Modelling low-carbon transitions in Colombia: macrofinancial opportunities and risks

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Applications of the GEMMES Model

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In January 2023, the Colombian government announced an end to new oil and gas exploration permits, while ensuring the continued exploitation of previously granted permits. It has made ecology, particularly climate, one of the cornerstones of its mandate. While all countries are now concerned by ecological transitions, these can nevertheless **affect productive and financial spheres in unequal ways**, depending on the structure of the economy and trade. Countries that rely heavily on **extracting and exporting natural resources are more likely to be affected by financial and economic imbalances when these exports decline due to reduced global demand or as a result of national dynamics.**

Colombia is no exception. While some of its neighbours (Venezuela, Brazil) are bigger oil producers, black gold nonetheless accounts for over a third of its exports, and Colombia is responsible for 1% of global oil production. The country is also the fifth-largest exporter of coal, 90% of it being sent to the United States. Altogether, hydrocarbons account for 55% of Colombia's exports, or USD 41 billion. They significantly affect government revenues, contributing 15% through taxes, Ecopetrol dividends, and "*regalías*" (royalties), with the oil industry alone accounting for 8% of total tax revenue (USD 4.5 billion) and representing a significant proportion of local authorities' investment capacity through the royalties system.

The economic literature has highlighted the consequences of such a concentration of a country's income on the exploitation of a single resource, a phenomenon also known as the "Dutch disease" (Corden, W. M. and Neary, J. P.,1982). In many countries, discoveries of hydrocarbon reserves and their extraction have led to a significant increase in exports, a concentration of foreign direct investment (FDI) in these sectors, and an appreciation of the currency (the peso in the case of Colombia), reducing the competitiveness of industrial exports and leading to an unfortunate deindustrialisation. In Colombia, this syndrome seems to have crystallised during the country's transition from an agro-export model to its current mining-export model. Moreover, Colombia has also grappled with the financial dimensions of the "Dutch disease," (Botta, A., Godin, A., and Missaglia, M.,2016) with the surge in foreign investment, particularly targeting the mining and energy sectors, exacerbating the appreciation of the peso. This dynamic emphasised the country's vulnerability to boom-and-bust cycles, driven by global commodity price fluctuations and shifting investor interests. Despite a period of peso depreciation following its earlier appreciation during the commodity boom of 2004-2014, this adjustment did not reverse the deindustrialisation trend that was underway, with a weak recovery of manufacturing exports. This scenario indicates the need for the country to stabilise capital flows and escape this trap without suffering too many injuries. Hence the need for a "Colombian cure" to the "Dutch disease." Using revenues from natural resources to further support a diversification strategy could partially help rebalance the country's development strategy. The Colombian economy therefore exhibits transition risks potentially emerging from the progressive reduction in exports of natural resources as a result of national decisions or a fall in global demand, which manifest in different dimensions such as the fiscal stance, the external balance, the real economic activity and the financial sphere.

Given that a voluntary or involuntary **move away from fossil fuels requires considerable effort on the part of the country and may induce significant macrofinancial instabilities**, this book aims to shed empirical light on this issue, based on the generation and evaluation of different scenarios. The main tool used for this purpose is presented in Chapter 2: the GEMMES (General Monetary and Multisectoral Macrodynamics for the Ecological Shift) macroeconomic model. It complements the results of other existing models, with the aim of **integrating and testing different Colombian public policies in the context of the country's energy transition and the global low-carbon transition**. To do so, special consideration is given to the country's economic structure and mode of integration in international financial markets (see Chapter 1).

Consequences of external economic shocks in Colombia

In this book, the GEMMES Colombia model is first used to analyse the effects of external economic shocks, such as **the possible reduction of global demand for fossil fuels due to current and future low-carbon transitions around the world.** The recent COP28 decision to draw up a roadmap to transition away from fossil fuels strengthens the probability of such dynamics. The results of the GEMMES model show that reduced external demand could further unbalance Colombia's current account. The scenarios highlight that if the trade deficit were to persist, it would reduce the foreign currency reserves, affecting the financing of imports and other payments in foreign exchange. This would exert pressure on exchange rates, resulting in a significant depreciation of the Colombian peso. Such a loss in the value of the national currency could encourage a flight of foreign capital, leading to an increase in interest rates, which would raise the cost of national debt (see Chapter 3) and add further depreciation pressures on the peso.

The impact of a shock to external demand for fossil fuels would **affect the Colombian population**. This would likely result in increased prices for imported goods and services, thereby creating inflationary pressures and diminishing purchasing power. In socioeconomic terms, a drop in export revenues, combined with downward pressure on global fossil fuel prices, could lead to higher unemployment and a greater need for social transfers, particularly for workers in the extractive sectors and sectors with strong productive linkages with them. This situation could also slow economic growth and reduce government revenues, leading to an increase in the budget deficit and, by extension, in public debt, which has already been deepened by the abovementioned exchange rate dynamics.

In addition to analysing the macroeconomic consequences of reduced Colombian hydrocarbon exports following a global low-carbon transition, the **book offers a simulation of two other types of external economic shock: the downgrading of Colombia's credit rating and the default of the Chinese property giant Evergrande (see Chapter 5)**. The results highlight the vulnerabilities of the Colombian economy to international dynamics.

Energy transition in Colombia: strategy and financing

Beyond addressing external economic shocks, Colombia **needs to align its national goals, especially that of achieving a just and inclusive energy transition**. To realise this objective and maintain fiscal, monetary, and social sustainability, the government intends to orchestrate its **transition around five key pillars**: increasing investment in clean energy and decarbonisation; planning the transition to alternatives to fossil fuels; improving energy efficiency; reviewing regulations to accelerate clean energy production; and reindustrialising the economy.

Colombia, while ranking as the sixth most advanced nation in Latin America in terms of the energy transition according to the World Economic Forum's Energy Transition Index,[1] and 12th in the world in hydroelectric production capacity, faces **two significant challenges** within the current international landscape in order to achieve a successful energy transition. The first challenge is securing the necessary **energy resources for this transition, and the second involves devising effective financing strategies to implement it.**

Regarding its capacity to produce energy, Colombia is experiencing a decline in its oil and gas reserves. This decline is already resulting in a decrease in the volume of extraction of these resources. Consequently, it poses a threat to the ongoing export of hydrocarbons and the ability to meet domestic demand, which is rising for petroleum-based fuels. This latter trend has led to a significant decrease in exports of diesel (by 20.3%) and gasoline (by 96.0%). Although coal reserves in Colombia are substantial, estimated at approximately 4.55 billion tonnes and anticipated to last around 52 years (during which time global demand is expected to decline), the situation is more critical for oil and gas resources. With only about 7.1 years of oil and 6.5 years of gas production remaining, these resources are considerably more limited.

Thus, **further expansion of renewable energies and electricity-based infrastructure is critical.** Colombia needs to enhance its general electrification programme, which could rely on biomass, wind, geothermal, and solar power—currently representing just 1% of the country's electricity mix—and hydroelectricity, which constitutes 70% of the mix. This strategy comes against the backdrop of a favourable international context characterised by falling costs for these energies. It will also help avoid future imports of fossil fuels and contribute to achieving the objectives of the National Energy Plan (2022–2052), which calls for 19 gigawatts (GW) of non-conventional renewable energy capacity by mid-century.

On the other hand, **financing a domestic energy transition remains a major challenge for the country** given the current economic indicators: inflation of 7% and above the central bank's target range, albeit on a downward path, unemployment around 10%, net public debt of the Central National Government at 58% of GDP, and the unfavourable international environment for attracting foreign capital. At the same time, the current

1. The World Economic Forum (WEF) scores reflect the performance of energy systems and the readiness of each country for the transition to a low-carbon economy.

fiscal policy framework aiming to a debt-to-GDP ratio not exceeding 55% exerts a further constraint. In this book, the GEMMES Colombia model is used to analyse the financing policies of the country's climate mitigation and adaptation plans, emphasising the macroeconomic consequences of the investment required to implement the Nationally Determined Contribution (NDC) (see Chapter 4). In particular, the model highlights the importance of using a combination of private investment and green financing instruments to finance the country's climate ambitions, which aim to reduce greenhouse gas (GHG) emissions by at least 51% by 2030.

Towards economic diversification

The external economic shocks mentioned above and the internal energy transition require a transformation of the country's production and export structures. In this respect, **by identifying the limits of an extraction-based economy, the book shows the importance of diversifying the economy, based on renewable energies, the strengthening of the manufacturing and high-value service activities and the sustainable use of biophysical resources**. One way of diversifying the Colombian economy could be through incentives to increase agricultural production. Such a reorientation could **reduce the country's current dependence on food imports** and thus contribute to its food sovereignty. While a reduction in exports weakens the currency, a successful substitution of imports by nationally produced goods would strengthen the peso. The sectoral analysis proposed in the book (see Chapter 6), based on an input-output matrix, also highlights the importance of the **industrial and tourism sectors** as key levers for reducing economic dependence on the extractive sector.

More specifically, this search for alternatives requires **industrial development focusing on the creation of new value chains for low-emission products**. This involves collaborating with countries that have strong political and economic ties to Colombia, a concept known as **"friendshoring."** Additionally, it requires the gradual integration of the Colombian economy into **global value chains**, which will involve technological upgrading and the development of domestic capabilities. This process aims not only to strengthen the country's position on the world market but also to move towards the goal of **energy and technological sovereignty.**

This exploration of alternatives must account for the fact that a substantial portion of the value in non-fossil fuel exports in fact relies on imports. This highlights **the importance of investing in local production of necessary raw materials and components for these exports ("reshoring").**

Green hydrogen may also be incorporated into the country's industrial and energy matrix, since **global demand for hydrogen is expected to grow.** This option would however require solutions to a number of challenges: mode of transport, high water consumption, lack of a value chain and of a regulatory framework. Finally, **diversification of the mining matrix** is also vital. The National Development Plan (2022–2026) already proposes to focus on the exploration, extraction, and formal marketing of strategic minerals or alloys such as copper, nickel-iron, cobalt, lithium, and molybdenum. The plan also includes measures to ensure compliance with environmental standards and to implement community participation procedures in the areas of influence of potential mines.

Fruitful technical cooperation

This book is the result of **six years of fruitful technical cooperation** between the National University of Colombia (UNAL), two Colombian government bodies—the Ministerio de Hacienda y Crédito Público (MHCP) (Ministry of Finance and Public Credit) and the Departamento Nacional de Planeación (DNP) (National Planning Department)—and the Agence Française de Développement (AFD) (French Development Agency). The model's ability to analyse the country's macroeconomic and energy situation makes it an indispensable tool for these partners and those involved in managing economic vulnerabilities and identifying the opportunities arising from the current transitions.

AFD, as part of its **research embedded in decision-making** approach, supported this entire project in two ways. The first, institutional, strengthened the capacities of the DNP and the MHCP in developing the GEMMES model. The second, academic, made it possible to build a conceptual and methodological framework in partnership with UNAL, which has constructed a reference framework for analysing fiscal, external, and monetary vulnerabilities linked to the low-carbon transition.

In this way, the GEMMES Colombia model, enriched by academic expertise and integrated into decision-making processes through collaboration with local ministries, is now an effective tool for **public policy dialogue**. Today, these exchanges have continued, and they are fuelled via the GEMMES strategic committee comprising the MHCP, the DNP, the Ministerio de Minas y Energía (MME) (Ministry of Mines and Energy), and the Banco de la República.

Furthermore, at the request of the Colombian authorities, GEMMES has now been integrated into the MHCP's range of macroeconomic models and will soon be coupled with other tools, mainly energy models. Building on previous efforts, these works will help shape Colombia's more resilient and sustainable future, illustrating the **power of applied research in resolving critical contemporary issues.**

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En enero de 2023, el gobierno de Colombia declaró la suspensión de la otorgación de nuevas licencias para la exploración de petróleo y gas, asegurando simultáneamente la continuidad y validez de las licencias previamente concedidas. El medio ambiente, y particularmente el cambio climático, se ha convertido en una piedra angular de su mandato. Aunque en la actualidad todos los países se **ven afectados por transiciones ecológicas, éstas pueden sin embargo afectar de manera desigual** a las estructuras productivas y financieras, en función de la estructura de la economía y de los intercambios comerciales. Los países con una fuerte dependencia en **extracción y exportación de recursos naturales tienen más probabilidades de verse afectados por desequilibrios financieros y económicos ante una reducción de estas exportaciones, provocada tanto por una disminución de la demanda global como por cambios en la dinámica interna.**

Colombia no está exenta de esta realidad. Aunque no es un gran productor de petróleo en comparación con sus vecinos Brasil y Venezuela, el oro negro representa sin embargo más de un tercio de sus exportaciones, y Colombia es responsable del 1% de la producción mundial de petróleo. El país es también el quinto exportador mundial de carbón, el 90% del cual se destina a Estados Unidos. En total, los hidrocarburos representan el 55% de las exportaciones colombianas, es decir, 41.000 millones de dólares. Tienen un impacto significativo en los ingresos del gobierno, contribuyendo en un 15% a través de impuestos, dividendos de Ecopetrol y regalías, representando la industria petrolera por sí sola el 8% de los ingresos fiscales totales (4.500 millones USD) y una parte importante de la capacidad de inversión de las autoridades locales a través del sistema de regalías.

La literatura económica ha destacado las consecuencias de tal concentración de los ingresos de un país en la explotación de un único recurso, fenómeno también conocido como "enfermedad holandesa" (Corden, W. M., y Neary, J. P., 1982). En muchos países, el descubrimiento y la extracción de reservas de hidrocarburos ha provocado un aumento significativo de las exportaciones, una concentración de la inversión extranjera directa (IED) en estos sectores y una apreciación de la moneda (el peso en el caso de Colombia), lo que ha disminuido la competitividad de las exportaciones industriales y llevado a una desindustrialización.

En Colombia, este fenómeno se ha manifestado durante la evolución del país desde un modelo basado en la exportación de productos agrícolas hacia su actual enfoque en la minería y exportación de recursos naturales. Además, el país ha experimentado las consecuencias financieras de la "enfermedad holandesa" (Botta, A., Godin, A., y Missaglia, M.,2016), en las que el incremento de la inversión extranjera directa, particularmente en los sectores de minería y energía, ha intensificado la revaluación del peso. Esta situación ha evidenciado la susceptibilidad del país a los ciclos económicos de auge y declive, motivados por los cambios en los precios internacionales de las materias primas y los cambiantes intereses de los inversores. A pesar de que el peso experimentó una depreciación después de su apreciación durante el boom de 2004-2014 de las materias primas, dicho ajuste no ha logrado revertir el proceso de desindustrialización, y el sector manufacturero este ajuste no invirtió las tendencias de desindustrialización en curso, y el sector manufacturero sigue padeciendo de una débil recuperación de las exportaciones manufactureras. Este contexto subraya la urgencia de que Colombia estabilice los flujos de capital y salga de esta encrucijada con el mínimo perjuicio posible. Por ello, surge la necesidad de hallar una "solución colombiana" para contrarrestar la "enfermedad holandesa". Reinvertir los ingresos de los recursos naturales en una estrategia de diversificación económica podría ser clave para reorientar el modelo de desarrollo nacional. De esta forma, la economía de Colombia se encuentra ante riesgos de transición relacionados con la disminución progresiva de las exportaciones de recursos naturales, ya sea por decisiones internas o por una caída en la demanda global, que se manifiesta por diferentes vectores como la orientación fiscal, la balanza exterior, la actividad económica real y la esfera financiera.

Dado que un alejamiento de los combustibles fósiles **requiere un esfuerzo considerable por parte del país y puede inducir importantes inestabilidades macrofinancieras**, este libro pretende aclarar empíricamente esta cuestión, a partir de la generación y evaluación de diferentes escenarios. La herramienta principal para este propósito se detalla en el Capítulo 2: el modelo macroeconómico GEMMES (General Monetary and Multisectoral Macrodynamics for the Ecological Shift). Esta herramienta complementa los resultados de otros modelos existentes, con el objetivo de **integrar y evaluar diferentes políticas públicas de Colombia en el marco de su transición energética y de la transición global baja en carbono**. Para este análisis, se toma en cuenta especialmente la estructura económica del país y su grado de integración en los mercados financieros internacionales (véase el Capítulo 1).

Consecuencias de los choques económicos externos en Colombia

En este libro, el modelo GEMMES Colombia se utiliza en primer lugar para analizar las consecuencias de choques económicos externos, **como el riesgo de una reducción de la demanda mundial de hidrocarburos originado por las transiciones hacia una economía baja en carbono que se están llevando a cabo actualmente y se prevén para el futuro a nivel mundial**. La reciente resolución de la COP28 de diseñar un plan para el abandono progresivo de los combustibles fósiles intensifica la expectativa de que se desarrolle una dinámica de este calibre. Hallazgos del modelo GEMMES indican que una disminución en la demanda internacional podría generar un desequilibrio mayor en la balanza de pagos de Colombia, subrayando que, de persistir el déficit comercial, se reducirían las reservas de divisas, lo que afectaría a la financiación de las importaciones y otros pagos en divisas. Esta situación ejercería presión sobre el tipo de cambio, conduciendo a una depreciación significativa del peso colombiano. Tal depreciación de la moneda nacional podría incentivar la salida de capitales extranjeros, resultando en un incremento de los tipos de interés y, por ende, en un aumento en el costo de la deuda pública (véase el Capítulo 3), exacerbando aún más la presión de depreciación sobre el peso.

Además, la disminución de la demanda internacional de combustibles fósiles **repercutiría negativamente en la ciudadanía colombiana.** Esto podría traducirse en un encarecimiento de los bienes y servicios importados, generando presiones inflacionarias y una disminución del poder adquisitivo. Desde una perspectiva socioeconómica, una reducción de los ingresos por exportaciones, sumada a una tendencia decreciente en los precios globales de los combustibles fósiles, podría resultar en un incremento del desempleo y en una mayor demanda de transferencias sociales, especialmente en los sectores de extracción, y sectores con fuertes vínculos productivos con ellos. Tal escenario también podría obstaculizar el crecimiento económico y reducir los ingresos públicos, ocasionando un aumento en el déficit presupuestario y, consecuentemente, en la deuda pública, situación que se ve agravada por las dinámicas cambiarias previamente mencionadas.

Adicionalmente, al examinar las repercusiones macroeconómicas de una disminución en las exportaciones de hidrocarburos colombianos debido a una transición global hacia una economía baja en carbono, el libro **también simula otros dos escenarios de choques económicos externos:** la rebaja en la calificación crediticia de Colombia y la moratoria del coloso inmobiliario chino Evergrande (detallado en el Capítulo 5). Estos análisis subrayan la sensibilidad de la economía colombiana a la dinámica internacional.

Transición energética en Colombia: estrategia y financiación

Además de enfrentar choques económicos externos, Colombia debe alinear sus objetivos nacionales, especialmente en lo que respecta a lograr una transición energética **gradual e inclusiva**. Con el fin de alcanzar esta meta y asegurar la sostenibilidad fiscal, monetaria y social, el Gobierno busca organizar su **transición alrededor de cinco pilares fundamentales:** aumentar la inversión en energías limpias y descarbonización; planificar la transición hacia alternativas a los combustibles fósiles; mejorar la eficiencia energética; revisar la normativa para acelerar la producción de energías limpias; y reindustrializar la economía.

Colombia, posicionada como el sexto país más adelantado de América Latina en transición energética según el Índice de Transición Energética del Foro Económico Mundial[2] y el duodécimo a nivel mundial en capacidad de producción hidroeléctrica, enfrenta **dos grandes desafíos** en el contexto internacional actual para asegurar el éxito de su transición energética. El primer reto consiste en garantizar los recursos energéticos necesarios para esta transición, y el segundo, en desarrollar estrategias de financiamiento efectivas para ejecutarla.

En cuanto a su capacidad para producir energía, Colombia está experimentando una disminución de sus reservas de petróleo y gas. Este declive ya se refleja en una reducción del volumen de extracción de estos recursos. Lo anterior, amenaza la continuidad de las exportaciones de hidrocarburos y la capacidad de satisfacer la demanda interna, cada vez mayor, de combustibles derivados del petróleo. Esta última tendencia ha provocado una caída significativa de las exportaciones de gasóleo (-20,3%) y de gasolina (-96,0%). Aunque las reservas de carbón en Colombia son considerables, estimadas en unos 4.550 millones de toneladas y con una duración prevista de unos 52 años (periodo durante el cual se espera que disminuya la demanda mundial), la situación es más crítica en lo que respecta a los recursos de petróleo y gas. Con sólo 7,1 años de

2. Las calificaciones del Foro Económico Mundial (FEM) reflejan el rendimiento de los sistemas energéticos y el grado de preparación de cada país para la transición a una economía baja en carbono.

producción de petróleo y 6,5 años de producción de gas, estos recursos son considerablemente más limitados.

