The El Niño climate event and its impact on Colombia's agricultural trade balance, 2009–2024

Evento climático de El Niño y su efecto en la balanza comercial del sector agrícola en Colombia, 2009–2024

O fenômeno climático El Niño e seu efeito na balança comercial do setor agrícola na Colômbia, 2009–2024

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Received: May 2nd, 2025
Accepted: August 10th, 2025
Available: September 5th, 2025

How to cite this article:
R.D. Díaz Mateus and C.D. González Acosta, "The El Niño Climate Event and Its Impact on Colombia's Agricultural Trade Balance, 2009–2024," *Revista Ingeniería Solidaria,* vol. 21, no. 3, 2025.
doi: https://doi.org/10.16925/2357-6014.2025.03.04

Research article. https://doi.org/10.16925/2357-6014.2025.03.04

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Abstract

Introduction: This article is derived from the research project entitled "Factors in the Measurement of the Fair Value of Biological Assets in Companies Listed on the Colombian Stock Exchange", developed by the University of La Salle and the Colombian Association of Faculties of Public Accounting (ASFACOP).

Problem: Colombia relies heavily on agricultural production for its foreign trade. Consequently, the El Niño phenomenon has significant implications for the country's trade balance, affecting crop yields, increasing production costs, and generating the need to import agricultural products and energy, particularly from alternative sources, to meet domestic demand.

Objective: To quantify the economic effects of the El Niño phenomenon in Colombia during the study period, analyzing its implications for the trade deficit and the structure of exports and imports within the agricultural sector.

Results: The findings indicate that during the periods of greatest intensity of the El Niño phenomenon (2015–2016 and 2023–2024), the Consumer Price Index (CPI) increased significantly, agricultural Gross Domestic Product (GDP) experienced a decline, particularly in the fishing subsector, and food imports increased due to reduced domestic production. Additionally, fluctuations in reservoir levels affected the performance of the energy sector, leading to higher electricity prices.

Conclusions: During the most severe El Niño episodes, exports of meat products and the productivity of both temporary and permanent crops, such as sugarcane, were adversely affected. Exports of commodities such as cocoa and sugar declined, while imports in the agricultural and energy sectors, particularly fossil fuels, increased considerably.

Originality: The study provides a more accurate assessment of the economic consequences of the El Niño phenomenon, contributing to the design of public policies aimed at improving responses to extreme climate events.

Keywords: Trade deficit, El Niño phenomenon, Inflation, Trade balance, Gross Domestic Product, Agricultural sector.

Resumen

Introducción: Este artículo es producto del proyecto de investigación "Factores en la medición del valor razonable de los activos biológicos de las empresas que cotizan en la Bolsa de Valores de Colombia", desarrollado por la Universidad de La Salle y la Asociación Colombiana de Facultades de Contaduría Pública (ASFACOP).

Problema: Colombia depende en gran medida de la producción agropecuaria para su comercio exterior; por ello, el fenómeno de El Niño tiene importantes repercusiones sobre la balanza comercial del país, afectando las cosechas, incrementando los costos de producción y generando la necesidad de importar productos agrícolas y energía para satisfacer la demanda interna.

Objetivo: Cuantificar los efectos económicos del fenómeno de El Niño en Colombia durante el período de estudio, analizando sus implicaciones sobre el déficit comercial y la estructura de exportaciones e importaciones del sector agropecuario.

Resultados: Los resultados muestran que durante los períodos de mayor intensidad del fenómeno (2015–2016 y 2023–2024) se presentó un incremento significativo del Índice de Precios al Consumidor (IPC), una reducción del Producto Interno Bruto (PIB) agropecuario, especialmente en el subsector pesquero, y un aumento de las importaciones de alimentos debido a la disminución de la producción nacional. Asimismo, las variaciones en los niveles de los embalses afectaron el desempeño del sector energético, incrementando los precios de la energía.

Conclusiones: Durante los episodios más intensos del fenómeno de El Niño, las exportaciones de productos cárnicos y el rendimiento de cultivos transitorios y permanentes, como la caña panelera, se vieron afectados negativamente. De igual manera, las exportaciones de productos como cacao y azúcar disminuyeron, mientras que las importaciones del sector agropecuario y energético, especialmente de combustibles fósiles, aumentaron de manera considerable.

Originalidad: El estudio proporciona una evaluación más precisa de las consecuencias económicas del fenómeno de El Niño, contribuyendo al diseño de políticas públicas orientadas a mejorar la capacidad de respuesta frente a eventos climáticos extremos.

Palabras clave: Déficit comercial, Fenómeno de El Niño, Inflación, Balanza comercial, Producto Interno Bruto, Sector agropecuario.

Resumo

Introdução: Este artigo é produto do projeto de pesquisa "Fatores na Mensuração do Valor Justo de Ativos Biológicos de Empresas Listadas na Bolsa de Valores da Colômbia", desenvolvido pela Universidade de La Salle e pela Associação Colombiana de Escolas de Contabilidade Pública (ASFACOP).

Problema: A Colômbia depende fortemente da produção agrícola para seu comércio exterior; portanto, o fenômeno El Niño tem repercussões significativas na balança comercial do país, afetando as colheitas, aumentando os custos de produção e gerando a necessidade de importar produtos agrícolas e energia para atender à demanda interna.

Objetivo: Quantificar os efeitos econômicos do fenômeno El Niño na Colômbia durante o período de estudo, analisando suas implicações para o déficit comercial e a estrutura de exportação e importação do setor agrícola. Resultados: Os resultados mostram que, durante os períodos de maior intensidade do fenômeno (2015–2016 e 2023–2024), houve um aumento significativo no Índice de Preços ao Consumidor (IPC), uma redução no Produto Interno Bruto (PIB) do setor agrícola, especialmente no subsetor da pesca, e um aumento nas importações de alimentos devido à diminuição da produção interna. Da mesma forma, as variações nos níveis dos reservatórios afetaram o desempenho do setor energético, elevando os preços da energia.

Conclusões: Durante os episódios mais intensos do fenômeno El Niño, as exportações de produtos cárneos e a produção de culturas temporárias e permanentes, como a cana-de-açúcar, foram afetadas negativamente. Similarmente, as exportações de produtos como cacau e açúcar diminuíram, enquanto as importações nos setores agrícola e energético, especialmente de combustíveis fósseis, aumentaram consideravelmente. Originalidade: Este estudo fornece uma avaliação mais precisa das consequências econômicas do fenômeno El Niño, contribuindo para a elaboração de políticas públicas voltadas para o aprimoramento da capacidade de resposta a eventos climáticos extremos.

Palavras-chave: Déficit comercial, fenômeno El Niño, inflação, balança comercial, Produto Interno Bruto, setor agrícola.

1. INTRODUCTION

The El Niño phenomenon is a climatic event characterized by the anomalous warming of surface waters in the central Pacific Ocean, which alters wind patterns and atmospheric pressure systems, thereby contributing to changes in global precipitation and

temperature patterns [1]. Historical evidence of this phenomenon has been documented over several centuries. South American fishermen reported unusual changes in Pacific Ocean waters as early as the seventeenth century [2]. Likewise, between 1789 and 1793, severe droughts were recorded in Asia, Australia, Mexico, and southern Africa. More recently, the 2015–2016 El Niño event triggered droughts and floods in various regions of the world, contributing to "disease outbreaks such as the Zika virus in South America and bleaching about one-third of the Great Barrier Reef in Australia" [2].

El Niño is among the most significant factors affecting food security and economic stability worldwide. A report by the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA) states that the recent consequences of this phenomenon have exacerbated food insecurity in Latin America and the Caribbean, affecting millions of people due to reduced agricultural production and rising food prices [3]. Since 2023, the World Meteorological Organization (WMO) has warned of increasing global temperatures in the coming years, potentially reaching record levels worldwide and likely causing more severe droughts in several strategically important regions [4]. Colombia is one of the countries that has historically been affected by the scope of this phenomenon, placing its socioeconomic system in a highly vulnerable situation and generating adverse consequences across different sectors, particularly affecting populations in the Pacific and Caribbean regions. Specifically, its impact on the country's climate has intensified droughts, damaging agricultural production and water supply systems, while rising temperatures have increased electricity consumption, leading to higher costs for households and industries. According to the Economic Projections of Grupo Bancolombia, "this climate event, which according to the most recent estimates would have a lower intensity with respect to the one that occurred in 2016, would impact crops more strongly during the first half of 2024" [5].

