

Considerations on energy under transition scenarios in Colombia

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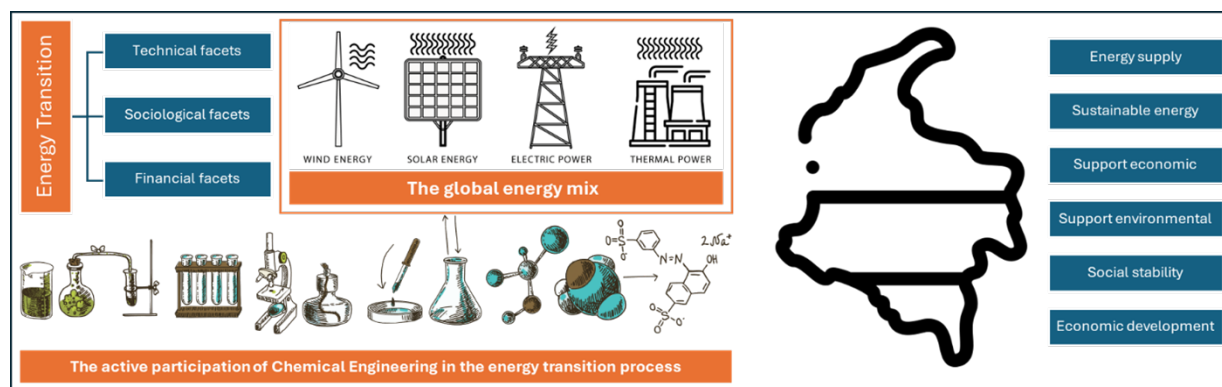
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Graphical abstract



Abstract

The energy transition is not just a challenge but a gateway to global sustainability and economic growth. It addresses the challenges of mitigating global warming while meeting society's basic demands. The transition encompasses technical, sociological, and financial facets, transforming the global energy mix and geopolitical landscape. This paper discusses the challenges and opportunities related to energy transition in Colombia. It emphasizes the role of thermal and electrical energy components in Colombia's macroeconomic spectrum and the active participation of Chemical Engineering in the energy transition process. With a rapidly growing population and evolving economy, Colombia faces the crucial task of ensuring a sustainable energy supply to support economic, environmental, and social stability. This discussion provides a glimpse into the complex interplay of population growth, economic development, and the energy sector in Colombia. It highlights its reliance on fossil fuels and the country's status as a net energy exporter, setting the stage for a comprehensive analysis of the country's energy transition journey.

Keywords: Energy transition; Global sustainability; Economic growth; Global warming; Energy matrix; Chemical engineering; Thermal energy; Electric energy; Colombia; Fossil fuels.

Reflexiones sobre la energía en Colombia frente a escenarios de transición

Resumen

La transición energética no es sólo un desafío, sino una puerta de entrada a la sostenibilidad global y al crecimiento económico. Aborda los desafíos de mitigar el calentamiento global y al mismo tiempo satisfacer las demandas básicas de la sociedad. La transición abarca facetas técnicas, sociológicas y financieras, transformando la matriz energética global y el panorama geopolítico. Este documento analiza los desafíos y las oportunidades relacionados con la transición energética en Colombia. Destaca el papel de los componentes de energía térmica y eléctrica en el espectro macroeconómico de Colombia y la participación activa de la ingeniería química en el proceso de transición energética. Con una población en rápido crecimiento y una economía en evolución, Colombia enfrenta la tarea crucial de garantizar un suministro de energía sostenible para apoyar la estabilidad económica, ambiental y social. Este análisis ofrece una visión de la compleja interacción entre el crecimiento de la población, el desarrollo económico y el sector energético en Colombia. Destaca su dependencia de los combustibles fósiles y el estatus del país como exportador neto de energía, preparando el escenario para un análisis integral del recorrido de transición energética del país.

Palabras clave: Transición energética; Sostenibilidad global; Crecimiento económico; Calentamiento global; Matriz energética; Ingeniería química; Energía térmica; Energía eléctrica; Colombia; Combustibles fósiles.

Considerações sobre energia em cenários de transição na Colômbia

Resumo

A transição energética não é apenas um desafio, mas uma porta de entrada para a sustentabilidade global e o crescimento econômico. Aborda os desafios de mitigar o aquecimento global, ao mesmo tempo que satisfaz as exigências básicas da sociedade. A transição abrange facetas técnicas, sociais e financeiras, transformando a matriz energética global e o panorama geopolítico. Este documento analisa os desafios e oportunidades relacionados com a transição energética na Colômbia. Destaca o papel dos componentes da energia térmica e elétrica no espectro macroeconômico da Colômbia e a participação ativa da engenharia química no processo de transição energética. Com uma população em rápido crescimento e uma economia em evolução, a Colômbia enfrenta a tarefa crucial de garantir um abastecimento energético sustentável para apoiar a estabilidade econômica, ambiental e social. Esta análise oferece uma visão da complexa interação entre o crescimento populacional, o desenvolvimento econômico e o setor energético na Colômbia. Destaca a sua dependência dos combustíveis fósseis e o estatuto do país como exportador líquido de energia, preparando o terreno para uma análise abrangente da jornada de transição energética do país.