Por lo tanto, es crucial continuar ampliando el espectro de las **energías renovables y acompañar la creación de infraestructuras eléctricas**. Colombia puede acelerar su programa de electrificación, apoyándose en la biomasa, la energía eólica, geotérmica y solar —que hoy día solo constituyen el 1% de la matriz eléctrica del país—, además de la hidroelectricidad, que ya representa el 70% del mix. Esta estrategia se desarrolla en un contexto internacional propicio, marcado por una reducción en el coste de estas energías. Asimismo, facilitará evitar futuras importaciones de combustibles fósiles y será clave para cumplir con los objetivos del Plan Energético Nacional (2022-2052), que anticipa 19 gigavatios (GW) de capacidad en energías renovables no convencionales para mediados de siglo.

Por otra parte, **financiar una transición energética a nivel nacional continúa siendo un desafío considerable para el país**, dados los indicadores económicos actuales: inflación del 7% y por encima del rango objetivo del banco central, aunque en senda descendente, desempleo en torno al 10%, deuda pública neta del Gobierno Nacional Central del 58% del PIB, y entorno internacional desfavorable para atraer capital extranjero. Al mismo tiempo, las normativas que exigen un equilibrio presupuestario estricto y un límite del 55% para la relación deuda pública/PIB imponen una intensa presión fiscal. Este libro emplea el modelo GEMMES Colombia para explorar las estrategias de financiamiento de las políticas de adaptación y mitigación del país, poniendo especial atención en las repercusiones macroeconómicas de las inversiones destinadas a cumplir con la Contribución Determinada a Nivel Nacional (NDC), (véase el Capítulo 4). En especial, el modelo subraya la necesidad de recurrir a una combinación de inversión privada y instrumentos de financiación verde para financiar las metas climáticas del país, que aspiran a reducir las emisiones de Gases de Efecto Invernadero (GEI) en un mínimo de 51% para el 2030.

Hacia una diversificación económica

Los choques económicos externos previamente mencionados, junto con la transición energética doméstica, requieren una reconfiguración de las estructuras productivas y de exportación del país. En este contexto, al señalar los límites de una economía centrada en la extracción, el libro resalta la necesidad de **diversificar la economía, apostando por las energías renovables y el fortalecimiento de las actividades**

manufactureras y de servicios de alto valor así como el uso sostenible de los recursos biofísicos. Una estrategia para diversificar la economía colombiana podría ser el impulso a la producción agrícola. Este enfoque no solo reduciría la actual dependencia de Colombia de las importaciones de alimentos, fortaleciendo su soberanía alimentaria, sino que también, al reemplazar satisfactoriamente las importaciones con productos nacionales, podría reforzar el peso colombiano. Además, el análisis sectorial que se ofrece en el libro, utilizando matrices de insumo-producto (detallado en el Capítulo 6), subraya la relevancia de los **sectores industrial y turístico** como elementos clave para disminuir la dependencia económica de la extracción.

Más específicamente, la búsqueda de alternativas implica un desarrollo industrial enfocado en la creación de **nuevas cadenas de valor para productos con bajas emisiones**. Esto conlleva colaborar con países que mantienen estrechos lazos políticos y económicos con Colombia, en una estrategia conocida como "friendshoring". Además, busca la integración progresiva de la economía colombiana en las cadenas globales de valor a través de la modernización tecnológica y del desarrollo de capacidades en el país. Este enfoque no solo pretende fortalecer la presencia del país en el mercado internacional, sino también avanzar hacia la **soberanía energética y tecnológica.**

Esta exploración de alternativas debe tener en cuenta el hecho de que una proporción sustancial del valor de las exportaciones de combustibles no fósiles depende en realidad de las importaciones. Esto resalta la necesidad de invertir en la producción local de materias primas y componentes necesarios para estas exportaciones, conocido como **"reshoring"**.

El hidrógeno verde también puede integrarse en la matriz industrial y energética del país, dado que **la demanda mundial de hidrógeno está llamada a aumentar**. No obstante, esta alternativa enfrenta desafíos como el método de transporte, el elevado consumo de agua, la falta de una cadena de valor establecida y la ausencia de un marco regulatorio hasta ahora. Por último, la **diversificación de la matriz minera** también es fundamental. El Plan Nacional de Desarrollo (2022-2026) propone centrarse en la exploración, extracción y comercialización oficial de minerales o aleaciones estratégicas como el cobre, el níquel-hierro, el cobalto, el litio y el molibdeno. El Plan también contempla acciones para asegurar la adherencia a las normativas ambientales y para implementar procesos de participación comunitaria en las áreas afectadas por potenciales operaciones mineras.

Una cooperación técnica fructífera

Este libro es el fruto de **seis años de una cooperación técnica fructífera** entre la Universidad Nacional de Colombia (UNAL), dos entidades gubernamentales colombianas –el Ministerio de Hacienda y Crédito Público (MHCP) y el Departamento Nacional de Planeación (DNP)– junto con la Agencia Francesa de Desarrollo (AFD). La capacidad del modelo para analizar la situación macroeconómica y energética del país lo convierte en una herramienta clave para estos socios y para aquellos involucrados en la gestión de las vulnerabilidades económicas y en la identificación de las oportunidades vinculadas a las transiciones en curso.

La AFD, **siguiendo su enfoque de investigación aplicada a la toma de decisiones**, ha respaldado este proyecto de dos formas. La primera, de carácter institucional, permitió reforzar las capacidades del DNP y del MHCP en el desarrollo del modelo GEMMES. La segunda, académica, mediante la creación de un marco conceptual y metodológico en colaboración con la UNAL, que desarrolló un marco de referencia para el análisis de las vulnerabilidades fiscales, externas y monetarias asociadas a la transición baja en carbono.

Como resultado, el modelo GEMMES Colombia, enriquecido por la experiencia académica y adaptado a los procesos de decisión a través de la colaboración con los ministerios locales, se ha transformado en una herramienta efectiva para el diálogo sobre políticas públicas. Actualmente, estos diálogos continúan y se promueven mediante el comité estratégico GEMMES, compuesto por el MHCP, el DNP, el Ministerio de Minas y Energía (MME) y el Banco de la República.

Por solicitud de las autoridades colombianas, GEMMES ha sido integrado en el conjunto de modelos macroeconómicos del MHCP y próximamente se vinculará con otros instrumentos, principalmente modelos energéticos. Basándose en esfuerzos anteriores, esta labor contribuirá a forjar un futuro más resistente y sostenible para Colombia, ilustrando el **poder de la investigación aplicada para abordar problemas contemporáneos críticos.**

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En janvier 2023, le gouvernement colombien a annoncé la fin de l'attribution de nouveaux permis d'exploration pétrolière et gazière, tout en assurant la poursuite de l'exploitation des permis précédemment accordés. Il a fait de l'écologie, et notamment du climat, l'une des pierres angulaires de son mandat. Si tous les pays sont aujourd'hui concernés par les transitions écologiques, celles-ci peuvent **néanmoins affecter les sphères productives et financières de manière inégale**, en fonction de la structure de l'économie et des échanges commerciaux entretenus. Les pays qui dépendent fortement de **l'extraction et de l'exportation de ressources naturelles sont plus susceptibles d'être affectés par des déséquilibres financiers et économiques lorsque ces exportations diminuent en raison d'une baisse de la demande mondiale ou de dynamiques nationales.**

La Colombie n'y fait pas exception. Elle n'est certes, pas un grand producteur de pétrole comparée à ses voisins brésiliens et vénézuéliens, l'or noir représente néanmoins plus d'un tiers de ses exportations, et la Colombie est responsable de 1 % de la production mondiale de pétrole. Le pays est également le cinquième exportateur de charbon, dont 90 % sont destinés aux États-Unis. Au total, les hydrocarbures représentent 55 % des exportations colombiennes, soit 41 milliards de dollars. Ils ont une incidence importante sur les recettes publiques, puisqu'ils y contribuent à hauteur de 15 % par le biais des impôts, des dividendes d'Ecopetrol et des « regalías » (redevances), l'industrie pétrolière représentant à elle seule 8 % des recettes fiscales totales (4,5 milliards d'USD) et une part importante de la capacité d'investissement des autorités locales par le biais du système de redevances.

La littérature économique a mis en évidence les conséquences d'une telle concentration des revenus d'un pays sur l'exploitation d'une seule ressource, un phénomène également connu sous le nom de « mal hollandais » (Corden, W. M., et Neary, J. P., 1982). Dans de nombreux pays, la découverte de réserves d'hydrocarbures et leur extraction ont entraîné une augmentation significative des exportations, une concentration des investissements directs étrangers (IDE) dans ces secteurs et une appréciation de la monnaie (le peso dans le cas de la Colombie), réduisant la compétitivité des exportations industrielles et conduisant à une désindustrialisation préjudiciable.

En Colombie, ce syndrome semble s'être cristallisé lors de la transition du pays d'un modèle agro-exportateur à son modèle minier-exportateur actuel. En outre, le pays a également été confrontée aux dimensions financières du « mal hollandais » (Botta, A., Godin, A., et Missaglia, M.,2016), où l'augmentation des investissements étrangers, en particulier dans les secteurs minier et énergétique, a exacerbé l'appréciation du peso. Cette dynamique a mis en évidence la vulnérabilité du pays aux cycles d'expansion et de récession, induits par les fluctuations des prix des matières premières au niveau mondial et par les intérêts changeants des investisseurs. Bien que le peso ait connu une dépréciation après une phase d'appréciation durant le boom des matières premières de 2004-2014, cet ajustement n'a pas réussi à inverser la tendance de désindustrialisation observée, le secteur manufacturier demeurant pénalisé par la faible reprise des exportations manufacturières. Ce scénario indique la nécessité pour le pays de stabiliser les flux de capitaux et de se libérer de cette situation difficile avec le moins de dommages possible. D'où la nécessité d'un « remède colombien » au « mal hollandais ». Réinvestir les revenus issus des ressources naturelles dans une stratégie de diversification pourrait aider à modifier en partie l'approche de développement du pays. L'économie colombienne présente donc des risques de transition qui se manifestent dans différentes dimensions telles que l'orientation budgétaire, le solde extérieur, l'activité économique réelle et la sphère financière. Ceux-ci sont potentiellement liés à la réduction progressive des exportations de ressources naturelles en raison de décisions nationales ou d'une baisse de la demande mondiale.

Étant donné qu'un éloignement volontaire ou involontaire des combustibles fossiles exige un effort considérable de la part du pays et peut induire d'importantes instabilités macrofinancières, cet ouvrage vise à apporter un éclairage empirique sur cette question, en construisant et évaluant différents scénarios. Le principal outil utilisé à cette fin est présenté dans le Chapitre 2 : le modèle macroéconomique GEMMES (General Monetary and Multisectoral Macrodynamics for the Ecological Shift). Il complète les résultats d'autres modèles existants, dans le but d'intégrer et de tester différentes politiques publiques colombiennes dans le contexte de la transition énergétique du pays et de la transition bas carbone mondiale. La structure économique du pays et son niveau relativement élevé d'intégration dans les marchés financiers internationaux (voir Chapitre 1) sont des aspects particulièrement pris en compte.

Conséquences des chocs économiques externes en Colombie

Dans cet ouvrage, le modèle GEMMES Colombie est d'abord utilisé pour analyser les conséquences de chocs économiques externes comme **le risque de réduction de la demande globale d'hydrocarbures due aux transitions bas carbone en cours et à venir à l'échelle globale**. La récente décision de la COP28 visant à élaborer une feuille de route pour abandonner les combustibles fossiles renforce la probabilité d'une telle dynamique. Certains résultats du modèle GEMMES montrent qu'une réduction de la demande extérieure pourrait déséquilibrer davantage la balance des paiements de la Colombie et soulignent que si le déficit commercial devait persister, ce qui affecterait le financement des importations et d'autres paiements en devises. Cela exercerait une pression à la hausse sur les taux de change, entraînant une dépréciation significative du peso colombien. Une telle perte de valeur de la monnaie nationale pourrait encourager la fuite des capitaux étrangers, entraînant une hausse des taux d'intérêt, ce qui augmenterait le coût de la dette nationale (voir Chapitre 3) et accentuerait les pressions dépréciatives sur le peso.

Par ailleurs, l'impact d'un choc sur la demande extérieure de combustibles fossiles **affecterait la population colombienne**. Il en résulterait une augmentation des prix des biens et services importés, créant ainsi des pressions inflationnistes et une diminution du pouvoir d'achat. Sur le plan socio-économique, une baisse des recettes d'exportation, combinée à une pression à la baisse sur les prix mondiaux des combustibles fossiles, pourrait entraîner une augmentation du chômage et un besoin accru de transferts sociaux, en particulier dans les secteurs extractifs et ceux ayant des liens productifs étroits avec eux. Cette situation pourrait également ralentir la croissance économique et réduire les recettes publiques, entraînant une augmentation du déficit budgétaire et, par extension, de la dette publique, déjà creusée par la dynamique du taux de change mentionnée ci-dessus.

Au-delà de l'analyse des conséquences macroéconomiques liées à la diminution des exportations d'hydrocarbures colombiennes suite à une transition bas carbone globale, **l'ouvrage propose une simulation de deux autres types de chocs économiques externes:** la dégradation de la note de crédit de la Colombie et la défaillance du géant chinois de l'immobilier Evergrande (voir le Chapitre 5). Les résultats mettent en évidence les vulnérabilités de l'économie colombienne aux dynamiques internationales.

Transition énergétique en Colombie : stratégie et financement

Au-delà des chocs économiques externes, la Colombie doit **aligner ses objectifs nationaux, en particulier la réalisation d'une transition énergétique progressive et inclusive.** Pour atteindre cet objectif et maintenir la viabilité fiscale, monétaire et sociale, le gouvernement entend orchestrer sa **transition autour de cinq piliers clés :** augmenter les investissements dans les énergies propres et la décarbonation ; planifier la transition vers des alternatives aux combustibles fossiles ; améliorer l'efficacité énergétique; revoir les réglementations pour accélérer la production d'énergies propres ; et réindustrialiser l'économie.

La Colombie, qui se classe au sixième rang des pays d'Amérique latine les plus avancés en matière de transition énergétique selon l'indice de transition énergétique du Forum économique mondial[3] et au douzième rang mondial concernant sa capacité de production hydroélectrique, est confrontée à **deux défis majeurs dans le paysage international actuel** afin de réussir sa transition énergétique. Le premier défi consiste à garantir les ressources **énergétiques nécessaires à cette transition, et le second à élaborer des stratégies de financement efficaces pour la mettre en œuvre.**

En ce qui concerne sa capacité à produire de l'énergie, la Colombie connaît un déclin de ses réserves de pétrole et de gaz. Ce déclin se traduit déjà par une diminution du volume d'extraction de ces ressources. Elle menace donc la poursuite des exportations d'hydrocarbures et la capacité à répondre à la demande intérieure, qui augmente pour les carburants à base de pétrole. Cette dernière tendance a entraîné une diminution significative des exportations de diesel (de 20,3 %) et d'essence (de 96,0 %). Bien que les réserves de charbon en Colombie soient importantes, estimées à environ 4,55 milliards de tonnes et prévues pour durer environ 52 ans (période pendant laquelle la demande mondiale devrait diminuer), la situation est plus critique en ce qui concerne les ressources en pétrole et en gaz. Avec seulement 7,1 années de production de pétrole et 6,5 années de production de gaz restantes, ces ressources sont considérablement plus limitées.

3. Les notes du Forum économique mondial (FEM) reflètent les performances des systèmes énergétiques et le degré de préparation de chaque pays à la transition vers une économie à faibles émissions de carbone.

Il est donc essentiel de **poursuivre l'expansion des énergies renouvelables et des infrastructures électriques.** La Colombie doit renforcer son programme d'électrification générale, qui pourrait s'appuyer sur la biomasse, l'éolien, la géothermie et le solaire – qui ne représentent actuellement que 1 % du mix électrique du pays – ainsi que sur l'hydroélectricité, qui constitue 70 % du mix. Cette stratégie s'inscrit dans un contexte international favorable caractérisé par une baisse des coûts de ces énergies. Elle permettra également d'éviter les importations futures de combustibles fossiles et contribuera à atteindre les objectifs du Plan national de l'énergie (2022-2052), qui prévoit une capacité de 19 gigawatts (GW) d'énergies renouvelables non conventionnelles d'ici le milieu du siècle.

D'autre part, le **financement d'une transition énergétique nationale reste un défi majeur pour le pays** compte tenu des indicateurs économiques actuels : une inflation de 7 % et supérieure à la fourchette cible de la banque centrale, bien qu'en baisse, un taux de chômage d'environ 10 %, une dette publique nette du gouvernement national central de 58 % du PIB et un environnement international défavorable à l'attraction des capitaux étrangers. Dans le même temps, la réglementation imposant un déficit budgétaire nul et un ratio dette/PIB ne dépassant pas 55 % exerce une forte contrainte fiscale. Dans cet ouvrage, le modèle GEMMES Colombie est utilisé pour analyser les politiques de financement des politique d'adaptation et d'atténuation du pays, en mettant l'accent sur les conséquences macroéconomiques des investissements visant à mettre en œuvre la Contribution Déterminée au niveau National (CDN) (voir Chapitre 4). En particulier, le modèle souligne l'importance d'utiliser une combinaison d'investissements privés et d'instruments de financement vert pour financer les ambitions climatiques du pays, qui visent à réduire les émissions de gaz à effet de serre (GES) d'au moins 51 % d'ici 2030.

Vers une diversification économique

Les chocs économiques externes mentionnés ci-dessus et la transition énergétique domestique requièrent une transformation des structures de production et d'exportation du pays. À cet égard, en identifiant les limites d'une économie basée sur l'extraction, **le livre montre l'importance de la diversification de l'économie, basée sur les énergies renouvelables le renforcement des activités manufacturières, des services à haute valeur ajoutée mais aussi l'utilisation durable des ressources biophysiques.** L'un des moyens de diversifier l'économie colombienne pourrait consister à encourager l'augmentation de la production agricole. Une telle réorientation pourrait **réduire la dépendance actuelle du pays à l'égard des importations de denrées alimentaires** et contribuer ainsi à sa souveraineté alimentaire. Alors qu'une réduction des exportations affaiblit la monnaie, une substitution réussie des importations par des produits nationaux renforcerait le peso. L'analyse sectorielle proposée dans l'ouvrage (voir Chapitre 6), basée sur des matrices entrées-sorties, met également en évidence l'importance des **secteurs industriel et touristique** en tant que leviers clés pour réduire la dépendance économique à l'égard du secteur extractif.

Plus précisément, cette recherche d'alternatives passe par un **développement industriel axé sur la création de nouvelles chaînes de valeur pour les produits à faible émission.** Cela implique de collaborer avec des pays qui ont des liens politiques et économiques forts avec la Colombie, un concept connu sous le nom de **« friendshoring »**. En outre, cela implique aussi d'intégrer progressivement l'économie colombienne dans les chaînes de valeur mondiales passant par une mise à niveau technologique et le développement de capacités locales. Ce processus vise non seulement à renforcer la position du pays sur le marché mondial, mais aussi à se rapprocher de l'objectif de **souveraineté énergétique et technologique.**

Cette exploration des alternatives doit tenir compte du fait qu'une partie substantielle de la valeur des exportations de combustibles non fossiles dépend en réalité des importations. Cela souligne l'importance **d'investir dans la production locale des matières premières et des composants nécessaires à ces exportations (« reshoring »).**

L'hydrogène vert peut également être intégré dans la matrice industrielle et énergétique du pays, étant donné que la **demande mondiale d'hydrogène devrait augmenter.** Cette option soulève toutefois un certain nombre de défis encore non résolus : mode de transport, consommation élevée d'eau, absence de chaîne de valeur et de cadre réglementaire à ce jour. Enfin, **la diversification de la matrice minière** est également clés. Le plan de développement national (2022-2026) propose déjà de se concentrer sur l'exploration, l'extraction et la commercialisation officielle de minéraux ou d'alliages stratégiques tels que le cuivre, le nickel- fer, le cobalt, le lithium et le molybdène. Le plan prévoit également des actions visant à garantir le respect des réglementations environnementales et à mettre en œuvre des processus de participation communautaire dans les zones affectées par d'éventuelles opérations minières.