In Colombia, the most intense El Niño events on record occurred during the periods 1997–1998 and 2015–2016. The Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) points out that the 1997–1998 phenomenon was one of the strongest and most devastating events experienced by the country, followed by the event recorded between 2015 and 2016, which serves as the starting point for this analysis. This event reached its maximum intensity toward the end of 2015 and remained at a very high level during January and part of February 2016 [6], significantly affecting both the environment and the national economy. Evidence of these impacts is reflected in reports from the Economic Commission for Latin America and the Caribbean (ECLAC), which indicate that high-intensity episodes, such as the

2015–2016 event, generated multimillion-dollar losses throughout the region, negatively affecting economic growth and commercial stability [7].

Furthermore, Corficolombiana estimated that the strong El Niño phenomenon would increase food inflation by between 2.9% and 6.1%, making it more difficult to achieve the inflation target established by the Central Bank of Colombia for 2024 [8]. Likewise, projections suggested that by 2024 the continued decline in reservoir levels would increase the risk of a deficit in the energy sector, thereby increasing operating costs and potentially generating economic instability, with repercussions on inflation and a widening current account deficit [9].

Environmental degradation and climate change have increased both the frequency and severity of these phenomena in recent decades. In Colombia, the consequences of El Niño affect not only the domestic economy but also foreign trade, as increases in the prices of imported and exported products aggravate the country's financial situation. According to Corficolombiana, in a report published in January 2024, El Niño "raises food inflation by an average of 3.9%, mainly affecting rice, banana, sugar cane, yucca and potato crops" [9]. Additionally, the livestock sector in Colombia experienced losses estimated at COP 122,000 million during the first 45 days of the year, accompanied by a daily reduction of 8% in milk production [10].

Regarding imports and exports in Colombia, this climatic phenomenon primarily affects the agricultural and energy sectors. With respect to exports, agricultural production is negatively impacted by prolonged droughts, which reduce the supply of products destined for international markets and consequently decrease export revenues. In this regard, the Economist Intelligence Unit (EIU) states that developing countries are more likely to be affected by climate change, particularly by El Niño events, because they often lack adequate infrastructure to mitigate these risks [11].

In terms of imports, the hydroelectric power generation sector—one of the most important pillars of Colombia's energy system—is adversely affected by declining rainfall and reservoir levels. Consequently, the Mining and Energy Planning Unit (UPME), in its 2024 report, highlighted an increase in monthly energy consumption in the country ranging from 6.0% to 9.3%, attributed to the increased use of air-conditioning and cooling equipment associated with the arrival of El Niño. The report also emphasized that the reduction in precipitation was generating considerable stress on the national energy system [12]. This situation evidences an increased dependence on alternative energy sources, particularly thermal generation, which requires imported fossil fuels. Furthermore, Colombia is currently engaged in an energy transition process projected toward 2050; however, this transition has been hindered by the unforeseen impacts generated by El Niño. In addition, projections indicate that achieving the target of

implementing mitigation measures equivalent to a 20% reduction in emissions would reduce the value of exports by between 8% and 9% by 2040, affecting the energy productivity of hydrocarbons, fossil fuels, and the transportation sector [13].

1.1 Literature Review and Theoretical Background

1.1.1 El Niño Phenomenon

El Niño is an oceanic–atmospheric oscillation that alters the climatic equilibrium of the central Pacific region. It is characterized by an anomalous increase in sea surface temperatures, which modifies atmospheric circulation patterns and wind dynamics [14]. In the case of Colombia, this phenomenon causes a significant reduction in rainfall, particularly in the Andean and Caribbean regions, while some areas in the southern part of the country may experience episodes of extremely intense precipitation. According to Caicedo García and Bonilla Pérez [15], El Niño events may be classified as moderate when temperature anomalies in the equatorial Pacific Ocean range between 1.0°C and 1.5°C, strong when anomalies range between 1.5°C and 2.0°C, and Super El Niño when they exceed 2.0°C, occasionally reaching extreme levels of intensity.

This oscillating pattern of ocean warming and cooling is also known as the El Niño–Southern Oscillation (ENSO), a climatic variability phenomenon characterized by changes in sea surface temperature in the central and eastern Pacific Ocean, particularly along the coasts of Ecuador, Peru, and southern Colombia, with recurrence periods ranging from two to seven years [16]. Under neutral conditions, trade winds circulate from areas of high atmospheric pressure toward areas of lower pressure across the Pacific Ocean, maintaining the normal climatic balance. However, these winds may weaken or even reverse direction, triggering the development of the phenomenon. The term "El Niño" was originally used by fishermen along the Peruvian coast in reference to the Christ Child, since the phenomenon typically occurred during December [2]. By 1960, it had become evident that the phenomenon also affected other countries and was associated with climatic changes across broader regions of the tropical Pacific. According to NASA [17], the intensity of this phenomenon has increased over time. Although its early manifestations were less severe, recent observations indicate that surface waters in the central Pacific have become warmer, while conditions in the western Pacific have become colder and drier.

1.1.2 El Niño and Its Effects on the Agricultural Sector and Hydroelectric Power Generation

Ramírez Builes et al. [18] highlight the significant effects of the El Niño phenomenon on coffee crops, particularly due to the proliferation of pests such as mealybugs and red spider mites. These increases are associated with higher temperatures, which accelerate insect metabolism and reproductive cycles, resulting in reductions in coffee production ranging between 18% and 25%. Colombia has an agro-export-oriented economy in which products such as coffee, bananas, sugar, and oil palm constitute a fundamental component of total exports [19]. Consequently, extreme climatic events such as El Niño negatively affect agricultural productivity, reducing crop yields, especially in regions such as the Coffee-Growing Zone, Magdalena Medio, and the Eastern Plains. Furthermore, rising domestic prices and the need to import basic food products to compensate for reduced domestic supply contribute to the deterioration of the agricultural trade balance [20].

In contrast, Bastianin, Lanza, and Manera [21] analyzed the influence of the El Niño–Southern Oscillation (ENSO) on Colombian coffee production, exports, and prices, finding a positive correlation between El Niño events and coffee production and exports in Colombia.

Likewise, Melo León et al. [22], through the application of economic models, estimated that by 2015 there was a 20% reduction in water availability and a 4.5% increase in electricity prices, which together would reduce Colombia's Gross Domestic Product (GDP) by approximately 0.6%. Reduced water availability also decreases navigability in the country's principal inland waterways, such as the Magdalena River, increasing transportation costs and consequently raising the prices of food products and coal. Additionally, losses associated with ecosystem services resulting from forest fires were estimated at 0.1% of GDP during the same period. These findings demonstrate that the lack of adaptation measures to climate variability represents a cost equivalent to approximately 0.7% of Colombia's GDP.

The Colombian energy sector depends primarily on water resources, which account for approximately 65%–70% of national electricity generation during an average year. During El Niño events, reductions in rainfall negatively affect reservoir levels and significantly decrease hydroelectric generation capacity. Consequently, energy-sector decision-making requires an increase in thermal power generation, which depends on fossil fuels—mostly imported—such as natural gas and coal. This situation increases electricity generation costs and adversely affects the country's energy trade balance [23].

In extreme events such as those recorded during 1997–1998 and 2015–2016, the demand for imported fuels increased by more than 15%. Combined with rising international fuel prices, this situation generated a significant increase in energy imports [24]. Therefore, El Niño should be understood not only as a climatic phenomenon but also as an economic factor that amplifies external imbalances, particularly in economies highly dependent on hydroelectric generation, such as Colombia's [7].