Palavras-chave: Transição energética; Sustentabilidade global; Crecimiento económico; Aquecimento global; Matriz energética; Engenharia química; Energia térmica; Energia elétrica; Colômbia; Combustíveis fósseis.

Introduction

Currently, humanity is undergoing a period of structural adjustment, which, in terms of global population sustainability, must address the mitigation or attenuation of global warming while maintaining the economic growth levels necessary to meet society's basic demands. This structural adjustment encompasses various technical, sociological, and financial facets translating into the "Energy transition". This process not only involves the transformation of the global energy mix but also entails a reordering of global geopolitics through the imposition of new standards and parameters for energy markets. The current energy flows, which largely depend on fossil fuels (crude oil, gas), have created blocks of energy-producing countries and blocks of energy-consuming countries (mainly thermal energy) whose buying and selling activities have allowed the creation of prices and logistical structures with a high degree of monetary investment.

This article aims to measure the specific impact that the components of thermal and electrical energy have within the country's macroeconomic spectrum to contribute to the debate on the speed at which Colombia should face the Energy

Transition process and, above all, to visualize how Chemical Engineering must actively participate in this process.

Population growth

Figure 1 shows the historical record of Colombian population growth based on the population registration conducted in 1973, 1985, 1993, and 2018. By analyzing this profile, it is possible to infer that the population over 60 years (1960-2020) has grown from approximately 15 million inhabitants to a figure very close to 50 million inhabitants, with an approximate linear growth of 580,000 new Colombians per year. This population growth rate doubled over 24 years (taking 1960 as the base year), mainly favoring urban growth. If this population growth rate remains constant over time, by the year 2050, we expect a Colombian population of about 67 million inhabitants. This figure would represent a 400 % increase compared to 1960.

Growth of this magnitude represents a significant challenge for sustaining the population, as it implies a need for the supply of goods and services (including energy) vital for the country's economic, environmental, and social sustainability.

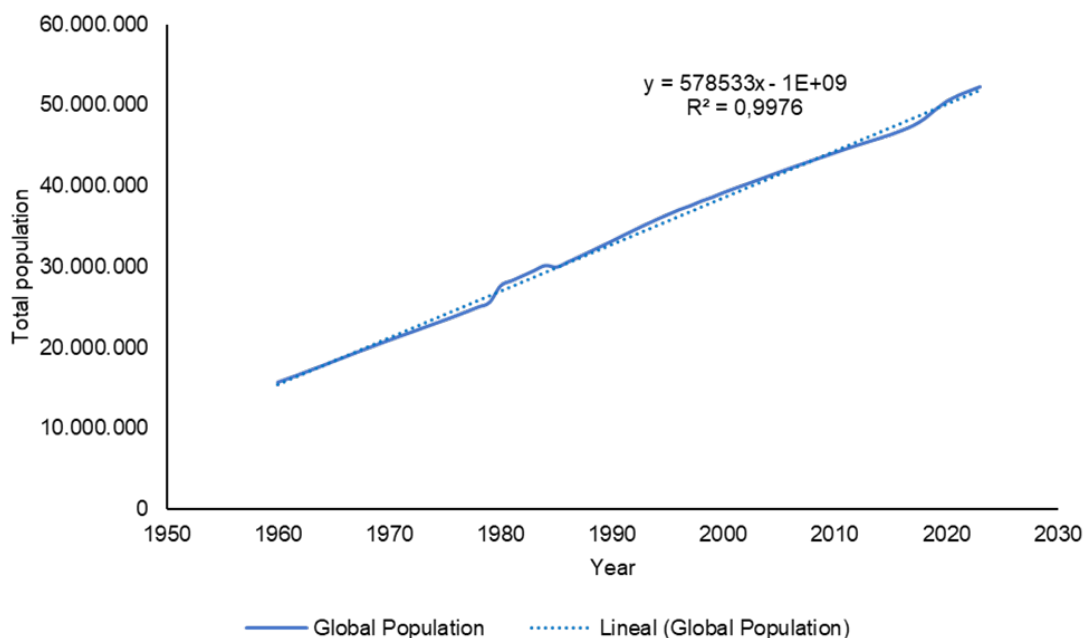


Figure 1. Historical trend of global Colombian population 1960-2023 [1].