Une coopération technique fructueuse

Cet ouvrage est le fruit **de six années de coopération technique fructueuse** entre l'Universidad Nacional de Colombia (UNAL) (Université Nationale de Colombie), deux organismes gouvernementaux colombiens – le Ministerio de Hacienda y de Crédito Público (MHCP) (Ministère des Finances et du Crédit Public) et le Departamento Nacional de Planeación (DNP) (Département National de la Planification) – et l'Agence française de développement (AFD). La capacité du modèle à analyser la situation macroéconomique et énergétique du pays en fait un outil indispensable pour ces partenaires et les personnes impliquées dans la gestion des vulnérabilités économiques et l'identification des opportunités liées aux transitions en cours.

L'AFD, dans le cadre de sa démarche de **recherche intégrée à la prise de décision**, a accompagné l'ensemble de ce projet autour de deux axes. Le premier, institutionnel, a permis de renforcer les capacités du DNP et du MHCP dans l'élaboration du modèle GEMMES. Le second, académique, a permis de construire un cadre conceptuel et méthodologique en partenariat avec l'UNAL qui a construit un cadre de référence pour l'analyse des vulnérabilités fiscales, externes et monétaires liées à la transition bas carbone.

Ainsi, le modèle GEMMES Colombie, enrichi par l'expertise académique et intégré dans les processus décisionnaires grâce à la collaboration avec les ministères locaux, est désormais un outil efficace de **dialogue de politiques publiques**. Aujourd'hui, ces échanges se sont poursuivis et sont alimentés par le comité stratégique GEMMES composé du MHCP, du DNP, du Ministerio de Minas y Energía (MME) (Ministère des Mines et de l'Energie) et du Banco de la República.

À la demande des autorités colombiennes, GEMMES a été intégré à la gamme de modèles macroéconomiques du MHCP et sera bientôt couplé à d'autres instruments, principalement des modèles énergétiques. S'appuyant sur les efforts précédents, ces travaux contribueront à façonner un avenir plus résilient et plus durable pour la Colombie, illustrant **le pouvoir de la recherche appliquée dans** la résolution de questions contemporaines cruciales.

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Chapter 1 – Characterising Colombia's economy amid the low-carbon transition process

This chapter presents an overview of the Colombian economy from a macroeconomic and environmental perspective. Over the last three decades, the country has taken on different commitments in its transition to a low-carbon economy, in particular the 2030 target to reduce greenhouse gas (GHG) emissions under the Nationally Determined Contributions (NDCs). This ambition reflects Colombia's acknowledgement of its peripheral economy status, characterised by a dependence on fossil fuels, a production structure with high structural heterogeneity, and low levels of diversification. Despite these challenges, the chapter shows that Colombia has enormous potential in natural resources and a privileged geographical position. The analysis aims to identify the economy's unique structures and the institutional limits that shape the foundation for a systematic and sustainable decarbonisation of production activities. This assessment is conducted within the limits of a feasible structural transformation, delineated by three main economic gaps: the external sustainability gap (growth limitations due to the balance of payments), the social gap (the need to alleviate inequality and poverty), and the environmental gap (achieving environmental efficiency and adhering to the Paris Agreement).

Chapter 2 – An open economy model for Colombia: theoretical considerations, empirical aspects

In the context of modern globalisation, peripheral economies are affected not only by international real business cycles but also by the financial dynamics of advanced economies. This adds to each economy's internal and structural features, creating complexities and interrelationships between domestic and external actors. Stock-flow consistent (SFC) models attempt to close existing methodological gaps in macroeconomic modelling, analysing economies' real and financial spheres in an integrated way. This chapter describes the process of adapting and calibrating an SFC model in continuous time for the Colombian economy. It presents a detailed account of the empirical macroeconomic model developed, capturing most of the country's institutional characteristics. The primary objective of this model is to function as an analytical tool and support mechanism for a wide range of academic and policy debates, as demonstrated in subsequent chapters.

Chapter 3 – Understanding the macroeconomic and financial vulnerabilities associated with the global low-carbon transition in Colombia

Based on the analysis of three scenarios of oil and coal exports over the period 2023–2050, this chapter highlights the greater macroeconomic and financial fragility that the global low-carbon transition (and subsequent decline in demand for fossil fuels) may entail for the Colombian economy. The decline in fossil fuel exports will deeply affect Colombia's real and external sectors and deteriorate its fiscal and financial conditions. Ensuring a constant stream of international flows can help mitigate the negative impacts of the global transition in the long term. Still, the main driver of a recovery lies in industrial policy. Colombia will need to reduce its import dependency and diversify its exports (increasing the export base with sophisticated and higher value-added goods and services)—which will require coordinated actions between industry, finance, and the government. Implementing these policies early is a priority, since such structural transformations take time to materialise.

Chapter 4 – Financing a national energy transition in the context of a global low-carbon transition

Colombia faces multiple challenges in climate change mitigation and adaptation as well as biodiversity protection, which require significant investments made by the public and private sectors. Using the SFC model presented in Chapter 2, this chapter analyses some of the macroeconomic, fiscal, and external sector impacts of the investments made to meet Colombia's Nationally Determined Contribution (NDC) by 2030, achieve carbon neutrality by 2050, and become more resilient to climate change. The analysis shows that these investments have multiple social, economic, and environmental returns, which allows us to envision these investments beyond a cost narrative. They will however generate short-to-medium-term fiscal and external sector pressures that may become vulnerabilities and transition risks in the absence of appropriate policy responses. A more ambitious policy of structural change is necessary to ensure the viability and sustainability of the transition. The scenarios tested include different financing approaches—ranging from conventional to mixed financing methods—and quantify different rates of decline in fossil fuel exports by 2.5% annually from 2023, alongside a 10% increase in the propensity to export non-traditional goods over a 15-year period.

Chapter 5 – Identifying Colombia's external fragility

Building on the analyses in chapters 3 and 4, this section focuses on quantifying other external vulnerabilities that the Colombian economy is facing, i.e., its exposure to other global economic dynamics. In a context where fiscal pressures have been aggravated by uncertainties related to the pandemic, inflation, and supply chain disruptions, this chapter addresses through various empirical scenarios how a credit rating downgrade (change in country risk perception) and the Evergrande bankruptcy could further impact Colombia's ability to finance its energy transition by raising borrowing costs and dampening investment and consumption. The simulation results indicate that a 120 basis point increase in the EMBI could lead to a decrease in GDP growth (lowering it from an expected 3% to 2%). Additionally, investment could fall by 0.5 percentage points and inflation could slightly increase from 3.0% to 3.05%. The country's international reserves are also expected to decrease by 1.5% long-term, reflecting the deterioration in Colombia's external accounts as a result of the need to finance the increase in the fiscal deficit. The simulation results therefore emphasise the necessity of sustainable financing mechanisms to support the energy transition. Policy options, including carbon taxes and green bonds, are discussed as viable strategies to mobilise resources for green infrastructure, enhancing fiscal stability and attracting foreign investment. Ultimately, the chapter shows that securing fiscal stability is vital for instilling confidence in international markets, mitigating risks, and fostering economic resilience.

Chapter 6 – Exploring the structure of the colombian economy in the context of the low-carbon transition using a structural decomposition analysis

Based on input-output matrices, the final chapter explores Colombia's structural dynamics in the light of the low-carbon transition. It first examines the openness of the economy and the productive matrix, highlighting how premature deindustrialisation has historically affected the country. The results indicate uneven structural changes between sectors, with significant transformations in the industrial sector under the influence of globalisation and the need to substitute domestic inputs, leading to a weakening of production chains and a reduction in economic complexity. Demand was the driving force behind production growth, hampered by limited technological progress and import substitution. Next, the chapter uses a sectoral perspective to highlight the country's current challenges in reducing GHG emissions, highlighting the fiscal, external, and socio-economic vulnerabilities affecting its decarbonisation efforts. Results show that Colombia is indeed exposed to transition risks, with almost 20% of the wage bill depending on sunset industries. Furthermore, about 60% of foreign currency revenue and 20% of fiscal revenue come directly from oil and coal, making it vulnerable in both external and fiscal dimensions. Agriculture, agribusiness, and tourism could partly reduce the negative impacts of decarbonisation and help secure economic stability, moving away from dependence on oil and coal.

Capítulo 1 – Caracterización de la economía colombiana en el proceso de transición baja en carbono

Este capítulo presenta las principales características de la economía colombiana desde una perspectiva macroeconómica y medioambiental. A lo largo de las tres últimas décadas, el país ha asumido diferentes compromisos de transición hacia una economía baja en carbono, en particular un objetivo para el 2030 de reducción de las emisiones de gases de efecto invernadero (GEI) en el marco de las Contribuciones Determinadas a Nivel Nacional (CDN). Esta ambición refleja el reconocimiento por parte de Colombia de su estado de economía periférica, dependiente de los combustibles fósiles, de su estructura productiva con alta heterogeneidad estructural y bajos niveles de diversificación. A pesar de estos retos, el capítulo muestra que Colombia tiene un enorme potencial en recursos naturales y una posición geográfica privilegiada. El análisis pretende identificar las estructuras singulares de la economía y los límites institucionales que conforman la base para una descarbonización sistémica y sostenible de las actividades productivas. Este proceso se lleva a cabo dentro de los límites de la viabilidad de la transformación estructural, delineada por tres brechas económicas primarias: la brecha externa (limitaciones al crecimiento debido a la balanza de pagos), la brecha social (el imperativo de aliviar la desigualdad y la pobreza) y la brecha ambiental (lograr la eficiencia ambiental y el cumplimiento de las metas del Acuerdo de París).

Capítulo 2 – Un modelo de economía abierta aplicado a Colombia: consideraciones teóricas y aspectos empíricos

En el contexto de la globalización moderna, las economías periféricas no sólo se ven afectadas por los ciclos económicos reales internacionales, sino también por la dinámica financiera de las economías avanzadas. Esto se suma a las características internas y estructurales de cada economía, creando complejidades e interrelaciones entre los actores internos y externos. Los modelos stock-flujo en la modelización macroeconómica consistentes (SFC) intentan colmar lagunas metodológicas existentes, analizando de forma integrada las esferas real y financiera de las economías. Este capítulo describe el proceso de adaptación y calibración de un modelo SFC en tiempo continuo a la economía colombiana. El modelo macroeconómico empírico presentado en esta sección ha sido desarrollado capturando la mayoría de las características institucionales del país. Su objetivo principal es funcionar como herramienta analítica y mecanismo de apoyo para una amplia gama de debates académicos y políticos, como se demuestra en los capítulos siguientes.

Capítulo 3 – Comprender las vulnerabilidades macroeconómicas y financieras colombianas asociadas a la transición hacia una economía baja en carbono mundial

A partir del análisis de tres escenarios de exportaciones de petróleo y carbón simulados entre 2023-2050, este capítulo subraya la mayor fragilidad macroeconómica y financiera que la transición mundial hacia una economía de bajo carbono (y la subsiguiente reducción de la demanda de combustibles fósiles) podría implicar para la economía de Colombia. La disminución de las exportaciones de combustibles fósiles afectará profundamente a los sectores real y exterior del país y deteriorará sus condiciones fiscales y financieras. Asegurar un volumen constante de flujos internacionales puede ayudar a mitigar los impactos negativos de la transición global a largo plazo. Aun así, el principal motor de la recuperación reside en la política industrial. Colombia tendrá que reducir su dependencia de las importaciones y diversificar sus exportaciones (aumentando la base exportadora con bienes y servicios sofisticados y de mayor valor añadido), lo que requerirá acciones coordinadas entre la industria, las finanzas y el gobierno. La aplicación temprana de estas políticas es prioritaria, ya que estas transformaciones estructurales tardan en materializarse.

Capítulo 4 – Financiación de una transición energética nacional en el contexto de transición baja en carbono mundial

Colombia se enfrenta a múltiples retos en materia de mitigación y adaptación al cambio climático, así como de protección de la biodiversidad, que requieren la realización de importantes inversiones por parte de los sectores público y privado. Utilizando el modelo SFC presentado en el Capítulo 2, esta sección analiza algunos de los impactos macroeconómicos, fiscales y externos de las inversiones realizadas para cumplir con la Contribución Nacionalmente Determinada (NDC) de Colombia para 2030, lograr la neutralidad de carbono para 2050 y ser más resilientes al cambio climático. El análisis muestra que estas inversiones tienen múltiples beneficios sociales, económicos y ambientales, lo que permite contemplarlas más allá de una narrativa de costes. Sin embargo, generarán presiones fiscales y exteriores a corto y medio plazo que pueden convertirse en vulnerabilidades y riesgos de transición en ausencia de respuestas políticas adecuadas. Es necesaria una política más ambiciosa de cambio estructural para garantizar la viabilidad y la sostenibilidad de la transición. Los escenarios contemplados incluyen distintos enfoques de financiación -desde los métodos convencionales hasta métodos de financiación mixtos- y cuantifican diferentes tasas de caída de las exportaciones de combustibles fósiles en un 2,5% anual a partir de 2023, junto con un aumento del 10% de la propensión a exportar bienes no tradicionales a lo largo de un periodo de 15 años.

Capítulo 5 –Identificación de la fragilidad externa de Colombia

Partiendo de los análisis de los capítulos 3 y 4, en los que –entre otros– se examinaron los impactos macroeconómicos de la disminución de las exportaciones colombianas de hidrocarburos en el contexto de una transición global hacia una economía baja en carbono, esta sección se centra en cuantificar otras vulnerabilidades externas a las que se enfrenta la economía del país, es decir, su exposición a otras dinámicas económicas globales. En un contexto en el que las presiones fiscales se han visto agravadas por las incertidumbres relacionadas con la pandemia, la inflación y las interrupciones de la cadena de suministro, el capítulo aborda a través de varios escenarios empíricos cómo una rebaja de la calificación crediticia (cambio en la percepción del riesgo país) y la quiebra de Evergrande podrían afectar aún más a la capacidad de Colombia para financiar su transición energética al aumentar los costes de endeudamiento y frenar la inversión y el consumo. Los resultados de la simulación muestran que un aumento de 120 puntos básicos en el EMBI podría provocar una disminución del crecimiento del PIB (reduciéndolo del 3% al 2%). Además, la inversión podría disminuir en 0,5 puntos porcentuales y la inflación podría incrementarse ligeramente del 3,0% al 3,05%. También se prevé que las reservas internacionales del país disminuyan un 1,5% a largo plazo, lo cual refleja el deterioro de las cuentas exteriores de Colombia como resultado de la necesidad de financiar el aumento del déficit fiscal. El capítulo explora, por lo tanto, los resultados de las simulaciones que enfatizan la necesidad de mecanismos de financiación sostenibles para apoyar la transición energética. Se discuten opciones políticas, incluidos los impuestos sobre el carbono y los bonos verdes, como estrategias viables para movilizar recursos para infraestructuras verdes, mejorando la estabilidad fiscal y atrayendo inversiones extranjeras. En última instancia, el capítulo muestra que garantizar la estabilidad fiscal es vital para infundir confianza en los mercados internacionales, mitigar los riesgos y fomentar la resiliencia económica.

Capítulo 6 – Exploración de la estructura de la economía colombiana en el contexto de la transición hacia una economía baja en carbono mediante un análisis de descomposición estructural

Basándose en las matrices de insumo-producto, el último capítulo analiza la dinámica estructural de Colombia a la luz de la transición hacia una economía baja en carbono. En primer lugar, examina la apertura de la economía y la matriz productiva, destacando cómo la desindustrialización prematura ha afectado históricamente al país. Los resultados indican cambios estructurales desiguales entre sectores, con transformaciones significativas en el sector industrial bajo la influencia de la globalización y la necesidad de sustituir insumos nacionales, lo que ha llevado a un debilitamiento de las cadenas de producción y a una reducción de la complejidad económica. La demanda ha impulsado el crecimiento de la producción, obstaculizado por el limitado progreso tecnológico y la sustitución de importaciones. A continuación, el capítulo utiliza una perspectiva sectorial para resaltar los retos actuales del país en la reducción de las emisiones de GEI, destacando las vulnerabilidades fiscales, externas y socioeconómicas que afectan a sus esfuerzos de descarbonización. Los resultados muestran que Colombia está realmente expuesta a los riesgos de transición, ya que casi el 20% de la masa salarial depende de las industrias en declive. Además, cerca del 60% de los ingresos en divisas y el 20% de los ingresos fiscales proceden directamente del petróleo y el carbón, lo que la hace vulnerable tanto en la dimensión externa como en la fiscal. La agricultura, la agroindustria y el turismo podrían reducir en parte los efectos negativos de la descarbonización y contribuir a garantizar la estabilidad económica alejándose de la dependencia del petróleo y el carbón.

Chapitre 1 – Caractériser l'économie colombienne dans le cadre du processus de transition vers une économie bas carbone

Ce chapitre présente une vue d'ensemble de l'économie colombienne d'un point de vue macroéconomique et environnemental. Au cours des trois dernières décennies, le pays a pris différents engagements pour passer à une économie bas carbone, en particulier un objectif de réduction des émissions de gaz à effet de serre (GES) à l'horizon 2030 dans le cadre des contributions déterminées au niveau national (CDN). Cette ambition reflète la reconnaissance par la Colombie de son statut d'économie périphérique, qui dépend des combustibles fossiles, d'une structure productive à forte hétérogénéité structurelle et de faibles niveaux de diversification. Malgré ces défis, le chapitre montre que la Colombie dispose d'un énorme potentiel en ressources naturelles et d'une position géographique privilégiée. Le fil conducteur de l'analyse cherche à identifier les spécificités structurelles de l'économie et les limites institutionnelles qui détermineront la configuration du processus de décarbonisation des activités de production. Cette évaluation est menée dans les limites de la faisabilité de la transformation structurelle, délimitée par trois principales écarts économiques: externe (freins à la croissance dus à la balance des paiements), sociale (l'impératif lié à la réduction des inégalités et de la pauvreté) et environnementale (l'obligation d'atteindre l'efficacité environnementale et d'adhérer à l'Accord de Paris).

Chapitre 2 – Un modèle d'économie ouverte pour la Colombie : considérations théoriques et aspects empiriques

Dans le contexte de la mondialisation moderne, les économies périphériques sont non seulement affectées par les cycles économiques réels internationaux, mais aussi par la dynamique financière des économies avancées. Cela s'ajoute aux caractéristiques internes et structurelles de chaque économie, créant des complexités et des interrelations entre les acteurs nationaux et externes. Les modèles stock-flux cohérents (SFC) tentent de combler certaines lacunes méthodologiques existantes dans la modélisation macroéconomique, en analysant les sphères réelles et financières des économies de manière intégrée. Ce chapitre décrit le processus d'adaptation et de calibrage d'un modèle SFC en temps continu pour l'économie colombienne. Il présente en détail le modèle macroéconomique empirique développé, capturant la plupart des caractéristiques institutionnelles du pays. Son objectif premier est de servir d'outil analytique et de mécanisme de soutien pour un large éventail de débats académiques et politiques, comme le démontrent les chapitres suivants.

Chapitre 3 – Comprendre les vulnérabilités macroéconomiques et financières de la Colombie liées à la transition vers une économie bas carbone mondiale

Sur la base de l'analyse de trois scénarios d'exportations de pétrole et de charbon sur la période 2023-2050, ce chapitre met en évidence la plus grande fragilité macroéconomique et financière que la transition mondiale vers une économie bas carbone (et le déclin subséquent des combustibles fossiles) pourrait entraîner pour l'économie colombienne. Le déclin des exportations de combustibles fossiles affectera profondément les secteurs réel et extérieur de la Colombie et détériorera ses conditions fiscales et financières. La garantie d'un volume constant de flux internationaux peut contribuer à atténuer les effets négatifs de la transition mondiale à long terme. Toutefois, le principal moteur de la reprise réside dans la politique industrielle. La Colombie devra réduire sa dépendance à l'égard des importations et diversifier ses exportations (en augmentant la base d'exportation avec des biens et services sophistiqués et à plus forte valeur ajoutée) – ce qui nécessitera des actions coordonnées entre les secteurs l'industriels, financiers et le gouvernement. La mise en œuvre rapide de ces politiques est une priorité, car ces transformations structurelles prennent du temps pour se concrétiser.