1.1.3 Literature on El Niño and Its Global Influence

Ubilava [25] states that the El Niño–Southern Oscillation (ENSO) significantly influences commodity prices and their predictability by affecting both supply and demand conditions, causing substantial fluctuations in market prices. Similarly, Cai and Sakemoto [26], through a partial wavelet approach, found that ENSO is directly associated with variations in agricultural, food, and commodity prices. Likewise, Nam [27] agrees with Ubilava's findings, concluding that ENSO fluctuations affect the real prices of primary commodities such as maize, sorghum, rice, palm oil, and coconut at both quarterly and annual frequencies.

Cashin, Mohaddes, and Raissi [28] conclude that the El Niño phenomenon directly affects national economies through its impact on agricultural production, commodity prices, and economic growth. For example, in Indonesia, products such as coffee, cocoa, and palm oil become more expensive during El Niño episodes. In addition, nickel production decreases due to the mining sector's dependence on hydroelectric energy. The authors also report significant inflationary pressures resulting from the high weight of food within consumer price index (CPI) baskets, representing 47.6% in India, 32.7% in Indonesia, and 33.0% in Thailand.

In another study, Cashin, Mohaddes, and Raissi [29] analyzed the global economic effects of the El Niño phenomenon and identified negative impacts on real GDP in Australia, Chile, India, Indonesia, Japan, New Zealand, and South Africa, while the United States and several European economies tended to benefit. Furthermore, El Niño negatively affects the supply of agricultural products that depend on rainfall, increasing food prices and inflation and contributing to social instability in countries that rely heavily on imported food commodities.

According to Gutiérrez [30], an assessment of the impacts of extreme ENSO phases on international wheat trade revealed significant effects on the major wheat-exporting countries, including Argentina, Australia, Canada, and Russia. Using a global dynamic model, the study found reductions in both wheat yields and exports. Likewise, Iizumi et al. [31] demonstrated how ENSO affects global yields of major

crops, reporting that maize, rice, and wheat production experience variations characterized by decreases of up to 4.3% and increases of approximately 0.8%, depending on regional conditions. Additionally, the authors indicate that ENSO negatively influences between 22% and 24% of global harvests.

In their study, Liu et al. [32] not only analyzed the economic repercussions of the El Niño phenomenon worldwide but also explored its potential intensification over time. Using a nonlinear climate–economic model calibrated with historical events, such as the 2015–2016 El Niño episode, they estimated global economic losses of approximately USD 3.9 trillion. Furthermore, their projections suggest that increasing ENSO intensity may be associated with higher pollutant emissions resulting from the continued use of fossil fuels. Similarly, Schober and Martin [33] conducted a panel regression analysis with fixed effects for 59 countries across 27 periods. Based on data from the IMF, BIS, and NOAA [41], they identified a relationship between public debt and GDP, finding that affected countries experienced an average increase of 0.6 percentage points in public debt as a proportion of GDP.

Andrian et al. [34] examined the effects of the El Niño phenomenon on the economies of the Andean countries. Their results indicate that economic growth in the region would decline between 0.2 and 0.5 percentage points during 2023 and between 1.3 and 4.4 percentage points in 2024, with Peru and Ecuador being the most affected countries. The authors further conclude that Colombia would be among the Andean countries experiencing the highest food inflation by the end of 2024, reaching an additional 3.3 percentage points if the phenomenon attains maximum intensity.

Similarly, Cruzado, Stratti, Asencio, and Beas [35] analyzed the evolution of Peru's GDP during the period 1980–2023 under the influence of extreme climatic events such as El Niño. Using a double-logarithmic linear regression model, they found that a 1% increase in El Niño intensity was associated with decreases of 1.51% in the agricultural sector, 1.46% in the mining sector, and 2.24% in the commercial sector. Significant reductions in GDP associated with commerce and mining were observed during 2009, 2015, and 2020, as well as during 2023.

Olivares and Zingaretti [36] conducted a study for Venezuela covering the period 1980–2014, employing the Standardized Precipitation Index (SPI) and combining Principal Coordinates Analysis with Cluster Analysis. Their results showed that crops such as cocoa and bananas experienced yield reductions of approximately 25% during the period 2014–2016. Likewise, Chambi Condori [37], in a study covering the period 2010–2018, explained how previous El Niño episodes affected up to 80% of the fishing sector in Peru, particularly in the Piura region, demonstrating that increases in temperature had a negative impact on the profitability and equity returns of fishing companies.

On the other hand, Barrios Pérez [38] analyzed the effects of El Niño on rice production and the international rice market, particularly in major producing countries such as China, India, Thailand, and Vietnam. The study found that adverse climatic conditions, including high temperatures and droughts, led to reductions in rice yields and increases in prices ranging from 15% to 20% during the 2009 moderate El Niño event and the 2015–2016 strong El Niño episode.

2. MATERIALS AND METHODS

Through a review of historical records and scientific and institutional databases, the economic impacts of the El Niño phenomenon on Colombia's agricultural sector were identified and analyzed. Accordingly, this research adopted a quantitative and descriptive approach based on the analysis of time series data published between 2009 and 2024, with the aim of identifying patterns and correlations between extreme climatic events and variations in Colombia's agricultural trade balance.

The study examined macroeconomic indicators associated with the agricultural trade balance, emphasizing critical variables such as the trade deficit, inflation, Gross Domestic Product (GDP), agricultural GDP, Consumer Price Index (CPI), Producer Price Index (PPI), nominal and real exchange rate depreciation, and energy prices. These data were collected from reliable secondary sources, including the Banco de la República, the National Administrative Department of Statistics (DANE), the ministries responsible for the agricultural sector and foreign trade, the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), and the Food and Agriculture Organization of the United Nations (FAO).

For data processing and analysis, Microsoft Excel was used for data cleaning, organization, and time-series modeling, while Power BI was employed for the interactive visualization of key indicators. These tools facilitated the identification of patterns and correlations among agroclimatic and trade-related variables. Subsequently, a multivariate analysis was conducted to explore the relationships between climatic phenomena, such as El Niño and La Niña, and agricultural trade flows, following methodological approaches similar to those proposed by Bernal et al. [40].

3. RESULTS

Figure 1 illustrates an initial period corresponding to the 2009 El Niño event, during which Colombia recorded a trade surplus of USD 1,665 million. However, during 2015

and 2016, significant trade deficits were observed, reaching USD 15,581 million in 2015, equivalent to 30.19% of the value of imports. Although the deficit decreased slightly in 2016 to USD 10,811 million, imports continued to exceed exports, representing a difference of 25.8%.

Likewise, data corresponding to 2023 and 2024, which were also influenced by the El Niño phenomenon, show trade balance deficits of USD 9,676 million and USD 10,811 million, respectively. Furthermore, an additional increase in the trade deficit was anticipated toward the end of the climatic event.

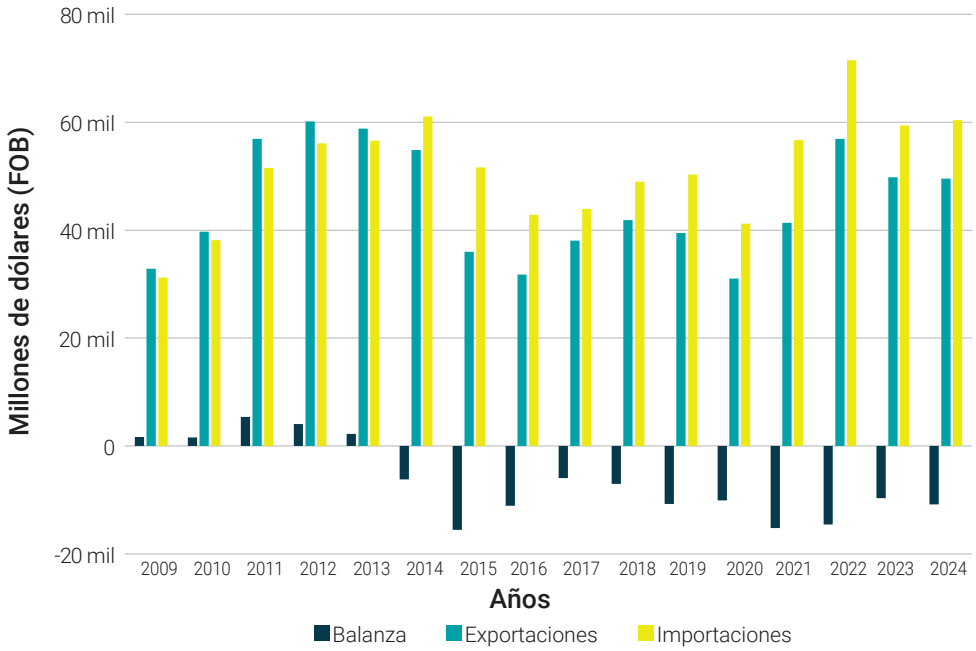

Figure 1. Trade balance in Colombia 2009 - 2024. Data: DANE.
Sources: DANE: Own elaboration.