Economic growth

Parallel to population growth, Colombian economy has shown an evolutionary process, as summarized in Figure 2. Despite multiple contingencies from external markets, internal political situations, and the pandemic effect, since 2005, it is possible to find numerous indicators of Gross Domestic Product (GDP) that are positive or equal to zero, which demonstrates relative stability. This, coupled with the population growth profile, shows that Colombian economy has responded to the growing demand for the population's basic needs without analyzing the distribution of wealth generation by sector.

However, regional data show a stratification of this economic growth, which allows differentiation among departments with some of them having more outstanding contributions to GDP than others, and that creates significant gaps for the country's industrialization advancement. Figure 2 shows, as an example, the GDP contribution of Antioquia

and Santander (Colombian departments).

Sectoral growth of the energy sector in Colombia. The current Colombian energy mix shows very defined characteristics that make it possible for the country to be a net energy exporter, mainly thermal. Figure 3 and Figure 4 summarize the historical behavior of the total energy production in the country by energy source and the difference between local consumption and energy production, respectively.

As observed, Colombia bases its energy potential on three primary fossil energies: coal, crude oil, and natural gas. These three fuels account for over 65 % of local primary energy production. It is important to note that the contribution of electrical energy as a secondary vector reaches figures close to 12 % of the total output. In other words, the country's current energy supply corresponds to a traditional extractive sector with large infrastructure investments and significant participation in generating income and value within the economy.

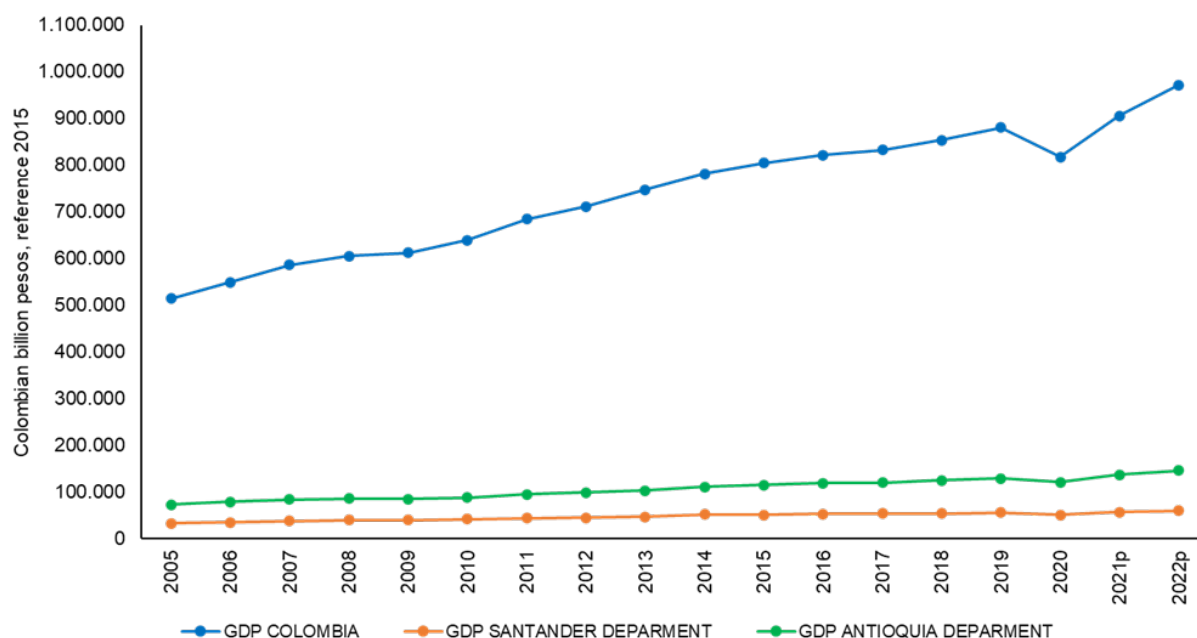


Figure 2. Historical GDP growth in Colombia and the contribution of the Departments of Antioquia and Santander (figures in Millions of USD) [2].