Chapitre 4 – Financer une transition énergetique domestique dans le contexte d'une transition globale

La Colombie est confrontée à de multiples défis en matière d'atténuation du changement climatique et d'adaptation à ses effets, ainsi que de protection de la biodiversité, qui nécessitent des investissements importants de la part des secteurs public et privé. À l'aide du modèle SFC présenté au chapitre 2, ce chapitre analyse certains des impacts macroéconomiques, fiscaux et sur le secteur extérieur des investissements réalisés pour atteindre la contribution déterminée au niveau national (CDN) de la Colombie d'ici 2030, parvenir à la neutralité carbone d'ici 2050 et accroître la résilience au changement climatique. L'analyse montre que ces investissements ont de multiples retombées sociales, économiques et environnementales, ce qui nous permet de ne pas uniquement envisager ces investissements sous le prisme des coûts. Ils engendreront toutefois des pressions budgétaires et sectorielles externes à court et à moyen terme, qui pourraient devenir des vulnérabilités et des risques de transition en l'absence de réponses politiques appropriées. Une politique plus ambitieuse de changement structurel est nécessaire pour assurer la viabilité et la durabilité de la transition. Les scénarios testés incluent des variations dans les approches de financement - allant du financement conventionnel au financement mixte - et quantifient différents taux de déclin des exportations de combustibles fossiles de 2,5 % par an à partir de 2023, ainsi qu'une augmentation de 10 % de la propension à exporter des biens non-traditionnels sur une période de 15 ans.

Chapitre 5 –Identifier la fragilité extérieure de la Colombie

S'appuyant sur les analyses des chapitres 3 et 4, qui – entre autres – ont examiné les impacts macroéconomiques du déclin des exportations colombiennes d'hydrocarbures dans le contexte d'une transition bas carbone mondiale, cette section se concentre sur la quantification d'autres vulnérabilités externes auxquelles l'économie colombienne est confrontée, c'est à dire son exposition à d'autres dynamiques économiques mondiales. Dans un contexte où les pressions budgétaires ont été aggravées par les incertitudes liées à la pandémie, à l'inflation et aux perturbations de la chaîne d'approvisionnement, le chapitre examine, à l'aide de divers scénarios empiriques, comment un abaissement de la note de crédit (changement dans la perception du risque pays) et la faillite d'Evergrande pourraient avoir un impact supplémentaire sur la capacité de la Colombie à financer sa transition énergétique, en augmentant les coûts d'emprunt et en freinant l'investissement et la consommation. Les résultats de la simulation montrent qu'une augmentation de 120 points de base de l'indice EMBI pourrait entraîner une diminution de la croissance du PIB (passant des 3 % attendus à 2 %). En outre, l'investissement pourrait diminuer de 0,5 point de pourcentage et l'inflation pourrait augmenter légèrement de 3,0 % à 3,05 %. Les réserves internationales du pays devraient également diminuer de 1,5 % à long terme, reflétant la détérioration des comptes extérieurs de la Colombie en raison de la nécessité de financer le déficit budgétaire croissant. Les résultats des simulations soulignent ainsi, la nécessité de mécanismes de financement durables pour soutenir la transition énergétique. Des options de politiques publiques, notamment les taxes sur le carbone et les obligations vertes, sont présentées comme des stratégies viables pour mobiliser des ressources pour les infrastructures vertes, renforcer la stabilité fiscale et attirer les investissements étrangers. Le chapitre insiste particulièrement sur l'importance de garantir la stabilité fiscale pour inspirer la confiance sur les marchés internationaux, atténuer les risques et favoriser la résilience économique.

Chapitre 6 – Exploration *via* analyse de décomposition structurelle de la structure de l'économie colombienne à l'aune de la transition bas-carbone

Basé sur des matrices entrées-sorties, le dernier chapitre s'intéresse aux dynamiques structurelles de la Colombie à l'aune de la transition bas carbone. Il examine d'abord l'ouverture de son économie et de sa matrice productive, en soulignant l'impact qu'a eu, historiquement, la désindustrialisation prématurée du pays. Les résultats indiquent des changements structurels inégaux entre les secteurs, avec des transformations significatives dans le secteur industriel sous l'influence de la mondialisation et de la nécessité de substituer des intrants nationaux, ce qui a entraîné un affaiblissement des chaînes de production et une réduction de la complexité économique. La demande a été le moteur de la croissance de la production, entravée par des progrès technologiques limités et la substitution des importations. Ensuite, le chapitre adopte une perspective sectorielle pour mettre en évidence les défis actuels du pays en matière de réduction des émissions de GES, en soulignant les vulnérabilités fiscales, externes et socio-économiques qui affectent ses efforts de décarbonisation. Les résultats montrent que la Colombie est effectivement exposée aux risques de transition, près de 20 % de la masse salariale dépendant des industries en déclin. En outre, environ 60 % des recettes en devises et 20 % des recettes fiscales proviennent directement du pétrole et du charbon, ce qui rend le pays vulnérable à la fois sur le plan extérieur et sur le plan fiscal. L'agriculture, l'agro-industrie et le tourisme pourraient en partie réduire les impacts négatifs de la décarbonisation et contribuer à garantir la stabilité économique, en s'éloignant de la dépendance au pétrole et au charbon.

Vulnerabilities, constraints, and opportunities of energy transition in Colombia: a structuralist approach

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Chapter 1

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Chapter 1

Vulnerabilities, constraints, and opportunities of energy transition in Colombia: a structuralist approach

Introduction

This chapter presents a general overview of the macroeconomic and environmental characteristics of the Colombian economy. The main thread of the analysis seeks to establish the structural specificities of the economy and the institutional constraints that define the initial conditions for shaping an ordered and sustainable process of decarbonisation of productive activities. This characterisation is fundamental for situating the expectations and objectives of adaptation to climate change in the short, medium, and long term. Taking a holistic view of the transformation processes—which includes adapting different theoretical models—, the responsibilities of institutional actors are evaluated in terms of their use of material and energy resources, as well as their greenhouse gas (GHG) emissions. This evaluation takes place within the framework of structural feasibility for transformation, the limits of which are defined by the three gaps of the economy: the external sustainability gap (growth restricted by the balance of payments); the social gap (the need to overcome levels of inequality and poverty); and the environmental gap (requirements to achieve environmental efficiency targets and fulfil Paris Agreement commitments to reduce GHG emissions by 2030).

This chapter has four sections. The first is the introduction. The second presents the environmental characteristics of the country, including a description of the institutional environment, an outline of environmental generalities, and a macroecological characterisation of production. The third section presents key aspects of the Colombian macroeconomy, including both real and financial elements, to describe the key characteristics of the productive regime. Finally, a three-gap model is used to estimate the constraints on the energy transition process in Colombia, which is linked to two simultaneous objectives: poverty reduction and growth consistent with a balance-of-payments equilibrium.

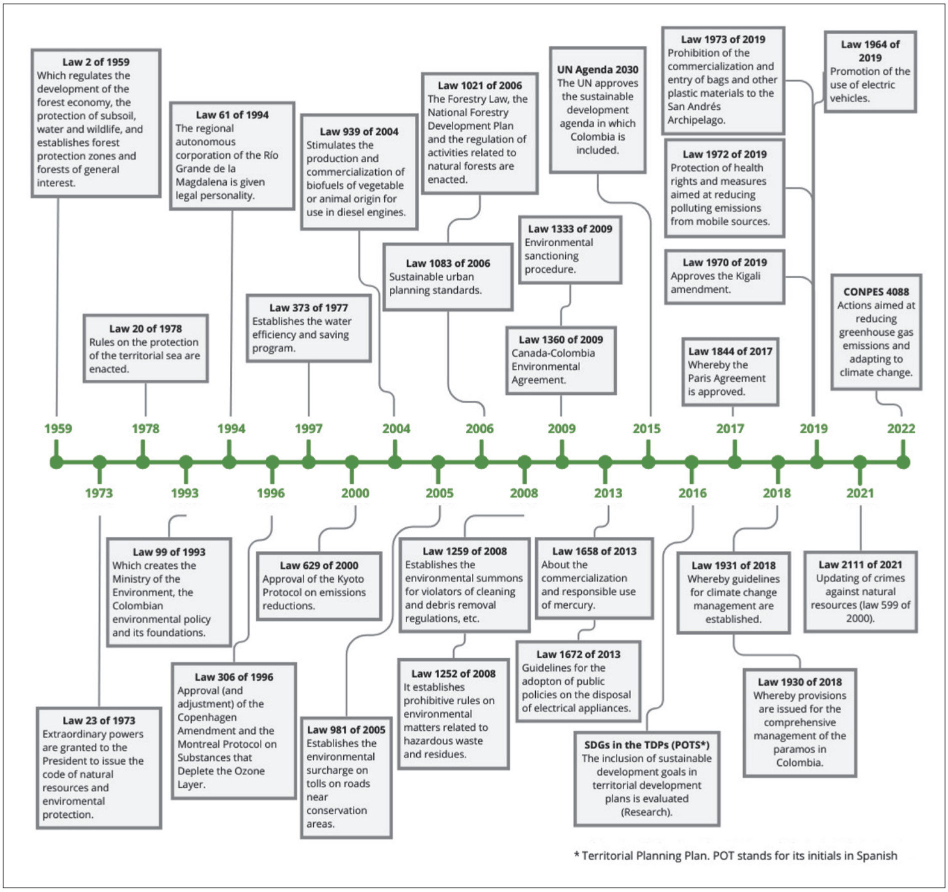
1. Environmental characteristics

Colombia's geographical location makes it a privileged territory in terms of the availability of water, mining, and biodiversity resources. It has a considerable range of energy sources and raw materials for production,[4] as well as an environmental heritage that positions it as a strategic environment, since it is vital to the survival of multiple ecosystems and species of all types of life,[5] and a fundamental environmental asset for the absorption of global CO_2 emissions (González-M *et al.*, 2016).

These environmental characteristics, structural conflict over land use in Colombia—dating back to the beginning of the Republic (see section 1.3)—, and a strong tradition of using legislation for regulation and to overcome conflicts have all contributed to the development of a legislative process in the country that aims to regulate interaction with the environment, as well as the usufruct of different actors of society. The consolidation of this process is summarised below.

4. Although oil and gas reserves declined between 2012 and 2020, positive average extraction growth rates have been maintained. Moreover, the topography of the country favours water as a source of energy; in 2020, 70.23% of the electricity generated was hydroelectric (Unidad de Planeación Minero Energética (UPME), 2021). And in 2015 it was estimated that the potential for electricity generation was up to six times greater than current production (UPME *et al.*, 2015).
5. According to the Instituto Humboldt, the country has 19,968 species of flowering plants; 30,000 species of insects; 1,524 species of bony fish; 763 species of amphibians; 571 species of reptiles; 1,889 species of birds; and 479 species of mammals, among other forms of life (Gómez & Cubillos, 2014).

Figure 1. ***Main regulations issued in Colombia on climate change (1959–2022)***



Source: Authors.

1.1. Commitments, challenges, and opportunities

Through a remarkable, accumulative process, the country has built an institutional framework for regulation and environmental protection, and for regulatory adaptation for the energy transition. Figure 1 maps this process onto a timeline, showing how this framework was built.

The timeline starts with Law 2 of 1959, a milestone for the identification and delimitation of the different ecosystems and types of areas composing the national territory. One of the important classifications resulting from this law is the "Forest Reserves Areas," which are territories delimited by their biophysical and ecosystem characteristics. The classification implies a special regime for both land titling and the determination of land uses.

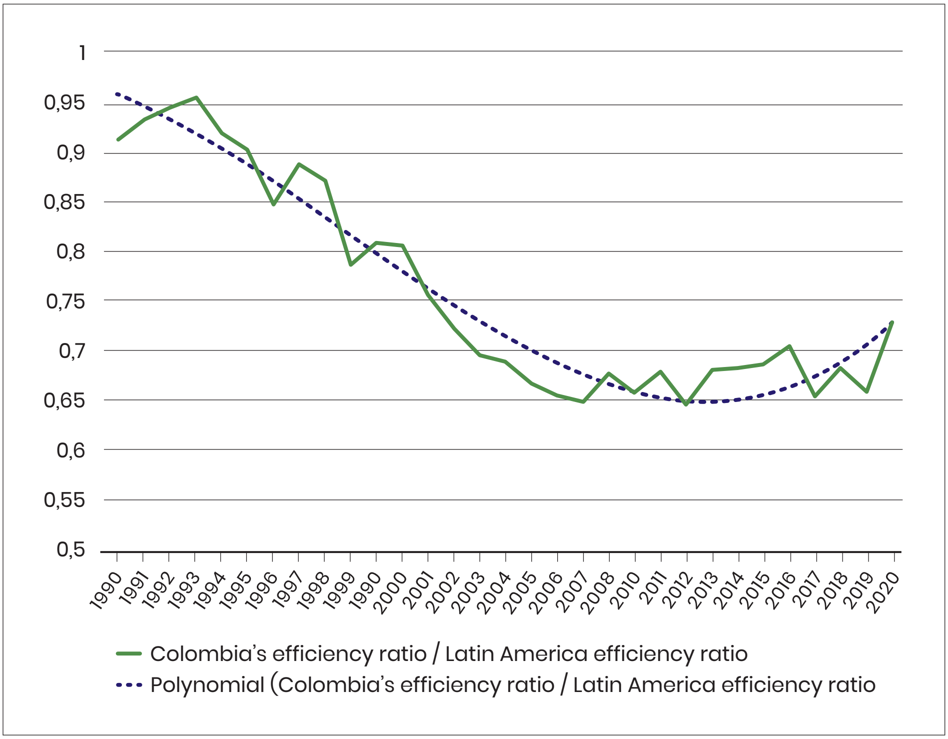
The enactment of Law 2 of 1959, Law 23 of 1973, and Law 10 of 1978 began a process of consolidation of a state policy for the care, preservation, and protection of the environment. This process was accelerated in the 1990s with the creation of the Ministry of the Environment, through Law 99 of 1993, and the subsequent signings and ratifications of bilateral and multilateral agreements for the defence of the environment and natural resources (Law 306 of 1996, Law 629 of 2000), as well as the establishment of norms seeking the protection and efficient use of natural resources (Law 61 of 1994, Law 373 of 1997).

Moreover, in the last decade of the twentieth century, regulations were introduced supporting the transition towards a low-carbon economy (Law 306 of 1996, Law 629 of 2000). This trend intensified in the first and second decades of the twenty-first century, with the following developments: signing of international agreements (Law 1360 of 2009; the United Nations Agenda 2030, adopted in 2015; Law 1844 of 2017; Law 1970 of 2019); adaptation of territorial regulations to the Sustainable Development Goals (SDGs) (implementation of the SDGs in all land-use plans as of 2016); regulations for the management of emissions and polluting waste (Law 1252 of 2008; Law 1259 of 2008; Law 1333 of 2009; Law 1964 of 2019; Law 1972 of 2019; Law 2111 of 2021); protection of vulnerable ecosystems (Law 981 of 2005; Law 1021 of 2006); and territorial measures aimed at suppressing the use and consumption of products with a high carbon footprint or generating quantities of waste that put multiple ecosystems at risk (Law 1658 of 2013; Law 1672 of 2013, Law 1973 of 2019). Finally, in 2023 the Colombian government issued the CONPES[6] 4088. This public policy document guides the national policy to reach the Paris Agreement goals, defining targets, roadmaps, and investments of close to USD 46.7 million.

It is worth highlighting the enactment of Law 1930 of 2018, whereby guidelines for climate change management are established. The law has become an obligatory reference for both public policy and policy on the environment and disaster risk management.

6. Consejo Nacional de Política Económica y Social (National Council for Economic and Social Policy).

Figure 2. ***Colombia's efficiency ratio, compared to Latin America—CO_2 emissions (kg per PPP $ of GDP)***



Source: Authors, based on data from World Bank.

Colombia thus has a body of legislation that supports a transformation to an environmentally friendly economy, in terms of the responsibilities associated with the production and consumption of goods and services. This corpus determines public policies aimed at climate change management and the care and protection of natural resources. It is a key precedent for public policy makers and national, departmental, and local governments.

The legislative framework has also had a significant impact on the country's energy efficiency performance, with Colombia showing a decreasing trend[7] compared to the region until 2012. Subsequently, however, the ratio of GHG emissions to gross domestic product (GDP) began to increase, implying that

7. $\left(\frac{\textit{Greenhouse gas emissions (GHG)}}{\textit{GDP (Y)}}\right)$

the relationship between increasing regulation and improvement of the country's technical efficiency stagnated and worsened during the second decade of the twenty-first century.

1.2. Characteristics of the environmental situation: Availability, sources, uses, and GHG emissions

Colombia is considered one of the most biodiverse countries in the region and the world, with significant available natural resources (see Chapter 4). This section presents some key environmental features of the production process: geographical availability of resources and conflicts regarding their use; energy uses and sources by activity; GHG emissions and removals.

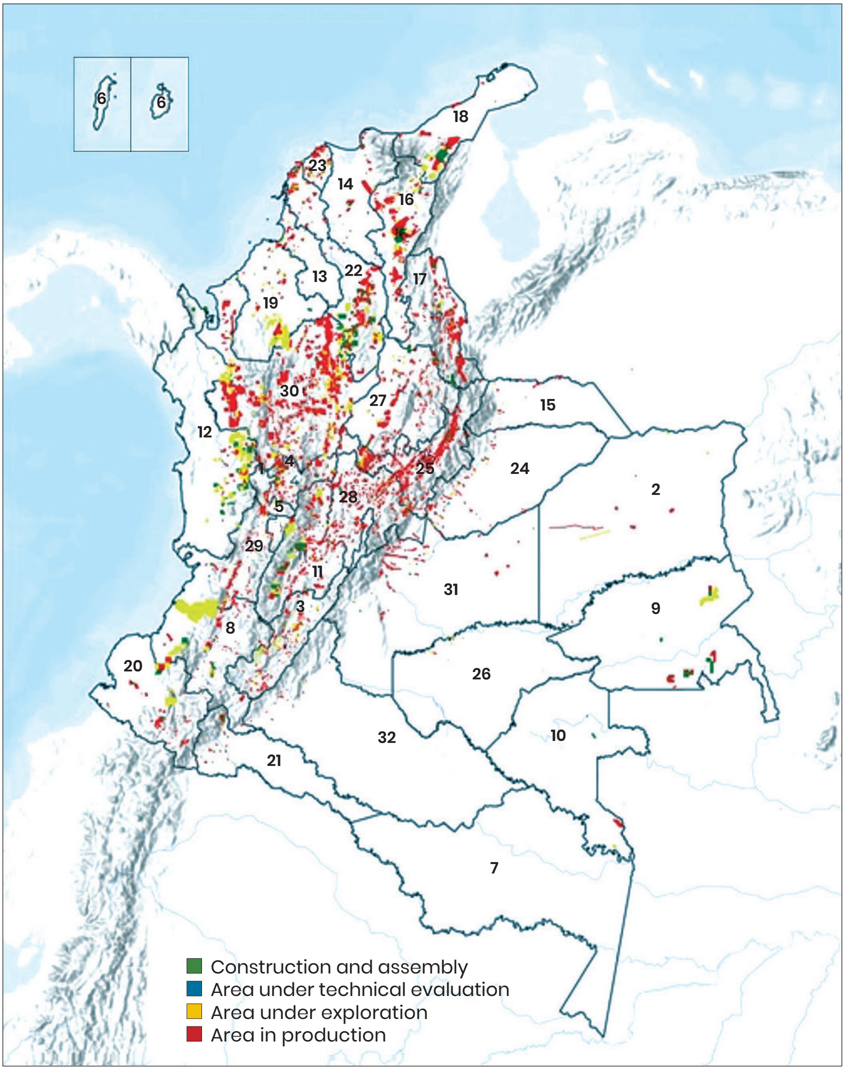
Oil and mining exploration areas (yellow) (see Figure 6 and Figure 3) are concentrated in the centre and north of the country; they are distributed throughout the exploration areas and along the entire central mountain range. Oil exploration areas (yellow) are concentrated in the eastern plains area (Meta, Casanare, and Arauca) and the Caribbean coast (Sucre, Magdalena, Atlántico, Cesar, and La Guajira) (see Figure 6), while mining exploration areas (yellow) are concentrated in the west (Cauca, Chocó, and Antioquia) and north of the country (Córdoba, Cesar, and La Guajira) (see Figure 3).

The territories that produce the most net CO_2 emissions, i.e., considering absorption, are concentrated in the centre of the country, mainly Caquetá, Meta, and Antioquia, with those that host mining exploration or exploitation (Meta, Caquetá) having particularly high net emissions (Figure 5). Those with the greatest forestry assets, such as Amazonas, Vaupés, and Guainía, manage to absorb a large proportion of their CO_2 emissions.