For the analysis of Colombia's nominal and real Gross Domestic Product (GDP), in Figure 2, a stable growth in both variables is identified, although with a slight deceleration in real GDP of 2.32% for the years 2015 and 2016, which suggests a reduction in economic growth adjusted for inflation, being one of the factors to highlight the El Niño phenomenon. Between the last quarter of 2016 to 2024, there is 89.18% growth in Nominal GDP, approximately 214,628 million Colombian pesos. From 2020 onwards, there is an abrupt drop in both indicators, as a result of the COVID-19 pandemic. However, in 2023, a sustained recovery is evidenced with nominal GDP growing at a much faster rate than real GDP, indicating a possible inflationary effect on the value of national production.

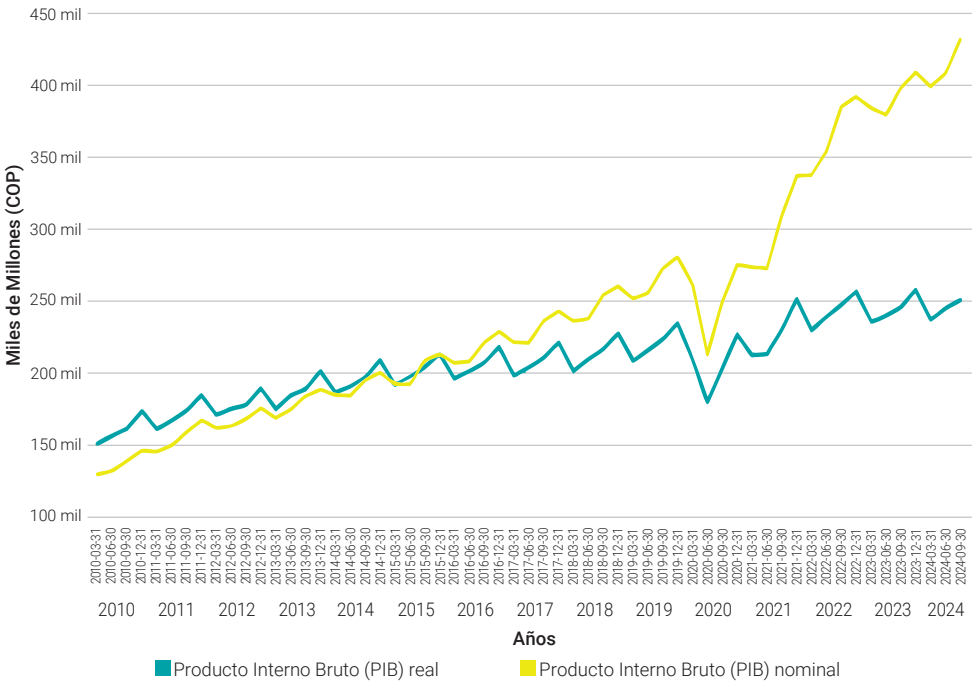

Figure 2. Nominal GDP vs Real GDP on a quarterly basis, 2009 - 2024. Data: Banco de la República and DANE.

Sources: Banco de la República and DANE: Own elaboration.

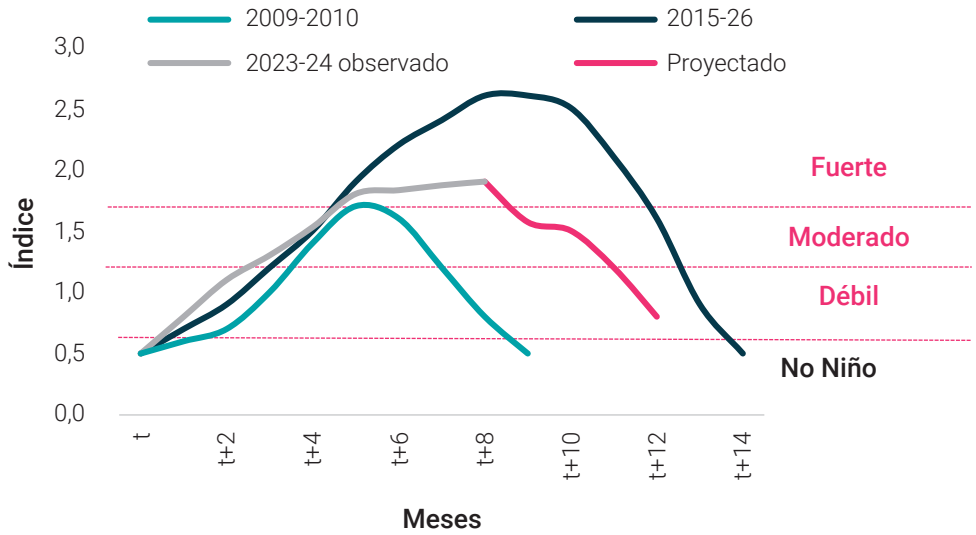

Figure 3. Periods of El Niño Phenomenon in Colombia. Data: NOOA and Corficolombiana.

Sources: Adapted from Corficolombiana, Investigaciones Económicas. El Niño Phenomenon surprises in intensity and duration (2024). https://investigaciones.corficolombiana.com/documents/38211/0/20242901.pdf/cbc4daa2-51d9-4fbd-4c74-99c1e9316be5

Figure 3 shows the periods of the El Niño phenomenon in Colombia, indicating its intensity through an index. Three main periods are identified: 2009-2010, 2015-2016 and 2023-2024. The 2009-2010 event was characterized by a low intensity. The 2015-2016 period presented a strong El Niño phenomenon. Finally, the 2023-2024 period, of which an observed and a projected part is shown (this study was done at the end of 2023), exhibits an intensity that started as moderate and intensified to strong.

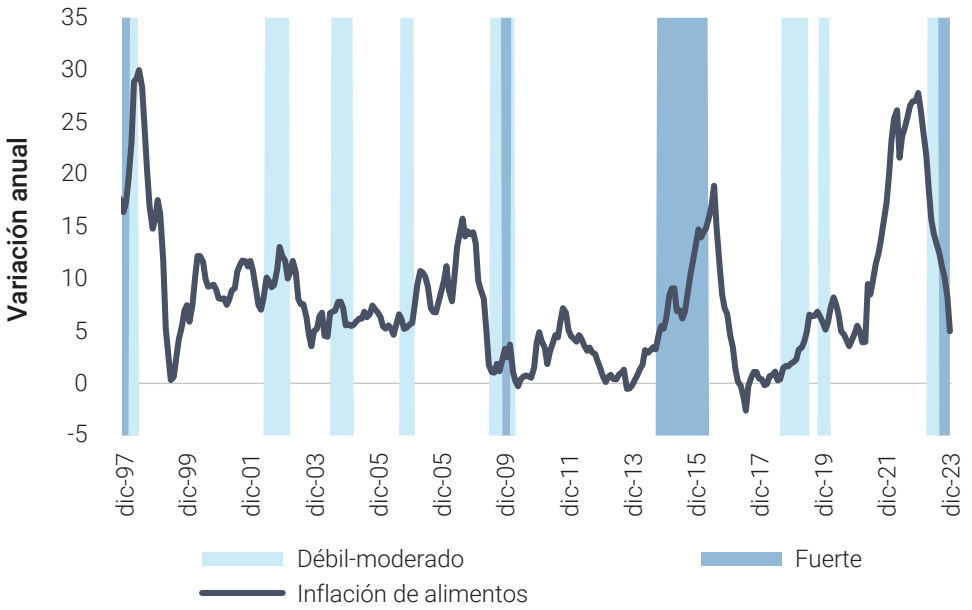

Figure 4. Food inflation and El Niño phenomenon. Data: NOOA, DANE.
Sources: Adapted from Corficolombiana, energy sector dynamics report (2023). https://investigaciones.corficolombiana.com/documents/38211/0/informe-dinamica-sectorial- energia-diciembre-2023.pdf

Figure 4 describes the annual variation of food inflation over time, from December 1997 to December 2023. The lower part shows periods associated with the El Niño phenomenon, distinguishing between events of weak to moderate intensity and a strong event. Thus, it is possible to analyze how there are inflation peaks for the periods of the climatic events in 2015 of 6.77% and in 2023 of 9.28%, the latter being the highest in almost 30 years, reaching its maximum in December.