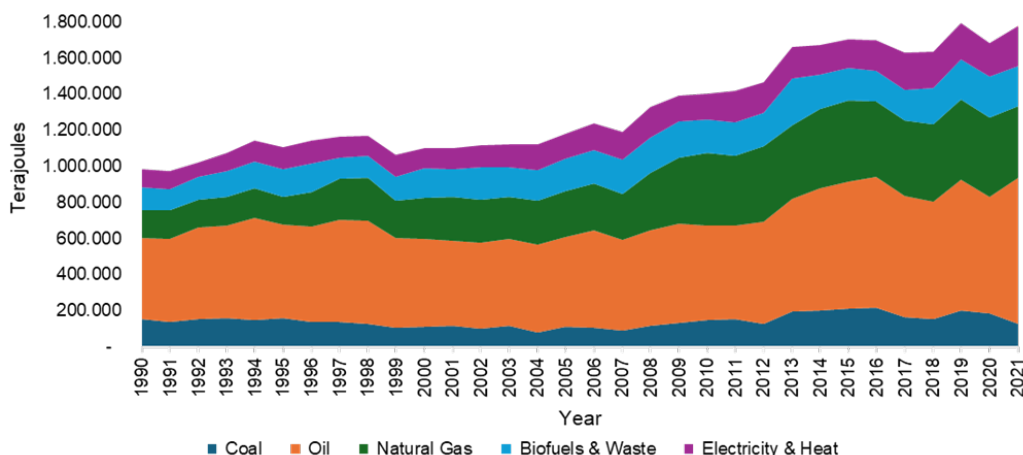


Figure 3. Historical total energy production by fuel in Colombia (figures in Terajoule). (1990-2022) [3].

Figure 4 outlines the distribution of the final energy destination in Colombia, where it is viable to assert that approximately 55 % of the net primary energy production is destined for international markets. Thus, "...In 2023, Colombia exported 54.5 million tons of thermal coal, leaving the country as one of the top five international traders of this product, surpassed only by Indonesia, Australia, South Africa, and Russia..." Similarly, Colombian crude oil exports 2023 reached 190 million barrels [4].

Contribution to the gross domestic product of the Colombian electrical component

According to national statistics generated by the National Administrative Department of Statistics (DANE) [2] for the year 2022, which groups information by economic activities, the Mining and Quarrying sector (which includes extractive activities of fossil fuels) is a significant contributor

to the national GDP, with three departments standing out in this regard: Guajira, Meta, and Santander. This indicates that while the country is a net energy exporter, regions contribute a significant percentage of that wealth within the administrative division, such as the three Departments above (Figure 5).

Figure 6 condenses the historical behavior during the period (2000-2020) of the contribution to the GDP of the Colombian electrical sector concerning 2015. It is important to note that the regions with significant participation in this economic activity differ from those where extractive potential is the main wealth-generating activity. Antioquia, Cundinamarca, and Bogotá stand out as major contributors. This sector has an evident upward trend, with growth close to 50% during that period, reflecting the electrification of some economic activities in the country.

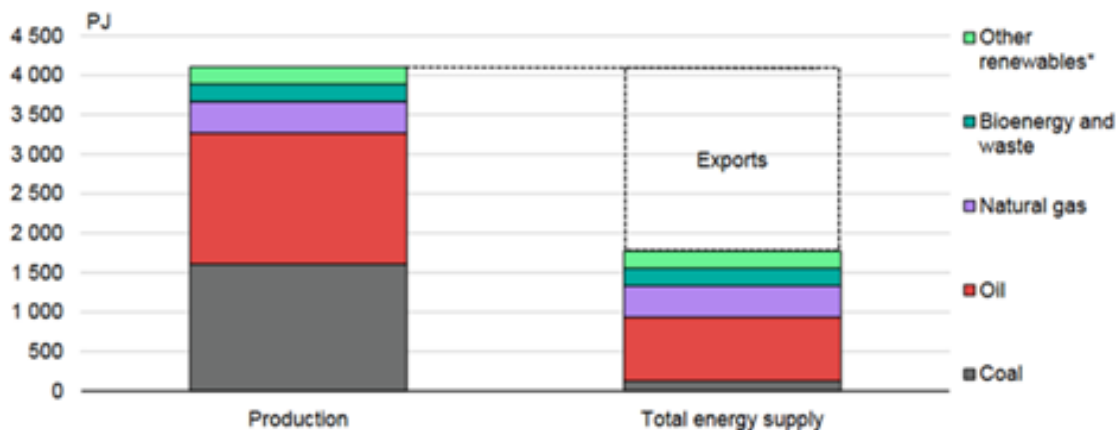


Figure 4. Energy export potential in Colombia 2023 [5].