Mining-energy exploitation and land use in general have given rise to at least 129 registered conflicts in communities living in nearby areas. Most of these conflicts have occurred in the centre and west of the country, mainly due to mining-related activity (49 registered conflicts) and fossil fuel and hydrocarbon exploitation (22 registered conflicts). The department of Valle del Cauca has the highest number of conflicts (14), followed by the departments of Antioquia (13) and Tolima (9) (Figure 4).

Resource availability and use (minerals and fossil fuels) is concentrated in specific areas of the country, leading to higher net CO_2 emissions in these areas and conflicts involving the communities that live there. The mining-energy extractive sector, the main source of economic growth in Colombia, is thus also the source of an environmentally and socially precarious situation (see Garay *et al.*, 2020 and Vélez *et al.*, 2015).

Figure 3. ***Mining exploration areas in Colombia (2023)***



States: **1.** Risaralda **2.** Vichada **3.** Huila **4.** Caldas **5.** Quindío **6.** San Andrés, Providencia y Santa Catalina **7.** Amazonas **8.** Cauca **9.** Guainía **10.** Vaupés **11.** Tolima **12.** Chocó **13.** Sucre **14.** Magdalena **15.** Arauca **16.** Cesar **17.** Norte de Santander **18.** La Guajira **19.** Córdoba **20.** Nariño **21.** Putumayo **22.** Bolívar **23.** Atlántico **24.** Casanare **25.** Boyacá **26.** Guaviare **27.** Santander **28.** Cundinamarca **29.** Valle del Cauca **30.** Antioquia **31.** Meta **32.** Caquetá.

Source: Authors, based on data from the Departamento Administrativo Nacional de Estadística (DANE) (Colombian National Statistics Office), the Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) (Institute of Hydrology, Meteorology and Environmental Studies), the Agencia Nacional de Hydrocarburos (ANH) (National Hydrocarbons Agency), and the Environmental Justice Atlas.

Figure 4. ***Environmental conflicts with communities***

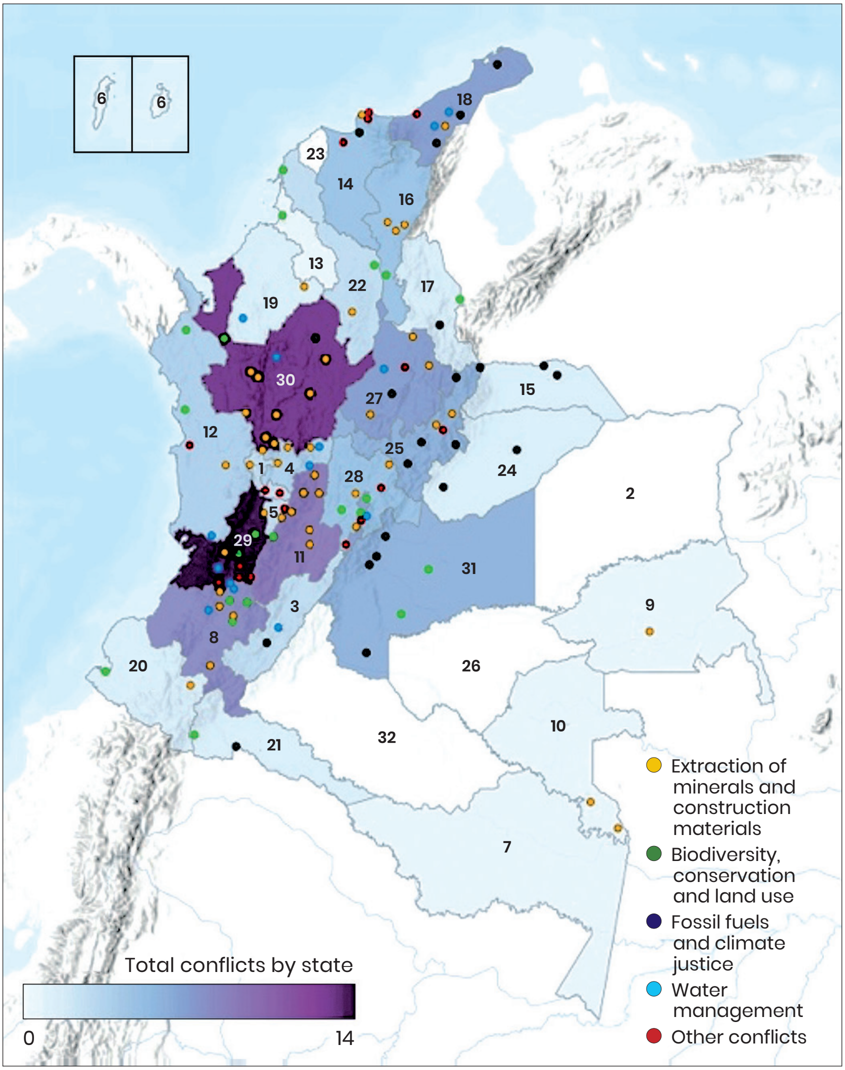


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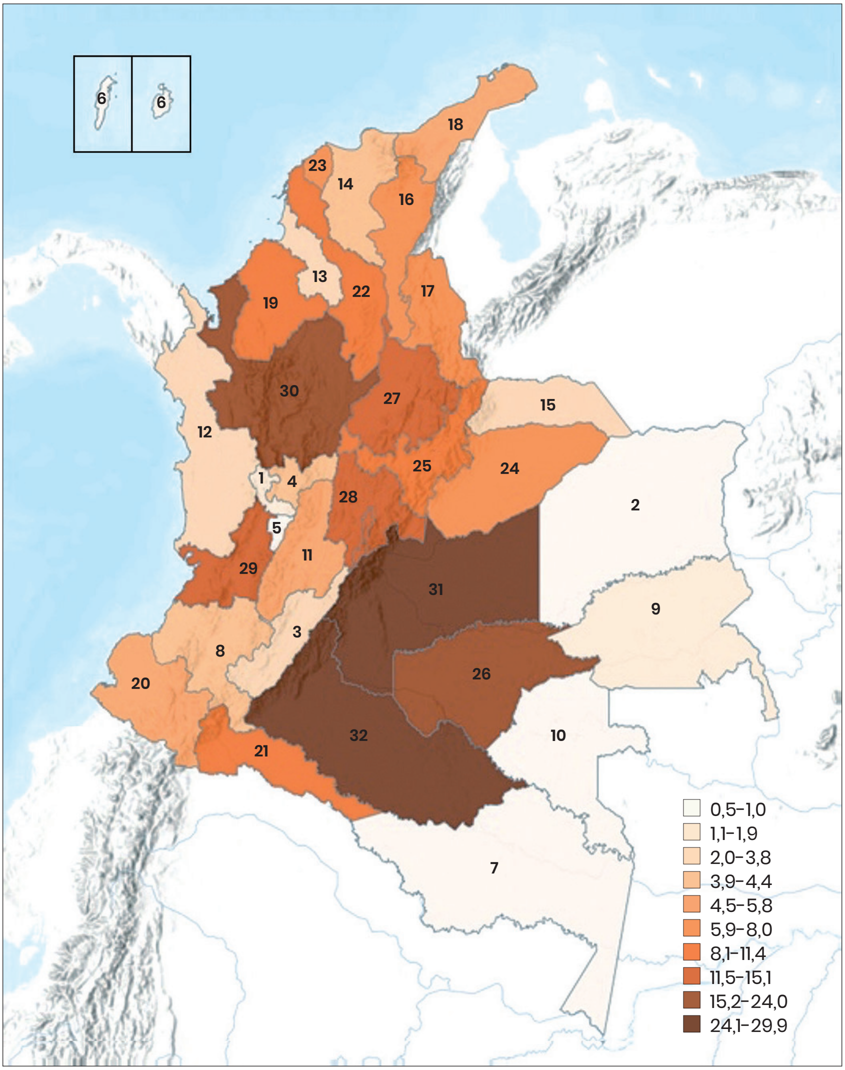
Figure 5. ***Net emissions by department (Mt of CO_2, 2012)***



States: **1.** Risaralda **2.** Vichada **3.** Huila **4.** Caldas **5.** Quindío **6.** San Andrés, Providencia y Santa Catalina **7.** Amazonas **8.** Cauca **9.** Guainía **10.** Vaupés **11.** Tolima **12.** Chocó **13.** Sucre **14.** Magdalena **15.** Arauca **16.** Cesar **17.** Norte de Santander **18.** La Guajira **19.** Córdoba **20.** Nariño **21.** Putumayo **22.** Bolívar **23.** Atlántico **24.** Casanare **25.** Boyacá **26.** Guaviare **27.** Santander **28.** Cundinamarca **29.** Valle del Cauca **30.** Antioquia **31.** Meta **32.** Caquetá.

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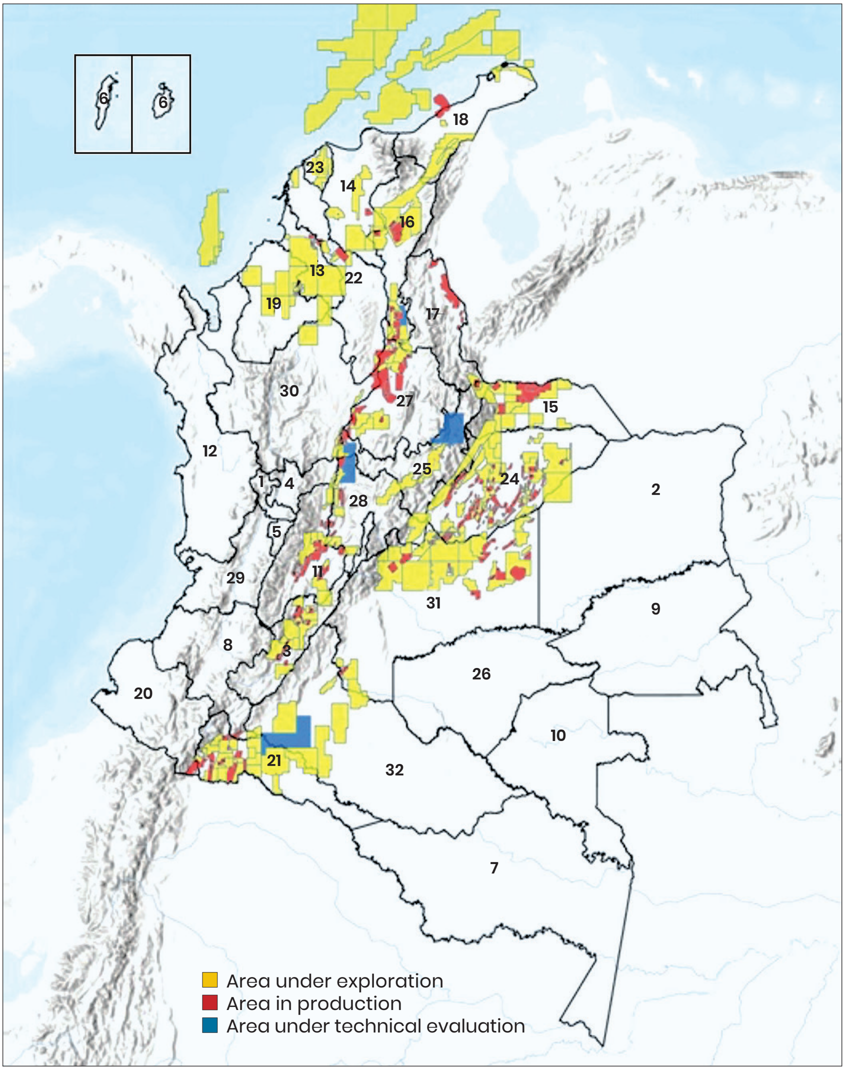
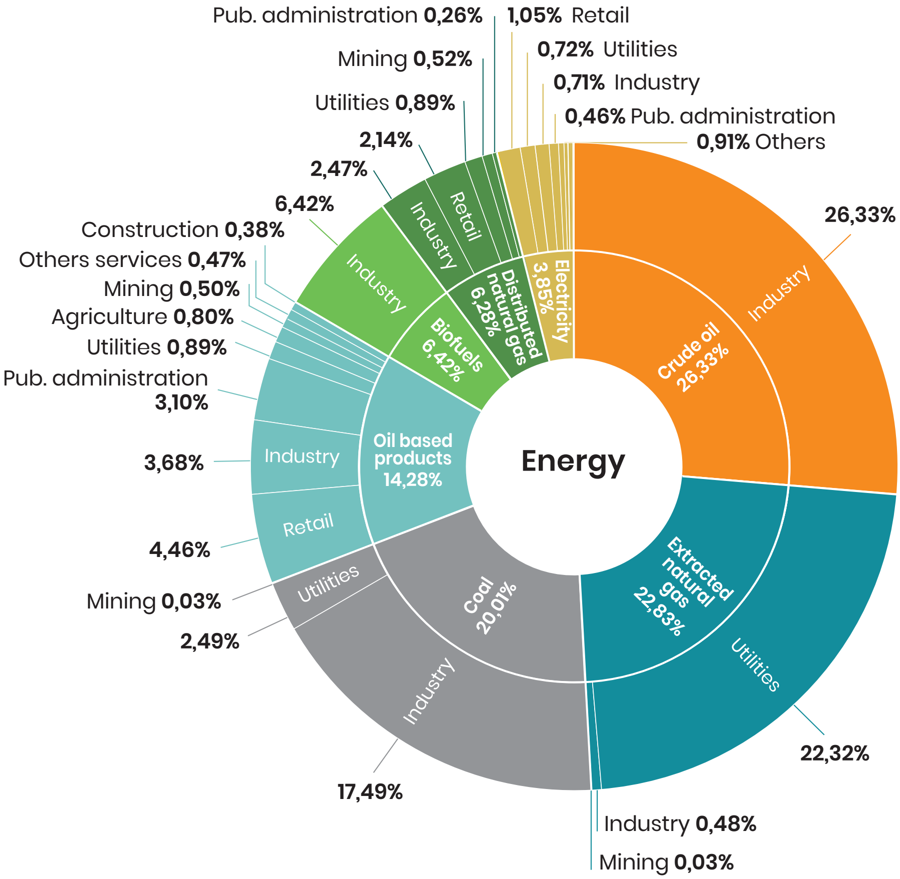
Figure 6. ***Oil exploration areas in Colombia (2023)***



States: 1. Risaralda **2.** Vichada **3.** Huila **4.** Caldas **5.** Quindío **6.** San Andrés, Providencia y Santa Catalina **7.** Amazonas **8.** Cauca **9.** Guainía **10.** Vaupés **11.** Tolima **12.** Chocó **13.** Sucre **14.** Magdalena **15.** Arauca **16.** Cesar **17.** Norte de Santander **18.** La Guajira **19.** Córdoba **20.** Nariño **21.** Putumayo **22.** Bolívar **23.** Atlántico **24.** Casanare **25.** Boyacá **26.** Guaviare **27.** Santander **28.** Cundinamarca **29.** Valle del Cauca **30.** Antioquia **31.** Meta **32.** Caquetá.

Source: Authors, based on data from the Departamento Administrativo Nacional de Estadística (DANE) (Colombian National Statistics Office), the Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) (Institute of Hydrology, Meteorology and Environmental Studies), the Agencia Nacional de Hydrocarburos (ANH) (National Hydrocarbons Agency), and the Environmental Justice Atlas.

Figure 7.[8] ***Energy use per sector in 2021 (as a percentage of total energy use)***

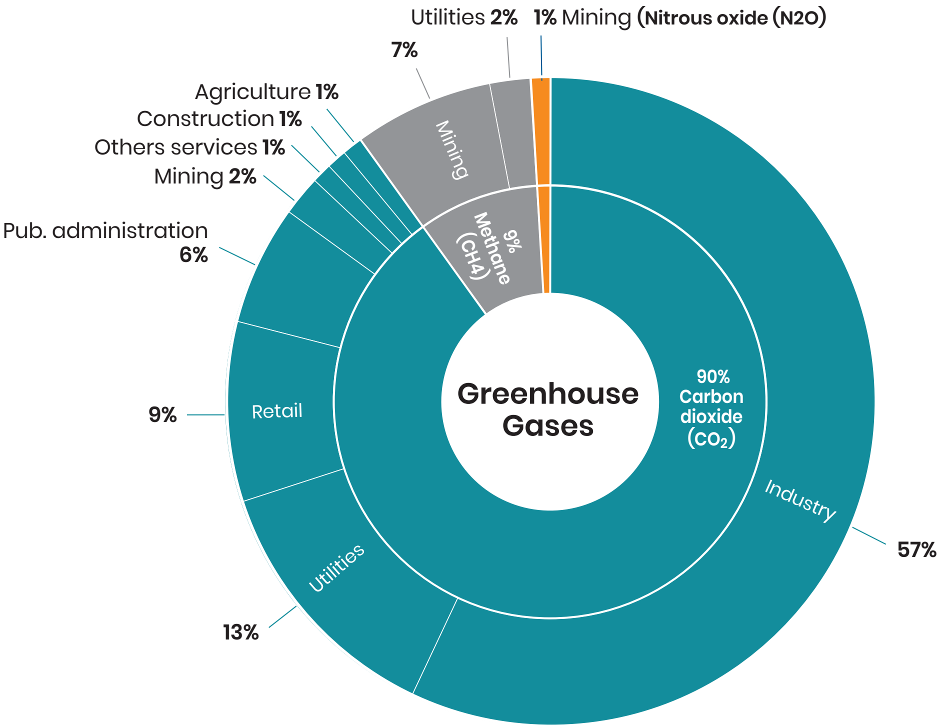


Note: Total energy use in Colombia in 2021 was 2,235,818 terajoules.
Source: Authors, based on data from DANE.

The main energy sources in Colombia are crude oil (26.3%), used solely by the industrial sector, followed by petroleum derivatives (22.8%), used by households and industry. Oil and its derivatives, natural gas, and coal thus account for 90% of the energy used in Colombia. Extracted natural gas (23%) is the main source for utilities and public administration, while distributed natural gas (6%) fuels homes and industries. Biofuels (6%), and electricity (4%) are the energy sources that account for the smallest proportions of the total used (Figure 7).

8. "Utilities" refers to services related to the supply of electricity, gas, steam, and air conditioning.

Figure 8. ***GHG emissions per sector in 2021 (as a percentage of total emissions)***



Note: Total GHG emissions in Colombia in 2021 were 102,427 gigagrams.
Source: Authors, based on data from DANE.

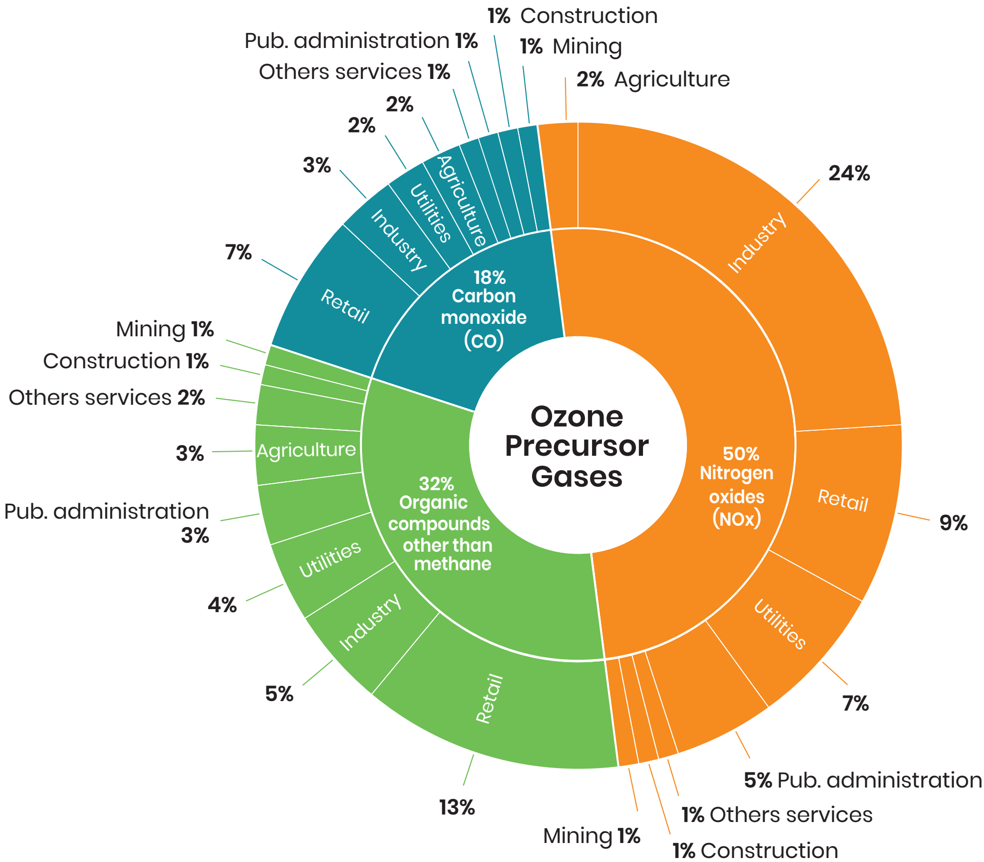
The industrial sector generates the most CO_2 emissions (57.3%), followed by utilities and retail (each sector generating 13.3 and 9.4% of total CO_2 emissions). CO_2 accounts for 80% of GHG emissions, while methane, mainly associated with the productive activity of the mining sector, contributes only 11% and nitrous oxide 0%.