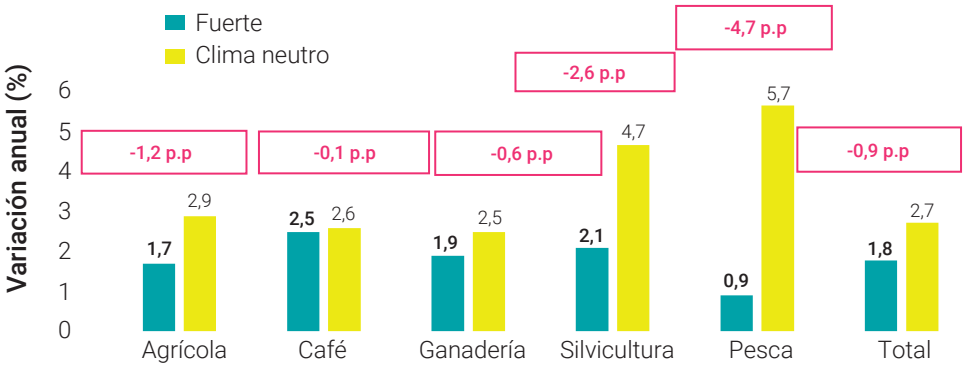

Figure 5. GDP growth of the Agro sector in periods of the Strong El Niño phenomenon (2006 - 2023). Data: DANE, NOOA.

Sources: Adapted from Corficolombiana, Investigaciones económicas El Niño Phenomenon surprises in intensity and duration (2024). https://investigaciones.corficolombiana.com/documents/38211/0/20242901.pdf/cbc4daa2-51d9-4fbd- 4c74-99c1e9316be5

Figure 5 analyzes how the Gross Domestic Product (GDP) of different agricultural subsectors has changed over the years, both in periods of "neutral weather" and during a "strong El Niño". GDP growth in most of the subsectors tends to be lower or even negative, such as agriculture with 1.2pp, during periods of strong El Niño compared to periods of neutral weather; particularly in the Forestry and Fishing subsectors with a decrease in growth during strong El Niño, indicated by 4.7 pp, 2.6 pp, showing that the agricultural sector is also negatively affected during strong El Niño.

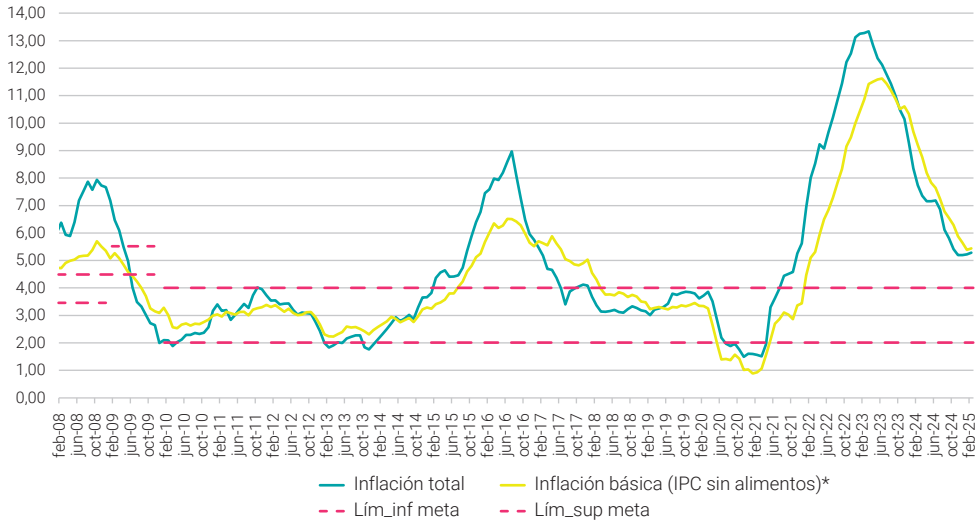

Figure 6. Total and core inflation* (excluding perishable and processed foods). Data: CPI, Board of Directors of Banco de la República and DANE.

Sources: Adapted from the Technical Department and Economic Information of the Banco de la República(2025).https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.banrep.gov.co%2Fsites%-2Fdefault%2Ffiles%2Fpaginas%2Fbie.xls

Figure 6 shows total and core inflation (excluding food) in Colombia from 2008 to the beginning of 2025, comparing it with the upper and lower limits of the inflation target proposed by Banco de la República. In 2009, inflation was declining after having reached very high levels in previous years, and was approaching the target range. By 2015, total inflation began to trend upwards, surpassing 8% in 2016, due to factors such as the peso devaluation and the El Niño phenomenon, which affected food and energy prices. After this peak, inflation began to decline and stabilized in the following years. In 2023, a new considerable increase in inflation is observed, reaching values above 13%, reflecting inflationary pressures derived from external and internal factors. Finally, by 2024, inflation shows a downward trend, although it is still above what is considered ideal, indicating that El Niño probably affected price stability in the country at this time.

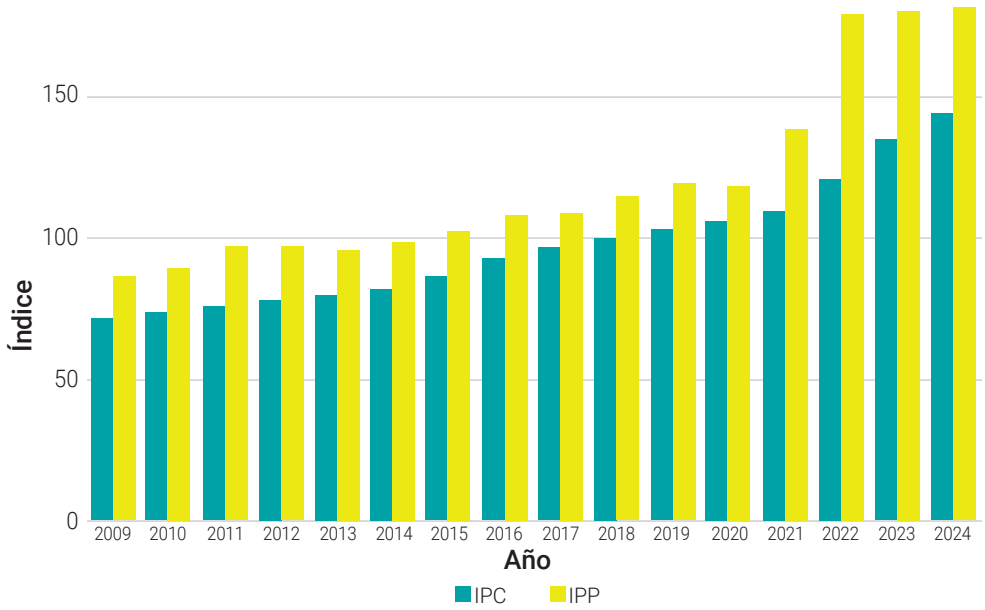

Figure 7. Consumer Price Index (CPI) vs Producer Price Index (PPI) 2009 - 2024. Data: DANE and Banco de la República.
Source: DANE and Banco de la República: Own elaboration.