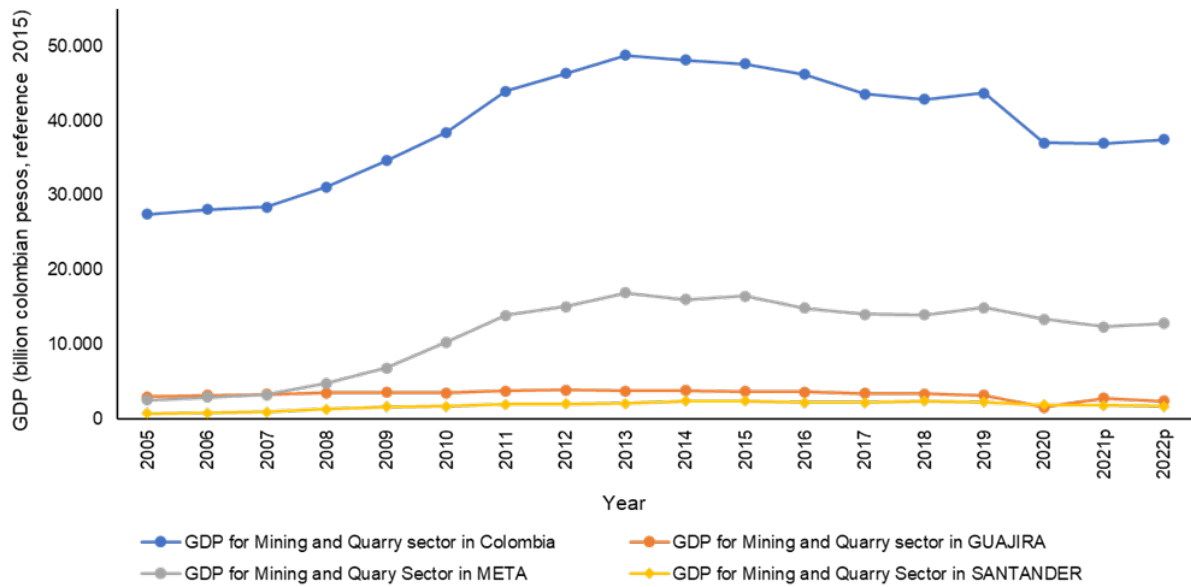


Figure 5. Gross domestic product of the mining and quarrying sector in 2015. National total and contribution of Guajira, Meta, and Santander [2].

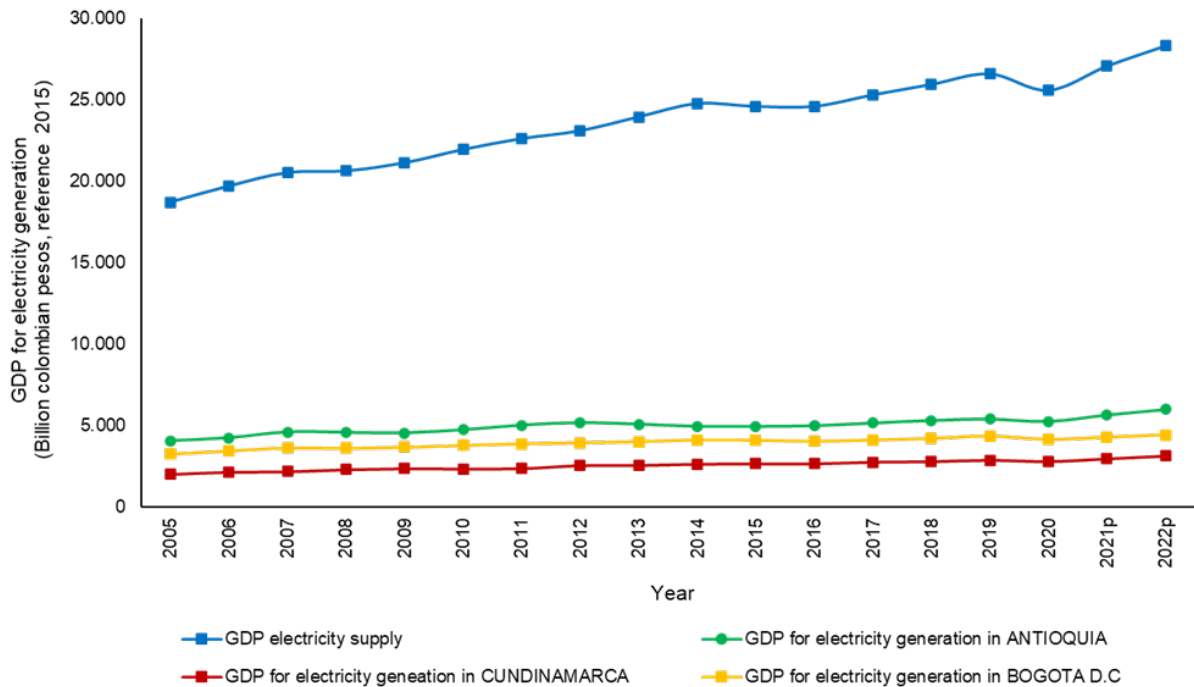


Figure 6. Contribution to the gross domestic product of the Colombian electrical sector from 2000-2020. Authors' elaboration with DANE references [2].

By combining the historical trend of Colombian population growth with the annual electrical energy consumption (in KWh), it is possible to preliminarily infer how per capita electrical consumption has evolved over the last 40 years (Figure 7).

