natural gas by 3.6% by 2025. For 2030, propane gas consumption is expected to increase by 70.3%, while firewood consumption decreases by 26%, resulting in an increase in propane gas consumption. On the other hand, natural gas consumption would increase by 7.2%.

In the post-COVID scenario (Figure 4), the demand is 3,347.9 GJ, with an increase of 31.4% in the urban area and 34.5% in the rural area between 2018 and 2040. Annual growth rates of 2.3% were observed for the urban area and 2.76% for the rural area in 2040. The expected growth rate for the urban sector is 2.76%, and in the rural sector, 2.97%, with cumulative rates of 58.6% and 53% in the urban and rural sectors, respectively.

These projections point to significant changes in heat demand in Berlin, highlighting both current trends and efficiency strategies and the impacts of the post-COVID scenario on heat consumption in the city.

At this point, it is relevant to mention that, for the projections of electricity and heat consumption until 2023, the data were validated through the research conducted by Becerra-Rodríguez (2024).

Figure 3. Heat Demand for Efficiency Scenario

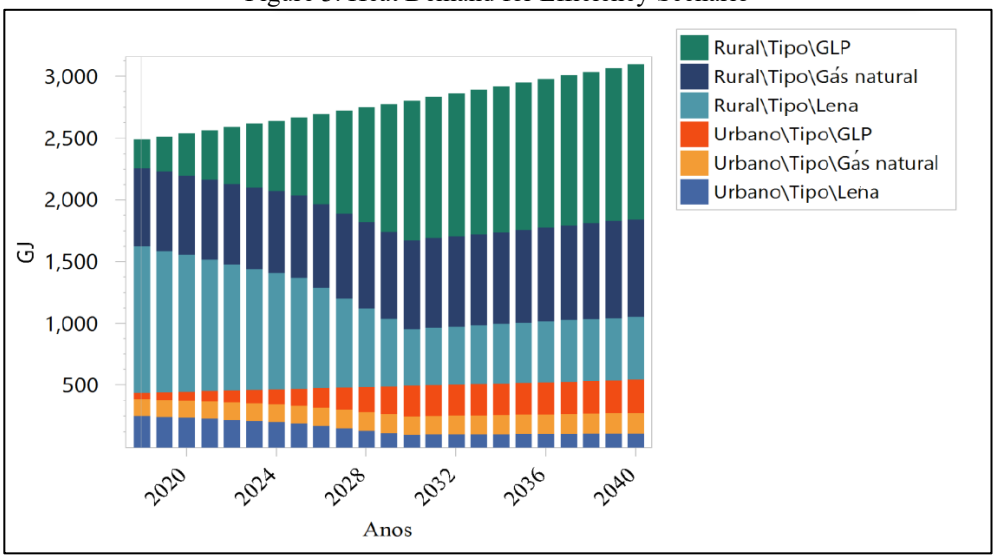
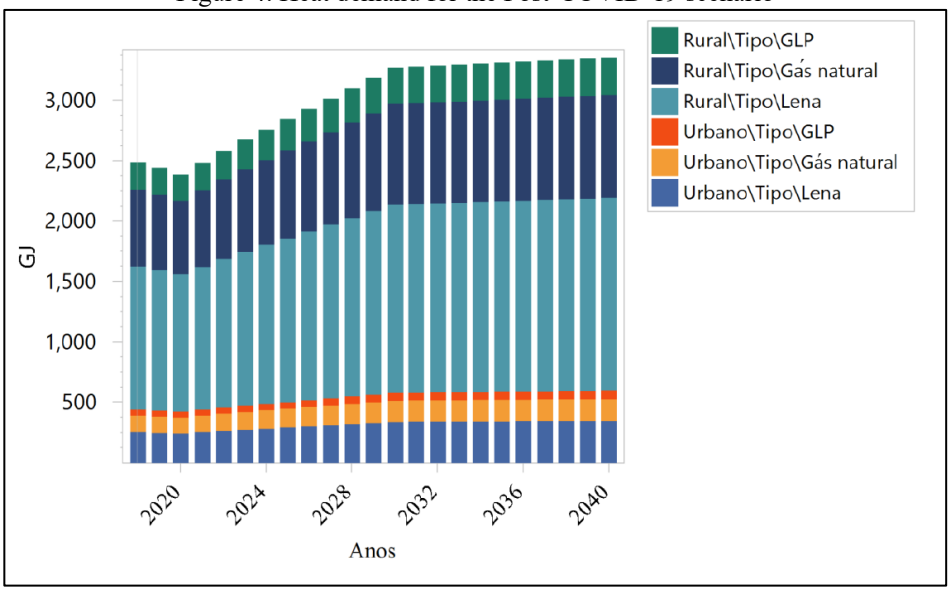


Figure 4. Heat demand for the Post-COVID-19 scenario



CONCLUSIONS

The energy demand projections for Berlin show a steady growth trajectory in both electricity and heat consumption in various scenarios. The conventional trend scenario highlights the urgency of strategic energy planning to address the continued increase in residential electricity demand, requiring infrastructure expansions, technology adoption, and implementation of sustainable policies. Initiatives aimed at improving energy efficiency, through innovative approaches such as upgrading equipment and implementing LED technology, aim to curb growing electricity consumption. The post-COVID-19 scenario, on the other hand, introduces significant dynamics, with a remarkable resilience in electricity demand after the drop caused by the pandemic in 2020. The cumulative growth rates underscore the

importance of adaptive strategies and sustainable measures to navigate uncertainty and strengthen a resilient energy sector.

With regard to the heat demand forecast, the trend scenario for Berlin points to a robust increase, highlighting the pressing need for sustainable energy sources. The efficiency scenario, on the other hand, reveals a strategic transition in line with environmental objectives, reducing dependence on firewood. Following the impact of COVID-19, the region experiences a notable reduction in heat consumption in 2020, followed by a vigorous recovery, indicating a commitment to recovery and growth. The cumulative growth rates underscore the adaptability of Berlin's energy landscape and its commitment to promoting sustainability. It is important to highlight that the validation of the projections of electricity and heat consumption until 2022 was ensured through a survey conducted by Becerra-Rodríguez (2024), giving robustness to the results presented.

NOMENCLATURE

AL – level of social or economic activity, %

EC – total energy consumption for a sector, GJ

PIB – brute domestic product

I – Specific sector

LGP – liquefied petroleum gas

LEAP – long-term energy alternative planning

UPME – Power Mining Planning Unit

SUI – single information system

t – period, year

TE – total final energy consumption, GJ

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