Likewise, Figure 7 shows the change between the Consumer Price Index (CPI) and the Producer Price Index (PPI) in Colombia from 2009 to 2024. For 2009, the CPI was 71.15 and the PPI was 85.25. When the weather event arrives in 2015, the CPI rose to 97.78 and the PPI to 108.01, showing an increase in both indicators. In 2016, with the continuation of the phenomenon, the CPI rose slightly to 101.58, while the PPI dropped to 107.07. The years 2023 and 2024, also marked by the El Niño phenomenon,

present a significantly higher CPI, reaching 179.23 and 179.89 respectively. The PPI in these years stands at 142.88 for 2023 and 133.9 for 2024. The data suggest that these periods also coincided with increasing inflationary pressure and this was reflected in the increase in the CPI and PPI. It is important to note that the El Niño phenomenon may affect food and energy prices, which has a direct effect on the CPI.

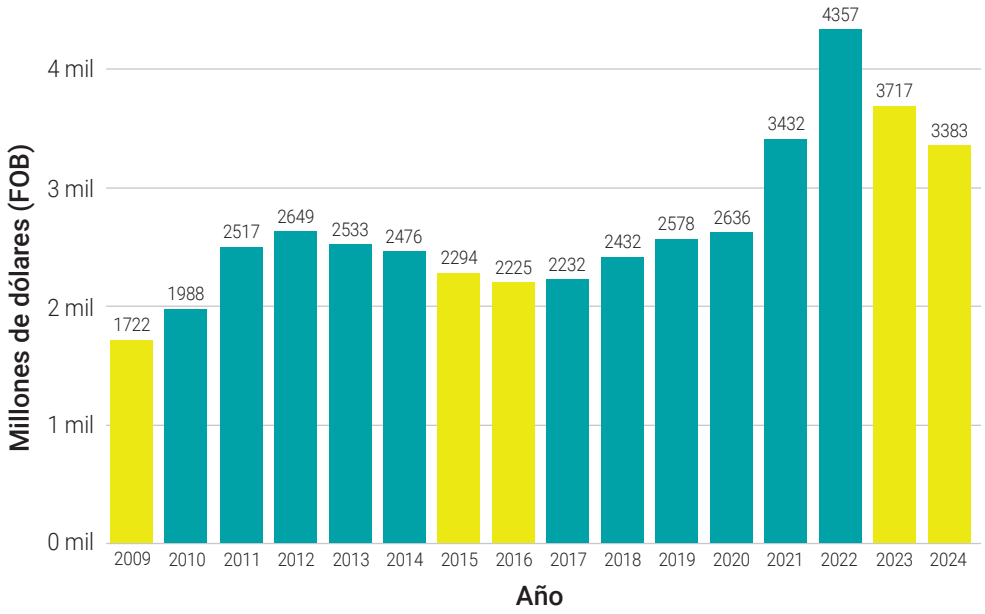

Figure 8. Imports in the Agriculture, livestock, hunting and forestry sector 2009 - 2024. Data: Banco de la República.
Sources: Banco de la República: Own elaboration.

On the other hand, imports of the agricultural sector are influenced by the effect of El Niño, for example, in 2009, there was a movement of 1722 million dollars. In 2015, they reached 2294 million dollars, with a decrease of 7.35% compared to 2014 and for 2016, it dropped by 3.01%. In 2023, it registered a high peak of 3717 million dollars, however, a 14.69% decrease was presented with respect to 2022 and in 2024, it also showed a decrease of 8.99%. (see Figure 8). In Colombia's exports by tariff in the categories of Live animals, Animal or vegetable fats and oils, Fish and crustaceans, mollusks and aquatic invertebrates, and Meat and edible offal, these products were chosen due to the variability they showed during the El Niño episodes.

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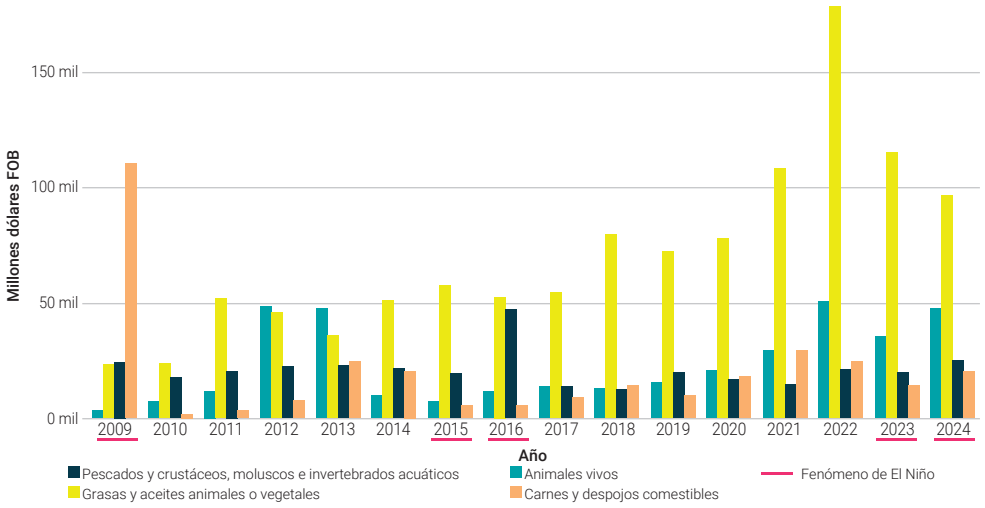

Figure 9. Exports by tariff in Colombia (Meat and oils). Data: DANE.
Sources: DANE: Own elaboration.

Figure 9 shows a decrease of 98.15% for meat and offal in 2010 compared to 2009, and the trend continues from 2015 to 2016 with another decrease of 73.17%. However, for the period from 2023 to 2024, there was an increase of 30.36%. The other products remain on the rise, with slight fluctuations over the years, with the exception of Fish which invoiced $47.488 Million Dollars (FOB) over the $5.510 Million Dollars of the previous year, a considerable increase of 761.85% during the El Niño period in 2016. Fats went from 2022 to 2023 from $178,115 Million to $115,052 Million, down 35% and by 2024, down another 16.12%.

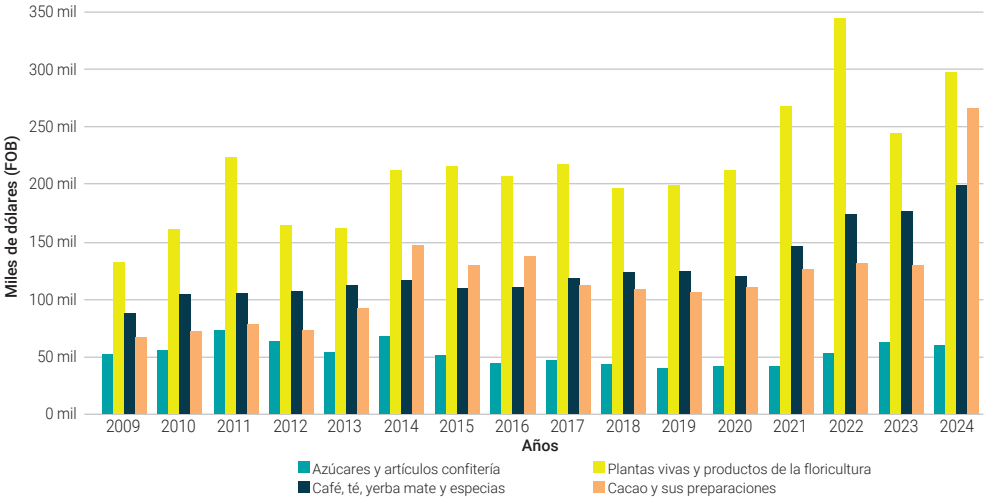

Figure 10. Exports of Sugar, Coffee, Floriculture and Cocoa 2009 - 2024. Data: DANE, Bank of the Republic.
Sources: DANE, Banco de la Republica: Own elaboration.

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Likewise, in Figure 10, the variables of sugar and confectionery, live plants and floriculture, cocoa and its preparations, and coffee, tea, and yerba mate were chosen as the products that present the most stable and reliable data for the research. For example, cocoa and flowers had a drop of 11.6% and 5.59% respectively for 2015 to 2016, but rose 5.97% and 1.49% and for 2023 to 2024, cocoa and its derivatives rose 106.04%. Coffee on the one hand between 2015 to 2016 fell by 4.3% and by 2023 fell by 28.95%, generating losses of almost $100,000 for the country. Sugars fell between 2015 to 2016, 12.5% and 2023 to 2024, 3.89%. Interestingly, live plants increased their export by 1.49% for the El Niño 2015 period and 12.79% for El Niño 2023.