The result of this combination can generate a non-linear adjustment model with a quadratic expression, indicating that the country's population is immersed in increased electricity consumption,

accentuated in the last 10 years.

It is important to highlight the country's historical behavior of electrical generation and its consumption by economic sectors. Since modifying the Colombian electrical industry in the 1990s, the government has had a stable energy supply with high reliability despite the climatic events, given the country's tropical position. Figure 8 summarizes this behavior.

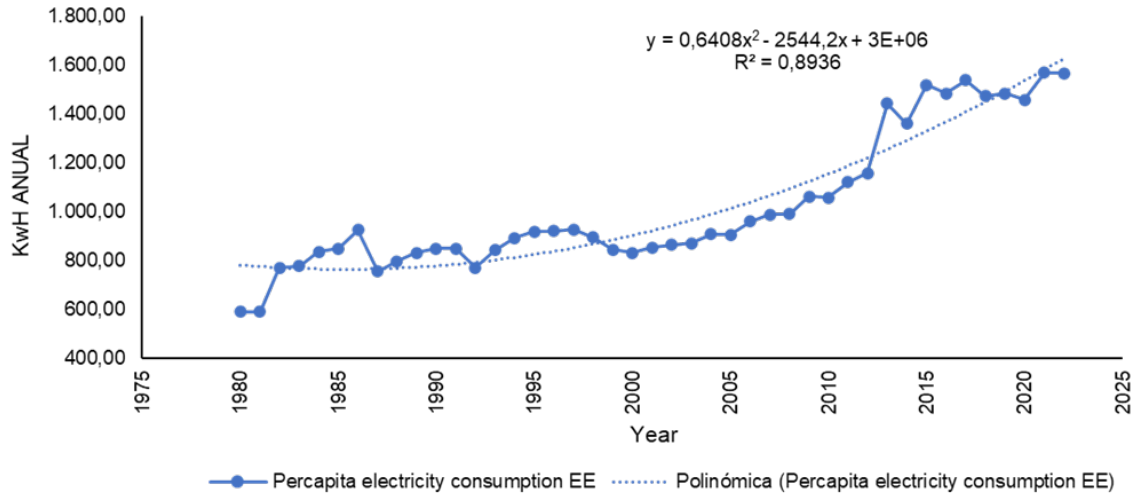


Figure 7. Historical Evolution of the Inference of Per Capita Electrical Consumption in Colombia: 1980–2022 (Source: authors).

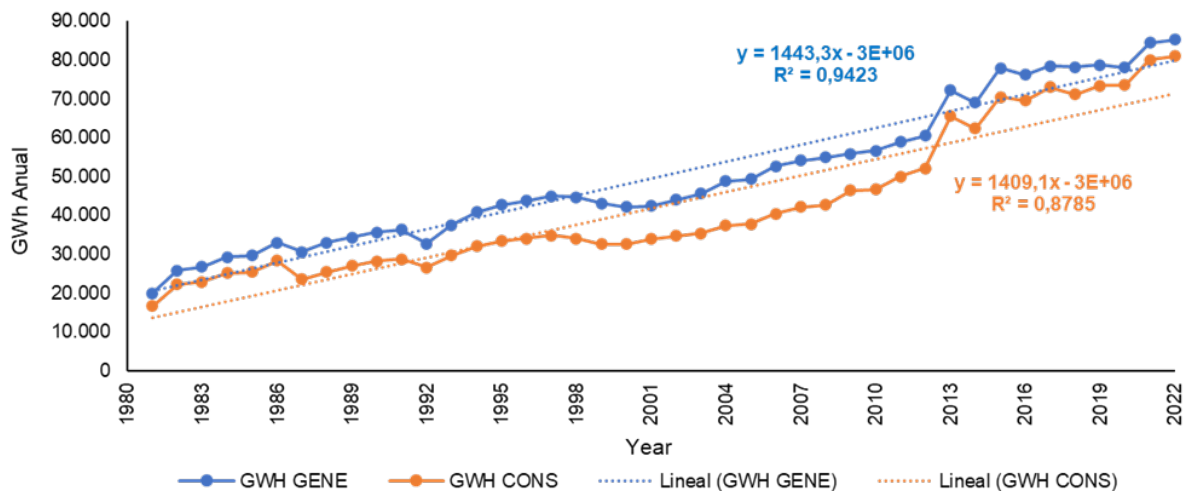


Figure 8. Historical record of electrical generation and consumption in Colombia, 1980-2022. Authors' elaboration with DANE reference [2] [National accounts, updated May 30, 2024].