Nitrogen oxide accounts for 50.4% of emissions of ozone precursor gases[9] (OPG), which are mostly generated by the industrial and retail sectors. Organic components other than methane (31.2% of total OPG emissions) are also mostly emitted by retail and industry. The remaining 18.1% of OPG emissions corresponds to carbon monoxide emissions, mainly from retail; and methane, 0.3%. Overall, retail and industry are responsible

9. Gases that contribute to ozone pollution.

for about 60% of GHG emissions and 64% of OPG emissions; they are thus the economic activities that contribute most to the country's environmental deterioration (Figure 9).

Figure 9. ***Emissions of OPGs by sector in 2021 (as a percentage of total emissions)***

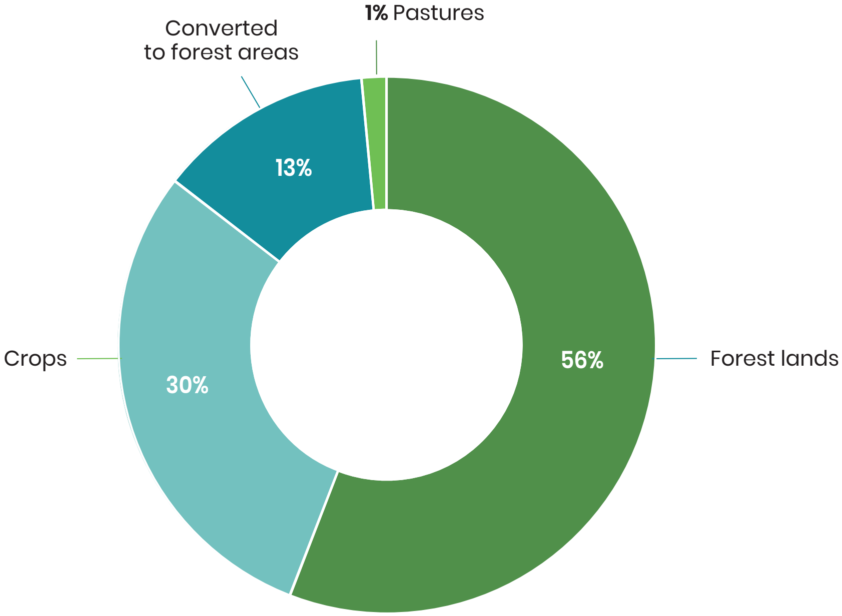


Note: Total emissions of OPGs in Colombia in 2021 were 834 gigagrams.
Source: Authors, based on data from DANE.

In terms of emissions absorption, forested areas absorb the highest percentage (56%), followed by crops (30%), and areas converted to forest (13%), hence the calls from different national and multilateral institutions to conserve and restore large zones of this kind in the country[10] (Figure 10).

10. See Aguilar-Garavito *et al.* (2017).

Figure 10. ***GHG absorption by sector 2019 (as a percentage of total absorption)***



Note: Total GHG absorptions in Colombia in 2019 were 22,659 gigagrams.
Source: Authors, based on data from DANE.

The economic outcome generally depends on the coordination among the different actors, i.e., individual decisions regarding production, consumption, indebtedness, the use of this or that technique, etc. (Ülgen, 2013). It is thus important to know how different actors will participate in terms of consumption of biophysical inputs and GHG generation during the production process. The following section attempts to characterise this participation, through resource-use matrices for water, energy, and GHGs, according to the activity and the institutional economic sector.

1.3. Water, energy, and GHG flow by institutional sector

In the multifactorial process of technological transformation, an important element is the political economy of the transition, i.e., who gains or loses in a particular process. Understanding this makes it possible to identify parties likely to support or oppose these productive transformation processes (Hirschman, 1968).

In short, the process of transition to low-carbon economies is equivalent to a process of productive structural change, understood as a quantitative and qualitative transformation of the production structure. This implies increased capacities, new connections between the components of the system, diversification of the sector itself and of indirectly related sectors (new sectors), the emergence of feedback processes and positive causation phenomena that give rise to increasing yields, and general increases in the efficiency of the system (Barletta & Yoguel, 2017).

However, rather than examining the motivations that drive these transformations, this section will describe the responsibilities of each actor in the economy (on the production side) in relation to the use of biophysical resources and the generation of GHG emissions. It will evaluate how actors can increase their efficiency, both in the use of biophysical inputs and in the generation of GHGs, by modifying their activities, taking into account the production of economic value. This evaluation will subsequently be used to identify which actors should be prioritised to ensure the sustainability of the process.

Constructing matrices of biophysical uses and GHG generation by institutional sector and activity requires an eclectic methodology that combines a macroeconomic perspective (institutional sectors, branches of economic activity) with an ecological approach (uses of resources such as water and energy; GHG emissions). This methodology emerges from Georgescu-Roegen's work on the need to understand the behaviour of stocks and flows of materials and energy in their different forms, as sources, wastes, and residues of economic processes (Georgescu-Roegen, 1971). It also takes as a reference various modelling exercises that seek to link each of the institutional actors of the economy (households, financial corporations, non-financial corporations, government, and the rest of the world) with the biophysical processes in which any human activity participates (King, 2020; Svartzman *et al.*, 2019; Dafermos, 2018).

The methodology was also based in part on the spirit of the "New Cambridge" (Godley and Cripps,1983) ideas regarding the relationship between the three financial balances of an economy (i.e., that the private sector balance plus the public sector balance is equal to the external sector balance). However, the accounting interpretation of an open economy does not reflect the complexity of the biophysical stocks and flows, in two main ways:

1. The dynamics of energy and materials usage, as well as the production of GHG emissions, require an approach that goes beyond economic transactions between actors; the ultimate exchange, in physical terms, is made with the environment, i.e., although the initial transactions involving biophysical resources and GHG emissions (both flows) are made between the different actors and the environment, with a particular actor implicated in the flows of these resources and wastes, the final stock of each type of resource or emission is a characteristic of the global environment.

2. The uses and emissions generated by the different biophysical elements can be measured using various units of measurement. The information presented below mainly illustrates environmental efficiency in terms of resource uses for production and in terms of emissions generated by such production.

Considering these two factors, an approximation of the matrices of biophysical uses and products by institutional sector and branch of economic activity has been constructed.[11] Figure 11 and Figure 12 show the total use of biophysical inputs (water and energy, respectively) for the total supply of the economy, i.e., the total amount of biophysical units used to generate domestic production added to the total amount of biophysical units used to generate imported production. Similarly, Figure 13 shows the total amount of GHG units emitted by production of the total supply.

A key difference between this accounting methodology and that of the three financial balances is that it does not produce a zero-sum result, i.e., since the flows of uses and emissions are not between actors but with the environment, the sum of the uses of biophysical resources and emissions for each branch

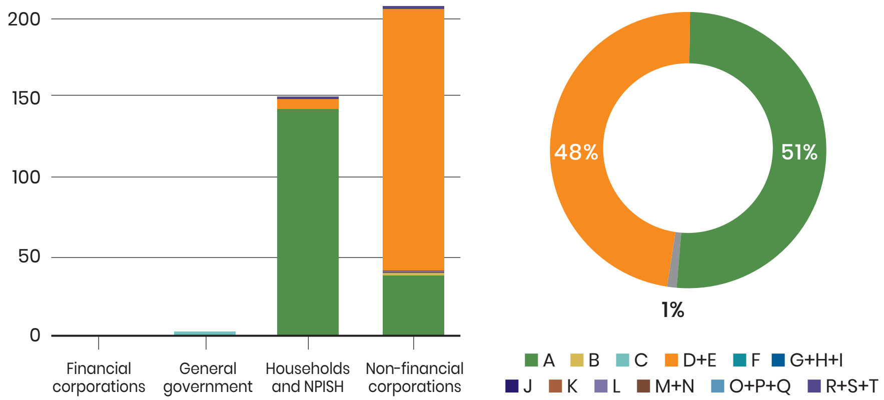
11. The matrices presented in this section were constructed based on different sources of information for the year 2018. The elaboration and calculations come from these matrices and were estimated based on data from DANE (national accounts; value added by branch of activity and institutional sector; environmental satellite accounts; GDP deflator, producer price index, etc.) and the Organisation for Economic Co-operation and Development (inter-country input-output matrices). Note: it was assumed that technical efficiency within each branch of activity remains constant by institutional sector.

of activity is greater than zero. In summary, the biophysical resources used and the GHG emissions generated by each institutional sector to guarantee the total supply of the economy function as a closed system; the sectors take resource flows from the environment and emit GHGs into the environment, regardless of their domestic or internal origin.

The water used for production (not including imports) totals 357,990 cubic hectometers. The branches of economic activity with the highest water use are: agriculture, livestock, hunting, forestry, and fishing (51.27% of the total); and electricity, gas, steam, and air conditioning supply (47.92%). Water use is concentrated as follows: the private sector uses 99.92% of the total water needed for production, with non-financial corporations accounting for 58%, and households and non-profit institutions serving households (NPISHs) for 41.92%. In the case of non-financial corporations, most of the water use is associated with the supply of electricity, gas, steam, and air conditioning; this institutional sector in this branch of activity uses 46.41% of the total water used for production. The highest water uses by households and NPISHs is associated with agriculture, livestock, hunting, forestry, and fishing; this institutional sector in this branch of activity uses 40.31% of the total water used for production (Figure 11).

We estimated that 7,367,758 terajoules of energy are required to produce the total amount of goods and services supplied in the Colombian economy. The branch of activity that requires the most energy to guarantee production is mining and quarrying (62.9% of the total), followed by manufacturing industries (18.7%), and electricity, gas, steam, and air conditioning supply (10.4%). In turn, in each of these branches, the demand for this resource is largely concentrated in the private sector (75.4%), particularly in non-financial corporations, although the public sector accounts for an important share (18%), while the rest of the world uses 5.7% of the total energy used to produce the imported supply (Figure 12).

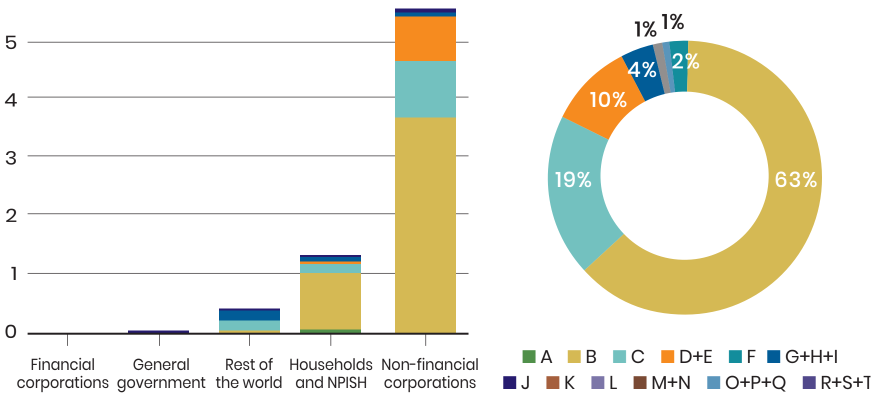
Figure 11. ***Water consumption 2018 (thousands of cubic hectometers)***



A: Agriculture, livestock, hunting, forestry, and fishing; **B:** Mining and quarrying; **C:** Manufacturing; **D + E:** Supply of electricity, gas, steam, and air conditioning; **F:** Construction; **G + H + I:** Wholesale and retail trade; repair of motor vehicles and motorcycles; transport and storage; accommodation and food services; **J:** Information and communications; **K:** Financial and insurance activities; **L:** Real estate activities; **M + N:** Professional, scientific, and technical activities; administrative and support services activities; **O + P + Q:** Public administration and defence; compulsory social security schemes; education; human health care, and social service activities; **R +S + T:** Artistic, entertainment and recreation activities and other service activities; activities of individual households as employers; undifferentiated activities of individual households as producers of goods and services for their own use.

Source: Authors.

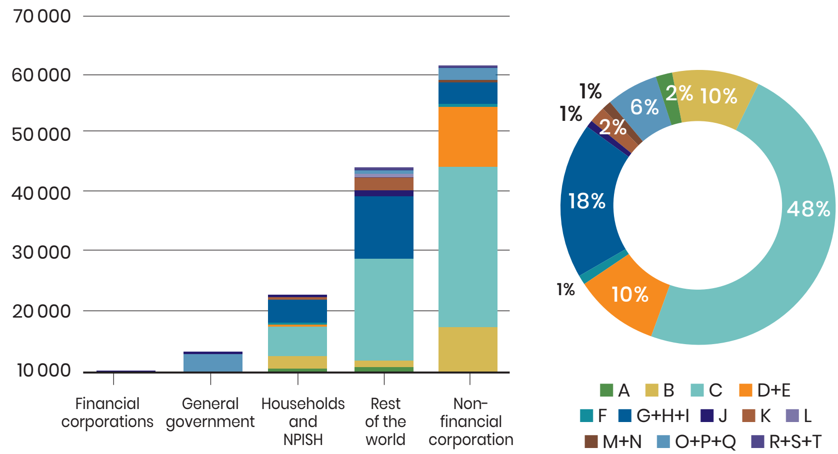
Figure 12. ***Energy consumption 2018 (millions of terajoules)***



A: Agriculture, livestock, hunting, forestry, and fishing; **B:** Mining and quarrying; **C:** Manufacturing; **D + E:** Supply of electricity, gas, steam, and air conditioning; **F:** Construction; **G + H + I:** Wholesale and retail trade; repair of motor vehicles and motorcycles; transport and storage; accommodation and food services; **J:** Information and communications; **K:** Financial and insurance activities; **L:** Real estate activities; **M + N:** Professional, scientific, and technical activities; administrative and support services activities; **O + P + Q:** Public administration and defence; compulsory social security schemes; education; human health care, and social service activities; **R +S + T:** Artistic, entertainment and recreation activities and other service activities; activities of individual households as employers; undifferentiated activities of individual households as producers of goods and services for their own use.

Source: Authors.

Figure 13. ***GHG emissions 2018 (gigagrams)***



A: Agriculture, livestock, hunting, forestry, and fishing; **B:** Mining and quarrying; **C:** Manufacturing; **D + E:** Supply of electricity, gas, steam, and air conditioning; **F:** Construction; **G + H + I:** Wholesale and retail trade; repair of motor vehicles and motorcycles; transport and storage; accommodation and food services; **J:** Information and communications; **K:** Financial and insurance activities; **L:** Real estate activities; **M + N:** Professional, scientific, and technical activities; administrative and support services activities; **O + P + Q:** Public administration and defence; compulsory social security schemes; education; human health care, and social service activities; **R +S + T:** Artistic, entertainment and recreation activities and other service activities; activities of individual households as employers; undifferentiated activities of individual households as producers of goods and services for their own use.

Source: Authors.

Total GHG emissions generated by the total supply of the economy total 118,735 gigagrams. These emissions are mainly concentrated in the manufacturing industries (48%), followed by wholesale and retail trade; repair of motor vehicles and motorcycles; transport and storage; accommodation and food services (18%). These two actors generate 50% of emissions coming from non-financial corporations, and the latter of the two generates 34% of emissions coming from the rest of the world. The next two highest emitters are mining and quarrying (10%); and electricity, gas, steam, and air conditioning supply (10%). The branches of economic activity in which non-financial corporations bear greater responsibility than the rest of the world are manufacturing industries (26%); supply of electricity, gas, steam, and air conditioning (10%); and mining and quarrying (10%). However, the rest of the world bears greater responsibility for the emissions of wholesale and retail trade; repair of motor vehicles and motorcycles; transport and storage; accommodation and food services (10%) (Figure 13).

The available information shows that the private sector (especially non-financial corporations) must be subject to requirements to improve environmental efficiency in terms of the use of biophysical resources and the generation of GHG emissions. The sector's responsibilities can be detailed depending on the matrix analysed. In the use of energy, the greatest responsibility falls on non-financial corporations and the government (Figure 12); in the use of water for production, this responsibility falls especially on non-financial corporations and households and NPISHs (Figure 12); concerning GHG emissions, this responsibility corresponds to non-financial corporations and the rest of the world (Figure 13).

2. Fundamentals of the colombian economy

In the previous section, a decomposition exercise was carried out to show the balance of use of biophysical resources and GHG emissions between the branches of activity of the economy and the institutional sectors. The double-entry cross-checking made it possible to establish responsibilities by branch and institutional sector. These results are a snapshot of the impacts and emissions generated by economic activities and the interactions of the three sectors: private sector (non-financial corporations, financial corporations, and households and NPISHs), public sector (government), and external sector (rest of the world). The sector-institutional matrix can be interpreted as a system of links that can help to identify the gradient of the transition, i.e., the direction and magnitude of the changes. This is an unavoidable element in the process of structural change since it is necessary to know and understand how the different institutional sectors function at the local level and their connection with the outside world (Barletta & Yoguel, 2017).

However, analysis of the "material and energy" outcome is insufficient to determine the patterns and stresses of the transition to a low-carbon, less fossil fuel-dependent economy. Given the speed of the changes required of branches of economic activity and institutional sectors to meet the commitments of the Paris Agreement, it seems appropriate to complement the first analysis with a detailed analysis of the production regime and an overview survey of the colombian economy.

Therefore, the previous section's macroecological analysis of production is complemented in this section with analysis of: the productive characteristics of the production regime; inequality; the characteristics of fiscal and monetary policies that directly and indirectly affect the balance sheets of the institutional sectors; and, of course, the sustainability of the process of transition to a low-carbon economy.

2.1. Balance-of-payments dominance and the energy transition of the colombian economy

One of the key characteristics of the Colombian economy, which is worth starting with since it summarises a common feature of a peripheral economy, is the "balance-of-payments dominance." This concept is the product of the Latin American theoretical legacy in which not only does the external sector impose a ceiling on long-term growth (see Prebisch, 1949; Thirlwall, 1979), but external shocks largely determine the short-term behaviour of the economy in question, through real (trade account) and financial (access to financing and movements in the interest rate) channels that generate procyclical impacts and have ambiguous effects on the exchange rate (Ocampo, 2016).

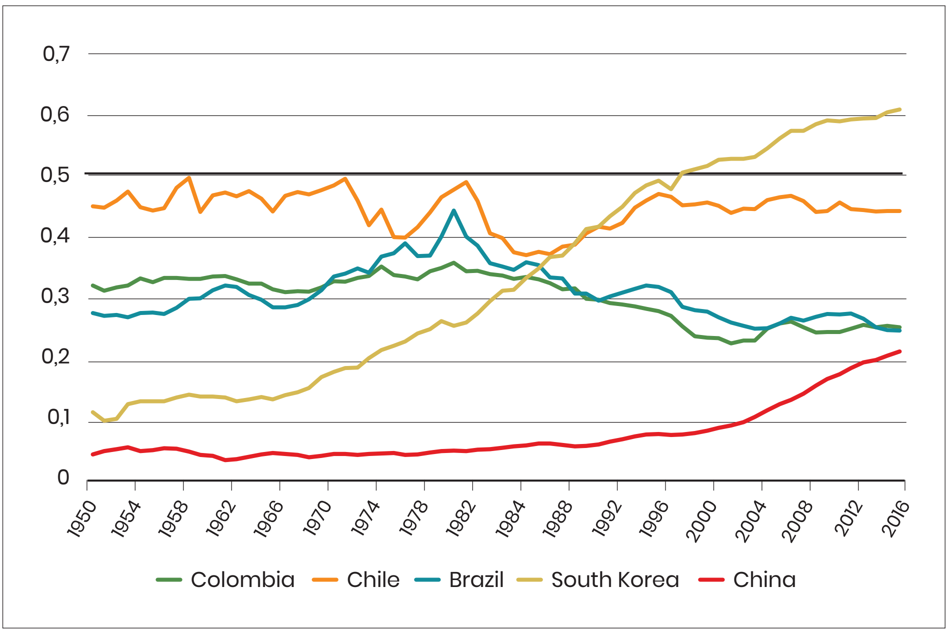
However, in the context of openness and liberalisation of capital markets, the main causes of imbalances and real volatility in Latin American countries have been the cycles of external financing flows and the procyclical behaviour of risk premiums. Thus, the common feature of the different international procyclical shocks that have had an impact on the region is that they were rooted in abrupt changes in available external financing (Titelman Kardonsky & Pérez Caldentey, 2015).