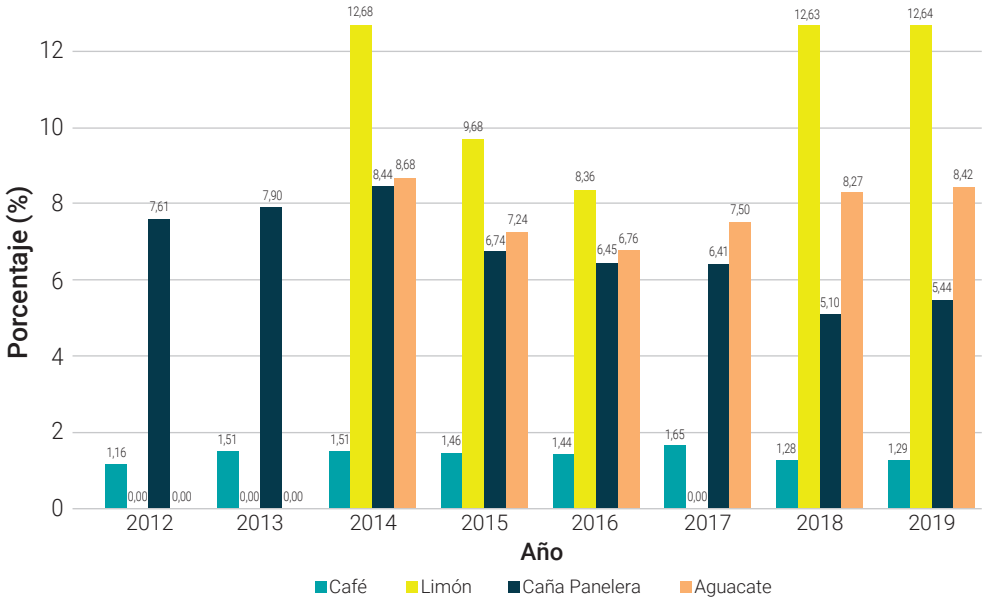

Figure 11. Yield (t/ha) Coffee, Lemon, Sugarcane, Panelera and Avocado by year. Data: DANE.

Sources: Own elaboration.

Figure 11 deals with the yield (t/ha) of lemon, coffee, sugarcane and avocado from 2012 to 2019, these data were taken due to the scarce data from DANE related to other agricultural products of permanent or transitory crops that show significant variations during a longer period of time. For the years 2014 to 2016, it is noted how there was a decrease in all yields, with 0.4%, 3%, 1.8% and 1.4% in their respective order from 2014 to 2015 and 0.02%, 1.3%,0.3% and 0.5% from 2015 to 2016. The most stable crop is coffee.

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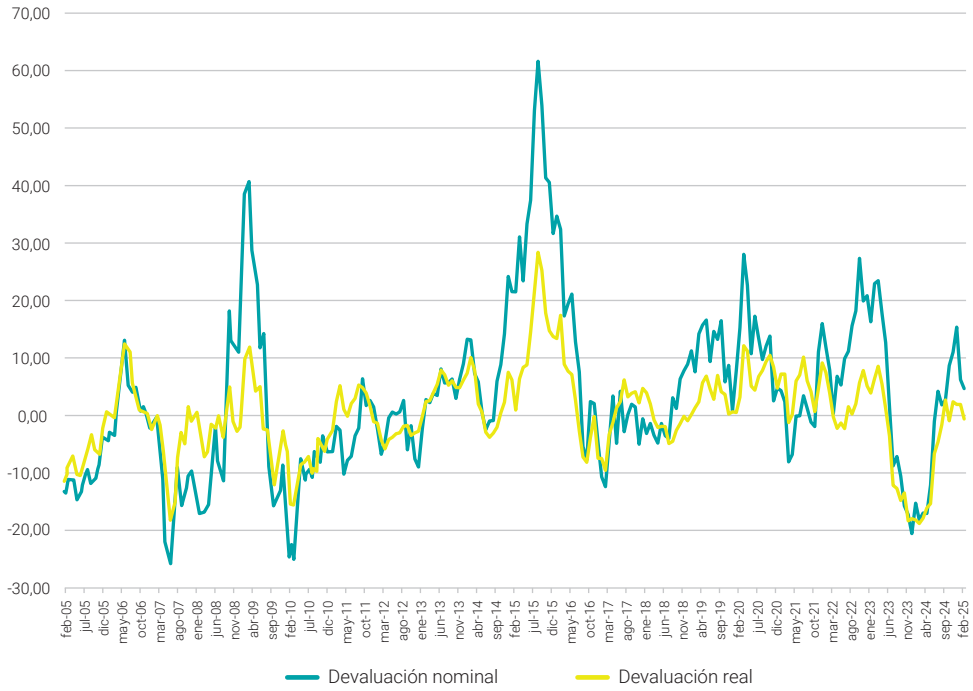

Figure 12. Nominal and real devaluation, 2005 - 2025. Data: "Nominal devaluation obtained from annual variation of market representative rate, certified by Superfinanciera. Real devaluation obtained from ITCRP - IPP."

Sources: Adapted from the Technical Department and Economic Information of Banco de la República (2025) https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.banrep.gov.co%2Fsites%2Fdefault%2Ffiles%2Fpaginas%2Fbie.xls

Figure 12 analyzes the evolution of nominal and real devaluation in Colombia from 2008 to the beginning of 2025. In 2009, there is a peak in nominal devaluation, with strong fluctuations, while real devaluation maintains a more stable behavior. In 2015, nominal devaluation reaches its highest point exceeding 50%, indicating a strong depreciation of the Colombian peso. In 2016, both indicators began to decline after the exchange rate crisis of the previous year. In 2023, new episodes of volatility are evidenced, with increases in both lines, suggesting pressures on the exchange rate. By 2024, nominal devaluation continues to show abrupt variations, while real devaluation, although less volatile, reflects a similar behavior, indicating persistent instability.

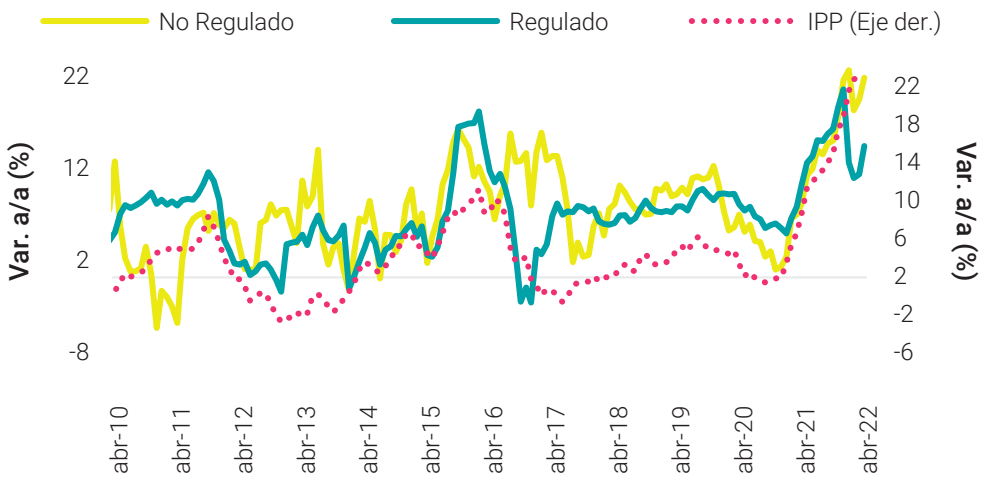

Figure 13. Growth of energy prices and the PPI. Data: XM and DANE.

Sources: Adapted from Corficolombiana, energy sector dynamics report (2023). https://investigaciones.corficolombiana.com/documents/38211/0/informe-dinamica- sectorial-energia-diciembre-2023.pdf.