On the other hand, despite the country's primary energy export potential, when the analysis focuses on the natural gas sector, the situation is very different regarding consumption and its projection. The following figure shows natural gas consumption in Colombia during 2017-2021, measured in Million Standard Cubic Feet per Day (MMSCFD), highlighting that global consumption was stable at around 900 MMSCFD during that period. The leading consumer sectors are industrial/commercial, thermoelectric, oil, residential, mobility

with natural gas vehicles, and petrochemical. See [Figure 9](#).

While self-sufficiency in natural gas for the current situation is assured, it cannot be established that the problem will continue in the same way in the coming years. Therefore, it is interesting to know the percentage participation of the country's economic sectors in the consumption of this energy source since fuel substitution efforts and, thus, the beginning of the path toward an energy transition may depend on this projection ([Figure 10](#)).

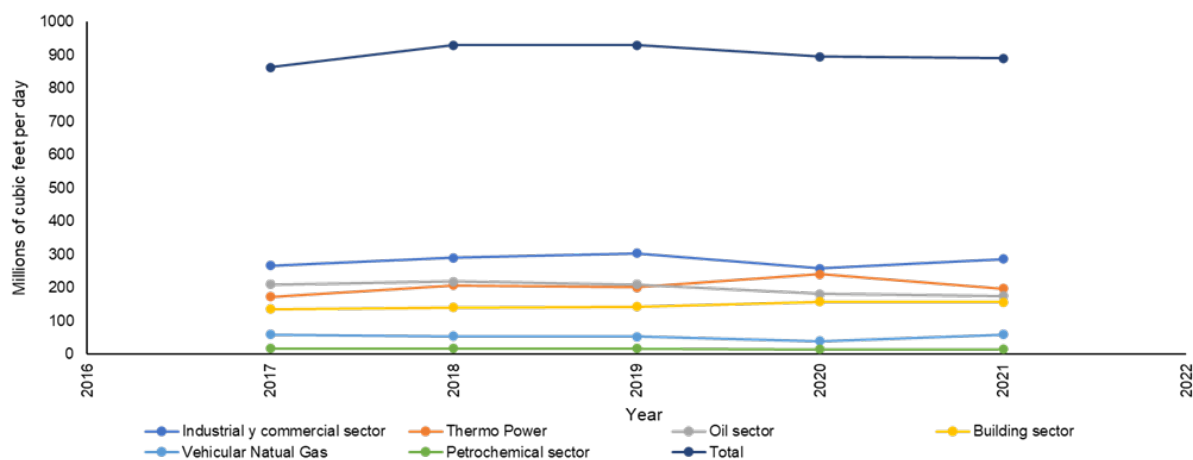


Figure 9. Historical consumption of natural gas in Colombia by economic sectors, period 2017-2021 [6].

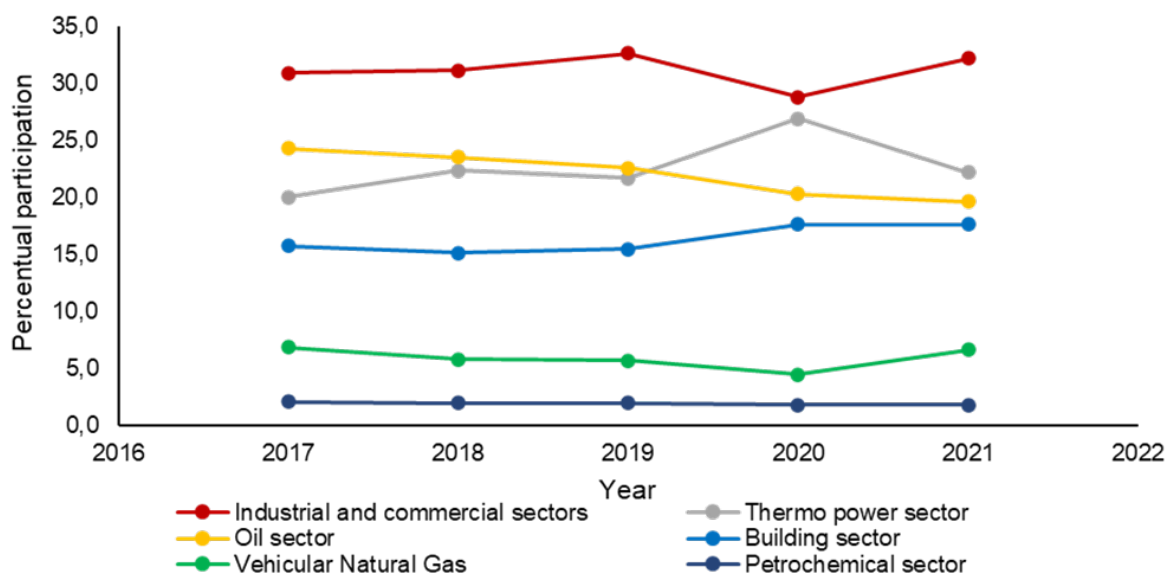


Figure 10. Percentage participation in natural gas consumption by economic sectors, period 2017-2021 [6].