However, in the energy transition process of a peripheral economy such as Colombia's, two specificities must be recognised: (1) the persistence of a dual production structure, where modern high-productivity sectors coexist with traditional sectors in which a large part of the economically active population work; and (2) the concentration of foreign trade in a few primary goods or the exploitation of natural mineral and energy resources. Both characteristics condition the patterns of growth and income distribution in the long term. Abeles and Pérez Caldentey (2022) see this as the main burden of the external sector in the region since the predominant type of linkage with international trade does not modify the income elasticities of exports, which remain low and are the result of a low degree of productive diversification and low productivity growth.

Moreover, what economists at the Economic Commission for Latin America and the Caribbean (ECLAC) call "structural heterogeneity" inhibits the diffusion of intersectoral technical change, which slows productivity growth and aborts convergence processes (Pérez Caldentey, 2015). Similarly, specialisation in natural resources and primary goods configures a "rent-seeking" society that distorts the allocation of resources and reduces growth. This situation also leaves room for episodes of the "Dutch disease," as a consequence of real (in terms of trade) or financial external shocks, which change domestic relative prices and reduce the profitability of non-traditional tradable sectors (Botta *et al.*, 2016; Goda & Torres, 2013). Both phenomena contribute to the deterioration of income and wealth distribution.

Figure 14 shows the evolution of the relative productivity of Mexico, Brazil, Chile, Colombia, China, and South Korea, as compared to the United States. As can be seen, there is a glass ceiling (0.5), which none of the countries in the Latin American region has managed to overcome. Conversely, South Korea, which in the 1950s and mid-1960s had the worst records of the group for this indicator, experienced a structural break that accelerated the rate of growth of relative productivity. This was a direct consequence of the programme of structural change and industrialisation that the country's authorities pursued without interruption, combining a whole catalogue of unconventional policies. Moreover, not only did South Korea break through this barrier but it maintained its accelerated rate of convergence, despite the 1997 crisis. The other economy that shows a similar pattern and whose evolution shows rapid convergence is China (Palma & Pincus, 2022).

Figure 14. ***Convergence with the United States, as a percentage of US productivity***



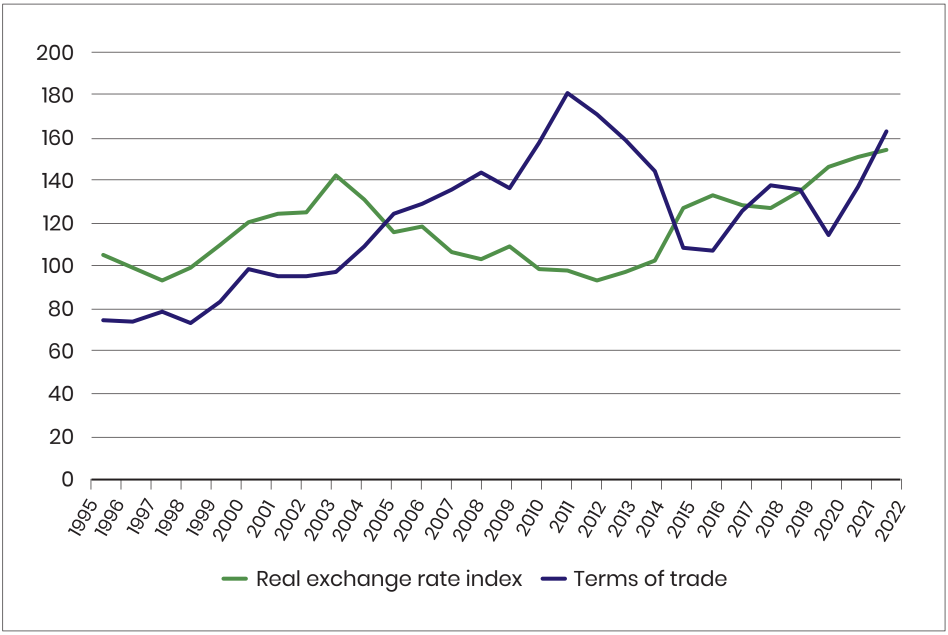
Source: Authors, using Palma and Pincus (2022).

Colombia is an interesting case. Between 1950 and 1967 the indicator practically stagnated. Only when sectoral policies aimed at promoting non-traditional exports were implemented and the crawling peg system was adopted to manage the exchange rate was there a slight and sustained increase in the convergence rate. The external debt crisis ended that upward trend, with the economy suffering a sharp setback. The rate of convergence declined steadily until 2003; even the 1990 economic opening and financial deregulation did not stop the deterioration.

A small rebound can be identified during the commodity price super-cycle between 2003 and 2014, but the effect was transitory. Economic authorities found it difficult to maintain countercyclical policies, so much so that the pattern of speeding up "appreciation pressures during booms and depreciation pressures during crises" (Ocampo, 2016; 2019) was replicated. Figure 15 shows the relationship between the real exchange rate and the terms of trade, and how this coincides with the pattern described above.

In the next subsection, we present the principal characteristics of the Colombian economy's production regime, which are consistent with the balance-of-payments dominance hypothesis.

Figure 15. ***Real exchange rate compared to terms of trade (1995 = 100)***



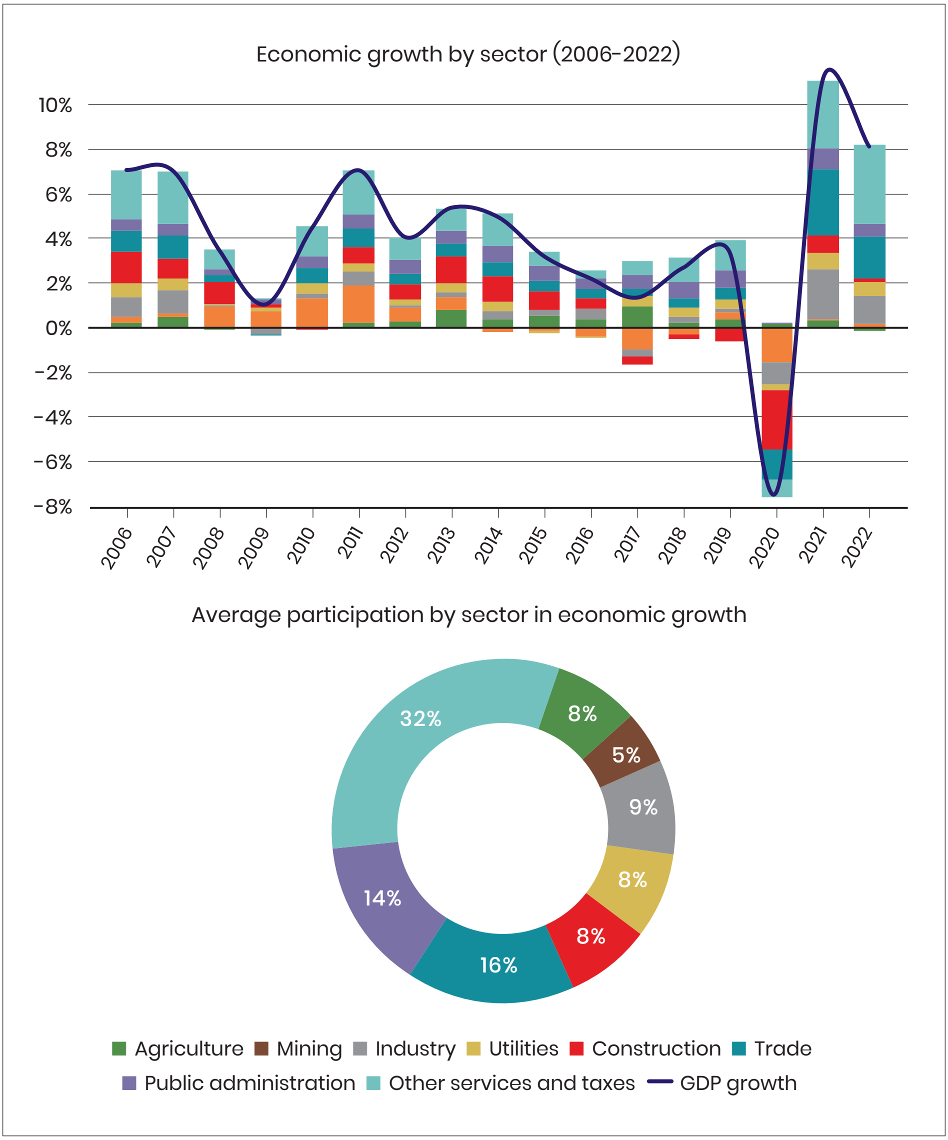
Source: Authors based on data from Banco de la República.

2.2. General profile: Growth, production structure, external balance (current account), and inequality

As mentioned in the previous subsection, from 2003 to 2014 the economy maintained a growing trend within the framework of the commodity super-cycle. Until the end of the cycle, the mining-energy branch of economic activity was the one that contributed the most to economic growth; however, post 2014, the mining sector was badly affected by the fall in international commodity prices and presented negative growth rates until 2018 (Figure 16).

Before the COVID-19 pandemic, the Colombian economy in general was growing at an increasing pace, but the health crisis led to a decrease in production in the country of close to 7%, and the economic growth rate of 2020 was the lowest of the period 2006–2022.

Figure 16. ***Economic growth by sector***



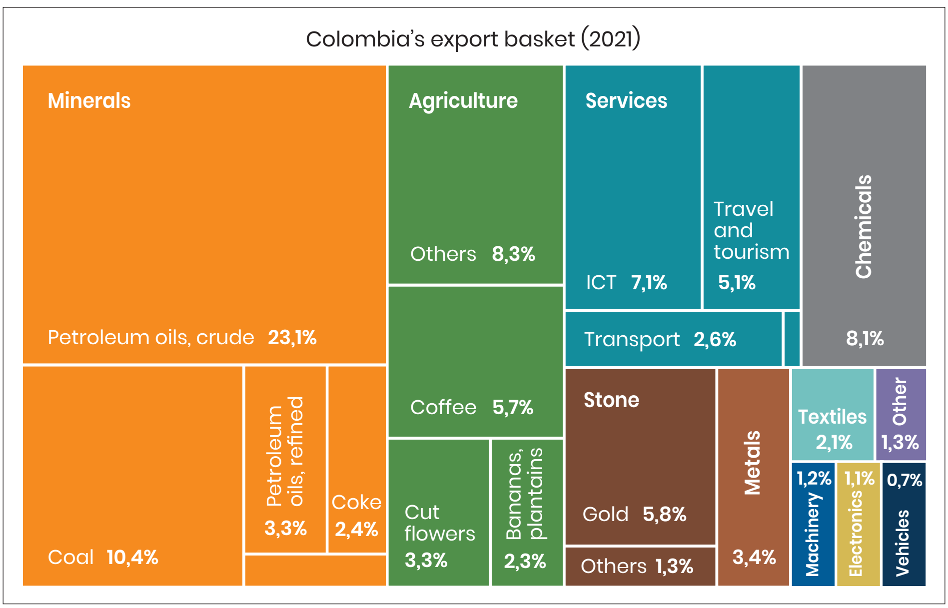
Source: Authors based on data from DANE.

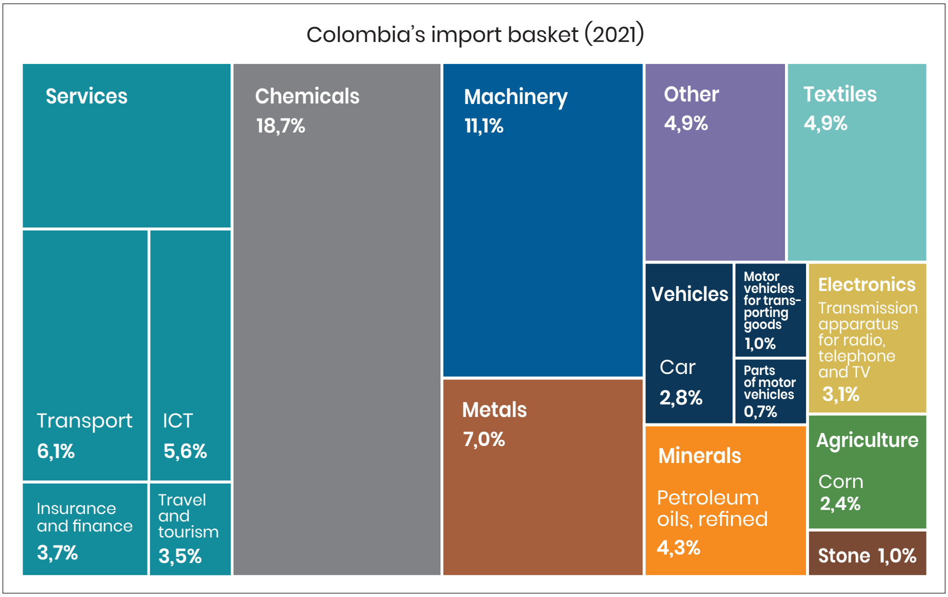
The ring in Figure 16 shows the effects of the re-primarisation resulting from the financial Dutch disease (Botta *et al.*, 2016), as the commodity super-cycle that strengthened mining's contribution to growth generated a parallel process of deindustrialisation and strengthening of other non-tradable sectors associated with financial income, such as services (accounting for an average of 32% of growth) and construction (16% of growth). Another noteworthy feature of Colombian economic growth is the role of the state, since public administration expenditures (14% of growth) are a great dynamising factor both at the macro level and in many territories of the country.

In the previous section, reference was made to the fact that the result of the external balance was taken as a given, i.e., in the short term, the country has very little freedom to influence it, which implies that present results depend on the type of relationship established with the rest of the world, both in commercial and financial terms.

The Colombian export basket is strongly focused on the mining-energy sector, including a high dependence on crude oil production, which represents 23.1% of the basket. Oil (crude or refined) alone accounts for just over 26.4% of all products exported by Colombia during 2021, while coal and its derivatives account for 12.8%. The next largest sectors are services (mainly tourism and transport) and agriculture (coffee, flowers, and bananas). These three sectors (mining-energy, services, and agriculture) alone account for just over 79.7% of the 2021 export basket (Figure 17).

Figure 17. ***Colombia's export and import baskets (2021)***



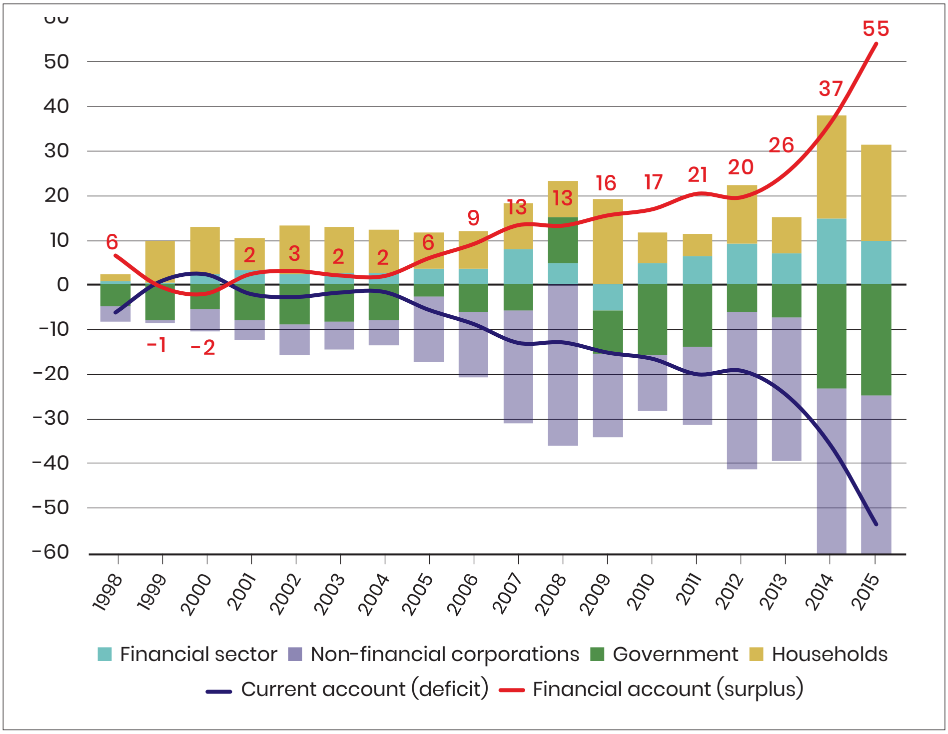


Source: Authors based on data from Atlas of Economic Complexity.

In terms of the import basket, the sector that imported the most during 2021 was services (19% of total imports), with transport and ICT (both 6%) and financial services (4%) the key subsectors. After services, the chemical and machinery sectors accounted for the largest shares. In contrast to exports, the import basket is widely diversified, a common phenomenon in countries with mainly interindustrial trade and specialised in raw materials, such as Colombia (Porcile & Holland, 2005). In general terms, Colombia tends to import goods from sectors that add much more value than the sectors it exports—namely, vehicles, electronic products, capital goods, and home appliances, which accounted for about 45% of total imports in 2021 (Figure 18).

This trade imbalance partly explains why the country has steadily increased its current account deficit since 2005. Non-financial corporations have contributed more than any other sector to the current account deficit, consistently increasing their obligations to the rest of the world since 2008. The government has also contributed to increasing the current account deficit, maintaining a growing trend in its external obligations. Households, conversely, are the best performing institutional sector, remaining in surplus during the period analysed, mainly because of remittances sent by Colombians living abroad.

Figure 18. ***Trade balance (1998–2015, trillions of COP)***



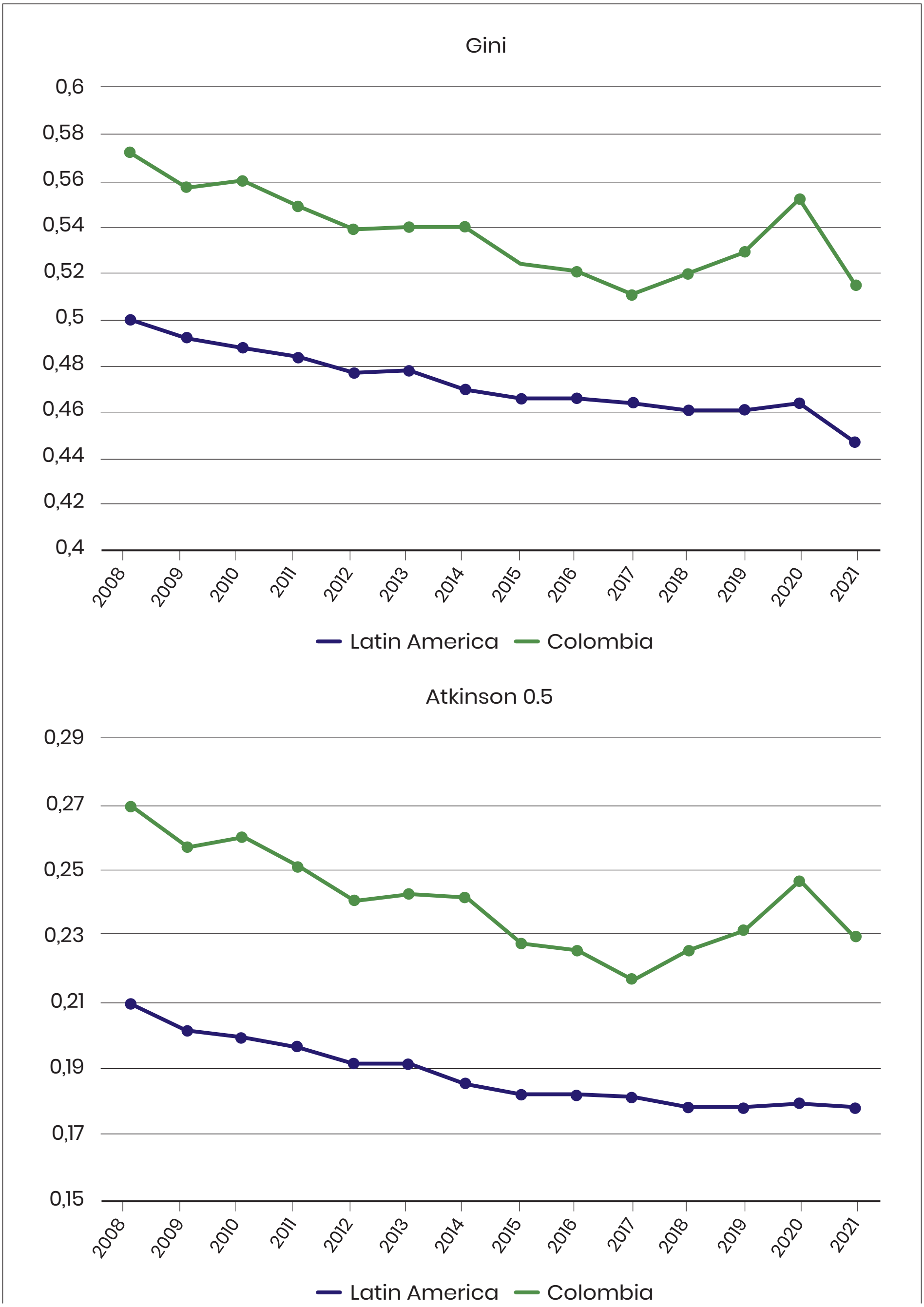
Source: Authors based on data from the special interinstitutional committee (CEI)-DANE.