Figure 13 shows the annual variation in percentage of energy prices for the unregulated and regulated market, compared to the annual variation of the Producer Price Index (IPP), the latter referenced on the right axis. Energy prices in both the unregulated and regulated markets experienced significant fluctuations over the period from approximately April 2010 to April 2015 to April 2022. In general, variations in unregulated energy prices tend to be more pronounced than those in the regulated market. The dotted line represents the annual variation of the PPI, showing a trend that is related to movements in energy prices.

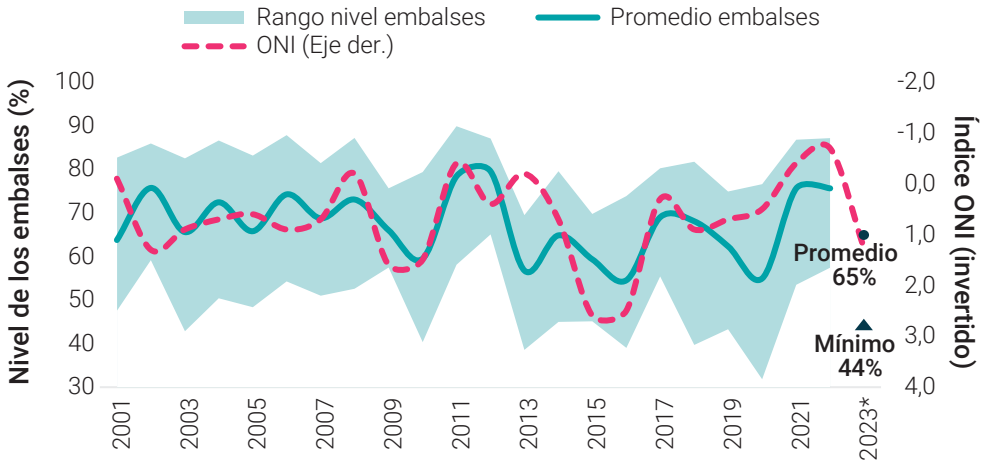

Figure 14. Reservoir levels and Oceanic Niño Index (ONI). Data: XM.

Sources: Adapted from Corficolombiana, energy sector dynamics report (2023). https://investigaciones.corficolombiana.com/documents/38211/0/informe-dinamica- sectorial-energia-diciembre-2023.pdf.

Figure 14 illustrates the evolution of reservoir levels in Colombia (left axis, percentage) and the inverted Oceanic Niño Index (ONI) (right axis) from approximately 2001 to 2023. The blue line represents the average reservoir level, while the dashed red line corresponds to the inverted ONI. The shaded areas indicate the variability range of reservoir levels.

In 2009, the average reservoir level remained relatively high, above 80%, although it declined to approximately 60% by the end of 2010, suggesting an impact associated with the presence of the El Niño phenomenon. Toward the end of 2015, reservoir levels exhibited a downward trend, although they remained above 65%. However, the inverted ONI showed a marked decline, reaching more pronounced negative values, indicating the strengthening of the El Niño phenomenon.

By 2023, reservoir levels experienced a more significant reduction, reaching a historic low of 44%, while the inverted ONI reached even lower negative values than those recorded in 2015. These results suggest that the intensity of the 2023 El Niño event was greater than that observed during 2015 and was strongly correlated with the reduction in reservoir levels.

4. DISCUSSION AND CONCLUSIONS

The results obtained demonstrate that Colombia's economic system is significantly influenced by natural phenomena such as El Niño. The analysis of Colombia's trade balance between 2009 and 2024 indicates that food inflation increased by 6.77% in 2015 and by 9.28% in 2024. Likewise, agricultural GDP growth was lower during periods when El Niño had a greater impact, with reductions of 1.2 and 2.6 percentage points, respectively. These findings suggest a decline in agricultural production resulting from severe droughts and disruptions in crop cycles, consistent with the studies conducted by Iizumi et al. regarding maize yields and by Gutiérrez concerning rice exports.

Although an attempt was made to verify the yield behavior of maize and rice crops in Colombia, insufficient historical information was available from governmental sources to establish a continuous series from 2009 to 2024. Nevertheless, Figure 11 presents data for lemon, coffee, sugarcane, and avocado crops, both permanent and transitory, which recorded impacts of 0.02%, 1.3%, 0.3%, and 0.5%, respectively, between 2015 and 2016.

On the other hand, sugar and coffee exports can be considered relatively stable products within international markets, as shown in Figure 9. Coffee represented 28.95% of exports in 2023, coinciding with the onset of the El Niño phenomenon. In

contrast, meat exports declined from 98.15% during the 2009–2010 period to 73.17% during 2015–2016, a situation associated with significant livestock losses caused by prolonged droughts and severe water stress conditions.

Furthermore, Figure 1 reveals trade balance deficits during the years affected by the climatic phenomenon, suggesting that restrictions in domestic production and increases in imports contributed to the deterioration of Colombia's trade balance, consistent with the findings of Abril, Melo, and Parra [39]. Additionally, Figure 12 illustrates changes in both nominal and real exchange rate depreciation, reflecting a scenario of limited exchange-rate incentives associated with inflationary pressures and imbalances in commodity supply and demand, substantially influenced by the El Niño phenomenon.

This relationship has also been highlighted by Cashin, Mohaddes, and Raissi in their studies published in 2015 and 2016, as well as by Schober and Martin in 2023, who emphasize that the consequences of El Niño extend beyond local impacts and generate significant international repercussions. Finally, Figure 14 provides evidence of the relationship between the Southern Pacific oscillation, its warm phases, and reservoir levels in Colombia, which tend to decline during the most intense periods of the phenomenon. This behavior may be associated with increases in energy prices and a greater tendency to import energy, as reported by Correa Flórez et al. in their 2024 study and by the Banco de la República in its 2018 report.

Based on these findings, it can be concluded that the El Niño phenomenon has a direct relationship with fluctuations in Colombia's trade balance. Trade imbalances intensified during 2015, 2019, and 2023–2024, reaching deficits of up to USD 15.5 billion and particularly affecting sectors highly dependent on climatic conditions, such as agriculture and energy.

During the most intense episodes of the phenomenon, exports of meat products and the yields of both transitory and permanent crops, such as sugarcane, were negatively affected by 73.17% and 5%, respectively. Likewise, exports of products such as cocoa and sugar declined by 11.6% and 12.5%, respectively. At the same time, imports associated with the agricultural and energy sectors increased, including fossil fuel imports used to compensate for the impacts of the phenomenon on energy production.

This situation may indirectly contribute to climate change and, consequently, to an increase in both the frequency and intensity of future El Niño events, reinforcing the need for public policies and adaptation strategies aimed at reducing the vulnerability of the Colombian economy to extreme climatic events.

Secondly, some sectors, such as coffee exports, were less affected by the El Niño phenomenon, demonstrating greater resilience to its impacts. Coffee exports increased by USD 300,000 (FOB) during this period, contributing to the stabilization of the trade deficit by the end of 2023. Despite the information and recommendations provided by the Ministry of Environment [40], the results indicate that substantial efforts are still required to strengthen Colombia's agricultural and forestry sectors. Furthermore, it is necessary to develop and implement more effective adaptation strategies to reduce economic vulnerability to extreme climatic events and mitigate their medium- and long-term impacts on the trade balance.

The findings of this research provide valuable inputs for future studies related to the effects of extreme climate-related phenomena on the agricultural and livestock sectors, particularly regarding their influence on trade flows between territories. First, future research should analyze the adoption of agricultural and livestock climate insurance mechanisms aimed at protecting small and medium-sized producers against losses caused by extreme climate variability. Second, it is important to examine sustainable financing alternatives for energy infrastructure projects that can mitigate the effects of water stress on irrigation systems and agro-industrial transformation processes. Finally, future studies should explore the incorporation of advanced technologies for the development of early warning systems and agroclimatic planning tools, integrated with institutional information systems and real-time data generated through generative artificial intelligence. These technologies could support decision-making processes in the most significant production chains associated with Colombia's exports under extreme climate scenarios.

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