Generation of greenhouse gas emissions in Colombia

According to the International Energy Agency (EIA), in 2021, Colombia reported total greenhouse gas emissions due to the combustion of fossil materials, close to 77 million tons of CO₂eq, representing 0.23 % of global emissions for the same year from the same source.

For 2000-2022, a growth of 40 % in Colombian emissions derived from fossil combustion is reported, mainly in the transportation sector [7].

There has also been a reported increase in fossil fuel production from 2000-2022, 42% for coal and 11 % for crude oil. When combining the emission volume and the Colombian population, the per capita emission of greenhouse gases related to energy reaches a value of 1.51 tons of CO₂eq/ (inhabitant. year).

Figure 11 illustrates this distribution of emissions according to the source where they originate.

Final considerations

- **GDP and Energy Divergence.** In Colombia, there is an expected growth in energy demand about the increase in GDP. This increase is reflected in a rise in emissions based on

a conventional energy matrix that relies on fossil fuels. In this sense, the challenge of the energy transition is to allow growth in energy demand to meet the needs of a society in emerging economic conditions with lower carbon intensity. Therefore, the technical challenge is to offer a diverse, renewable, and low-cost energy matrix that meets the growing demands of society while contributing to reducing greenhouse gas emissions.

- **Impact of Carbon Market on Efficiency.** Energy efficiency plays a vital role in energy transition. Engineering, in general, and chemical engineering, in particular, have an important task ahead of the Colombian industrial sector: to propose adopting technological improvements and better management practices for industrial processes. In this regard, financial or tax incentives established in the country will significantly impact this task. It should be noted that carbon credits or bonds will play an essential role in decarbonization processes given the financial difficulties most of the Colombian industrial sector faces in this decade.

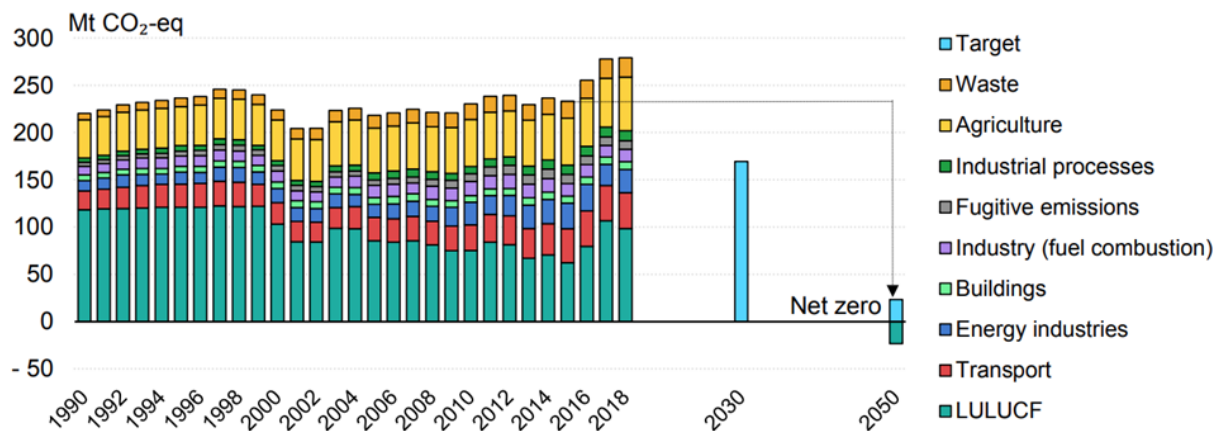


Figure 11. Historical evolution of greenhouse gas emissions generated by the sector in Colombia, period 1980-2018 and targets [8]

- **The Role of Chemical Engineering in the Transition.** Given the described panorama in the country, it is worth asking whether it is possible to formulate a technological strategy for Chemical Engineering in Colombia. A potential first step to take is to focus on achieving much higher levels of energy efficiency, particularly in the thermal component. Here, the adage “every waste pollutes” applies. As a second measure, it is evident that a rapid process of electrification of economic activities is advancing. Therefore, the industrial sector must consider how far this energy conversion is possible. This process is understood as the use of renewable electricity and the change from a thermal potential for raw material conversion to an electromagnetic motivator of these processes. Finally, Chemical Engineering in Colombia must recognize, identify, and take advantage of the natural potential that a country like Colombia offers. Topics such as sustainable land use, optimal biomass use, and the design and operation of conventional chemical processes now powered by electricity can be research and development topics for our young engineers.

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