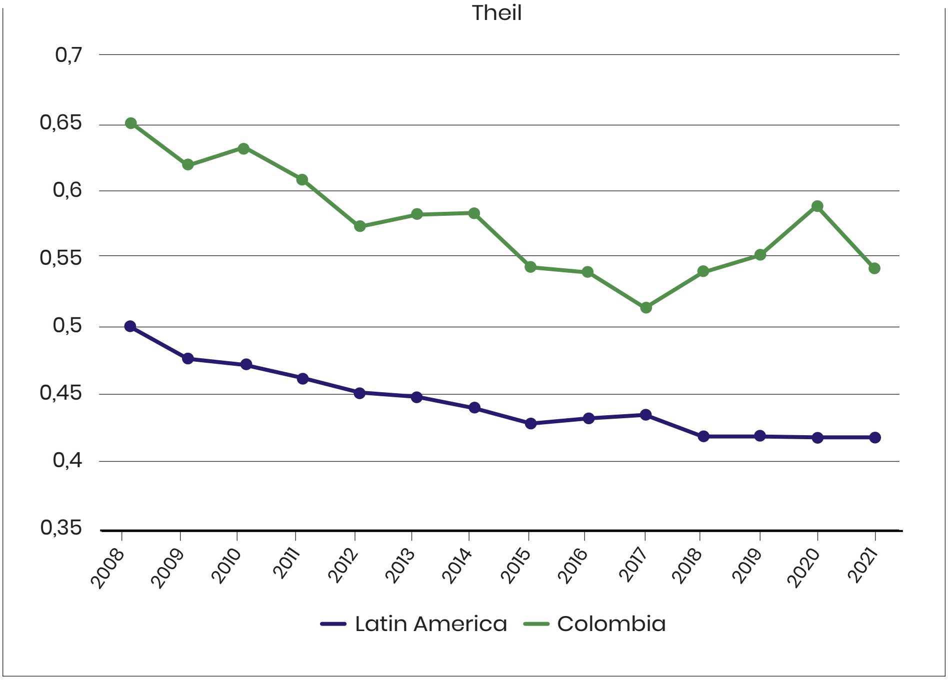
2.3. Inequality

The specificities of the Colombian production regime—typical of a rentier model—, in particular the dynamics of the mining-energy and services sectors (mainly the financial corporations), have sharpened a social structure that is markedly unequal. Indicators of income, wealth, and land ownership distribution show an unequal society, and this structure perpetuates the production regime because high concentrations of income[12] and wealth[13] weaken the purchasing power of the majority of the population, which in turn reinforces dependence on credit and household indebtedness (Guevara Castañeda, 2015).

12. According to the World Inequality Database (WID), in Colombia in 2021, the top 1% of the population in terms of income received 19.9% of the total pre-tax income of the economy; and the top 10% received 54.7%.
13. Also according to the WID, in Colombia in 2021, the top 1% of the population in terms of net personal wealth owned 34% of the total wealth of the economy; and the top 10% owned 64.8%.

Figure 19. ***Gini, Atkinson 0.5, and Theil indexes***





Note: All indicators are between 0 and 1, with 0 representing perfect equality and 1 representing perfect inequality.
Source: Authors based on data from ECLAC.

Income inequality indicators have been improving, but efforts to reduce inequality have not yielded substantial results, with inequality levels remaining above the Latin American average (see Figure 19). However, between 2008 and 2021 the overall trend for the region was downward, since 2018 income inequality indicators have been increasing. This trend was most acute in 2020, but changed in 2021.

Another institutional factor that plays an important role in inequality is taxation. Garay *et al.* (2020) show that the Colombian tax system is regressive because different tax rates are applied to people and firms in a non-progressive way: people and firms in the lowest deciles pay tax rates that are effectively higher than those of individuals in the highest deciles. In 2017 the top 0.1% of firms, by gross income, paid an average effective tax rate of 2%, while firms from the remaining 99.9% paid up to 2.32%.

Income inequality is reinforced by unequal access to land. The highly asymmetrical distribution of land and land access in Colombia (land Gini close to 0.9) has been fuelled by institutional characteristics such as the absence of structural agrarian reforms, the weakness of the state and its inability to control different territories, and the presence of illegal actors in the armed conflict who have accumulated land to gain wealth and power (Centro Nacional de Memoria Histórica, 2016).

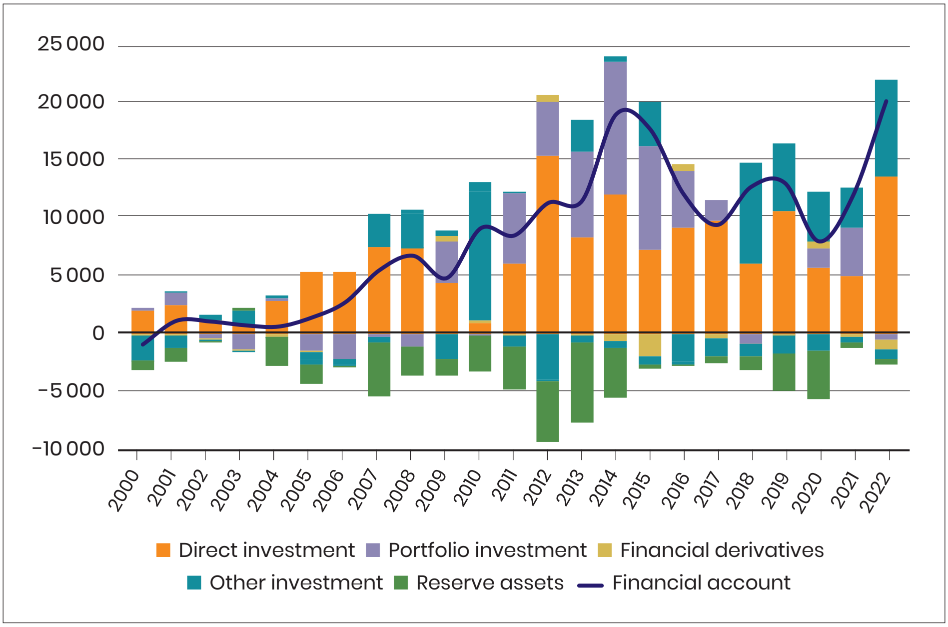
Most indicators worsen when disaggregated by gender. According to the World Bank's World Development Indicators, in 2019 women received 36.2% of the total pre-tax labour income of the economy. Opportunity to access the labour market is also unequal, as women spend more time on care activities than men; according to DANE, in the period 2016–2019, women spent 1.2 times longer completing these tasks than men. However, also according to DANE, in 2021 women represented a smaller share of the poor in Colombia than men, at 40.3%.

In Colombia, as in other regions of the world and particularly in periphery countries, measures to deal with the pandemic and its effects reversed progress in terms of reduction of poverty and inequalities (ECLAC, 2020a). By the end of 2020, 3.6 million people had fallen into poverty in Colombia. The population living in multidimensional poverty increased from 30.6% of the total population in 2019 to 32.9% in 2020. Poverty in Colombia's countryside and rural areas reached 46% of the population in 2020. Regarding monetary poverty, 39.3% of the Colombian population lives below the poverty line. These characteristics of the social structure generate tensions in both the social and political arena: in Colombia these have been increasing exponentially in the twenty-first century (Archila Neira, 2019).

2.4. Financial profile

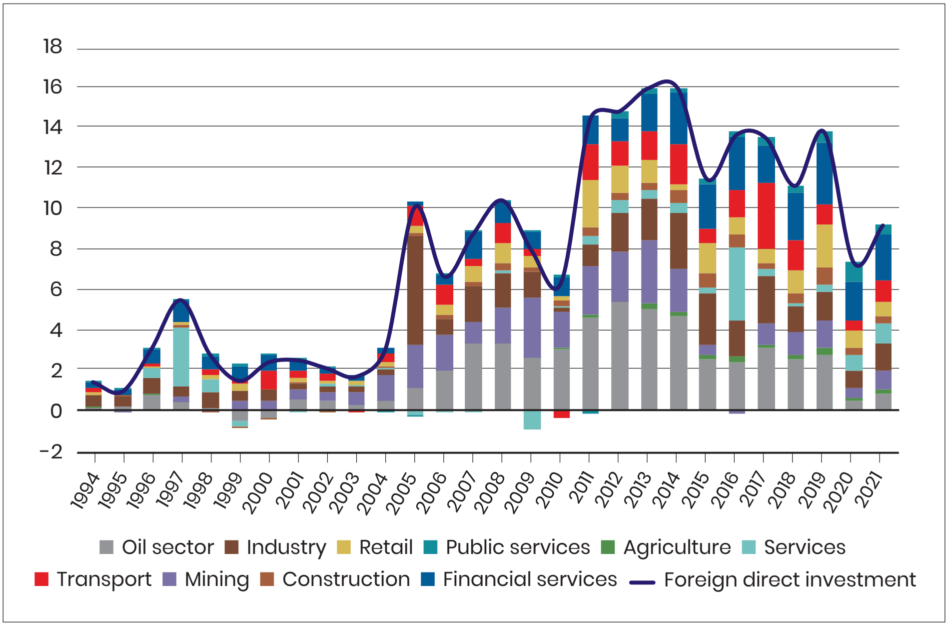
The result in the financial account is largely explained by foreign direct investment and portfolio investment, driven by the international commodity price boom and the abundance of liquidity in global markets. The growing surplus in the financial account from 2000 to 2014 (Figure 20) is largely a result of these features.

Figure 20. ***Financial account (millions of USD)***



Source: Authors based on data from Banco de la República.

Figure 21. ***Foreign direct investment by sector (billions of USD)***



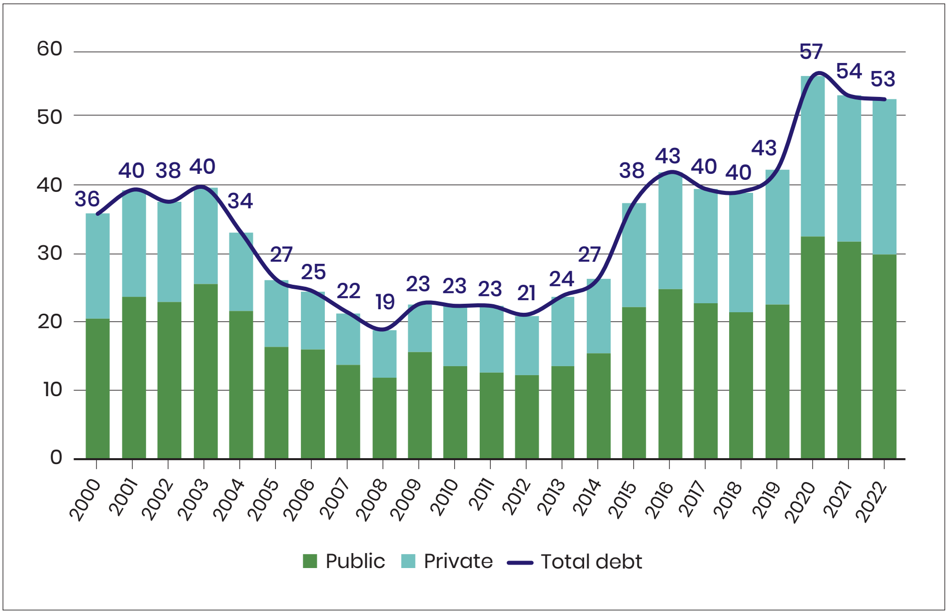
Source: Authors based on data from Banco de la República.

In Colombia between 2005 and 2021, the sector receiving the most foreign investment was oil, followed by mining and financial services. In general, foreign direct investment is highly volatile and sensitive to international commodity prices and international liquidity (Figure 21).

2.5. Debt and risk

Both external and domestic flows to finance the private and public sectors are on an upward trend. The participation of the government and the private sector reflects behaviour in line with the features noted in section 1.3.1, concerning the commodity super-cycle, the abundance of international liquidity, and the deliberate decisions to reduce public indebtedness, contrasting with rising indebtedness in the private sector. In 2020 both public and private indebtedness increased due to the COVID-19 pandemic, bringing Colombian debt to almost 57% of GDP (Figure 22).

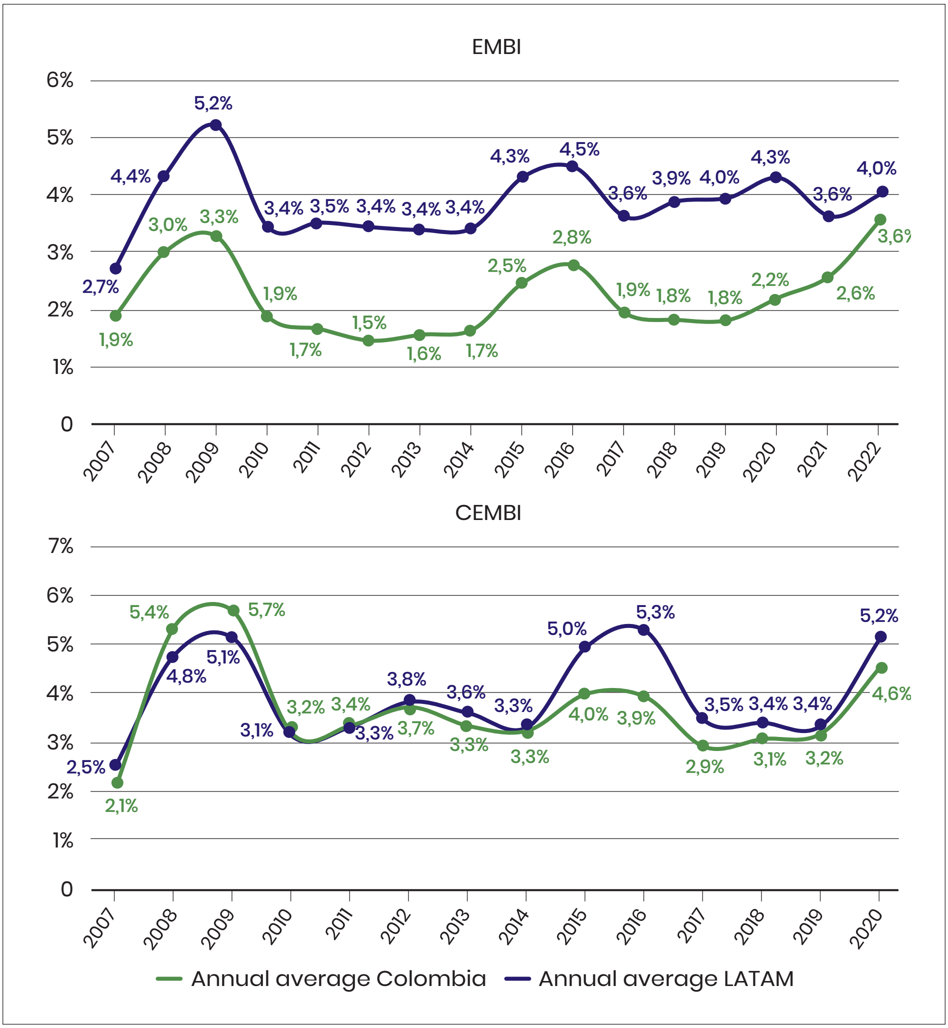
Figure 22. ***Public and private debt (as a percentage of GDP)***



Source: Authors based on data from Banco de la República.

Colombia's annual average Emerging Markets Bond Index (EMBI) has typically been lower than the Latin American average, although both Colombia and Latin America have experienced some identical trends: slight increases in 2008–2009, due to the financial crisis in developed countries, and in 2016, an election year in the United States. Since 2020, however, the gap between Colombian country risk and that of other countries in the region has been closing because of the pandemic, geopolitical tensions in Europe, and changes in the dynamics of international capital markets (see Figure 23).

Figure 23. ***Emerging Markets Bond Index (EMBI) and Corporate Emerging Markets Bond Index (CEMBI), Colombia and Latin America***

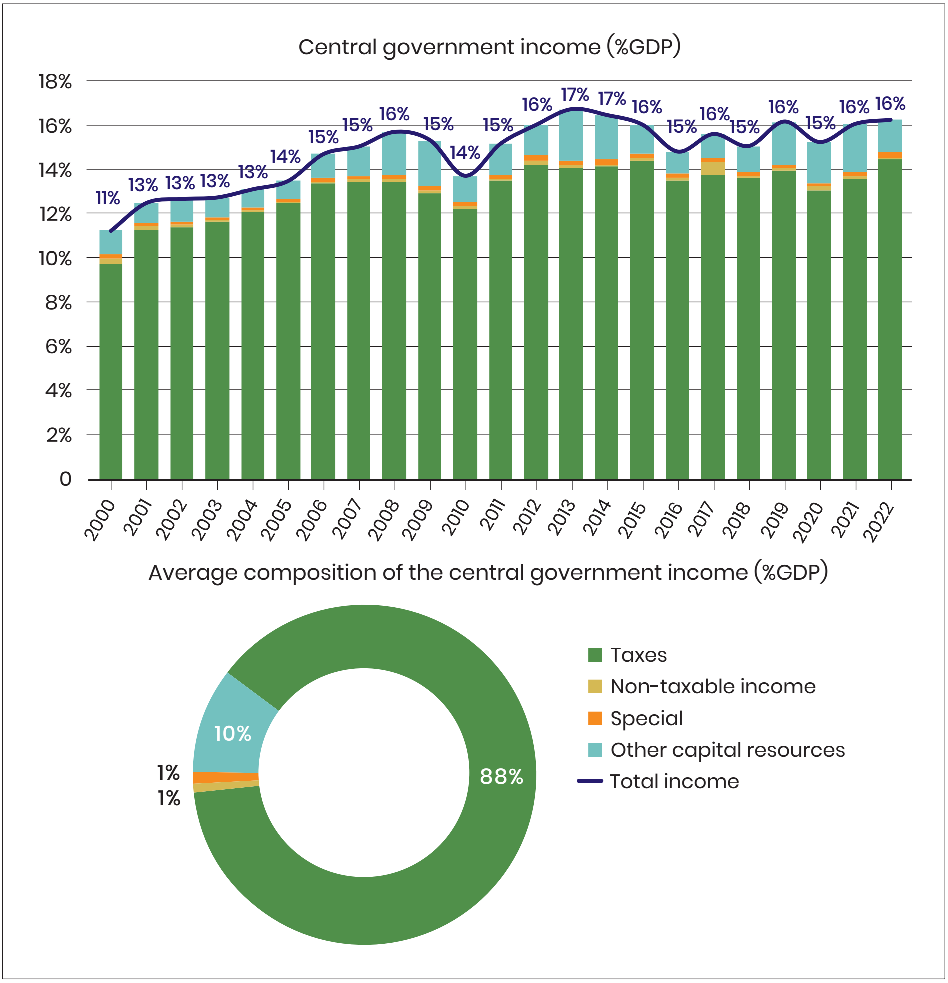


Source: Authors based on data from JP Morgan.

2.6. Fiscal performance profile

The Colombian central government's revenues progressively increased during the period 2000–2022, reaching 16% of GDP in 2022. On average, 88% of the state's revenues comes from tax collection. A further 10% comes from capital resources (Figure 22), which come from the profits of the main state-owned enterprises, particularly Ecopetrol (65%), and, to a lesser extent, public firms (3%), Banco de la República (the central bank) (1%), and others (Figure 23). Revenues are thus highly dependent on the economic cycle and specifically on the dynamics of oil production and the oil market.

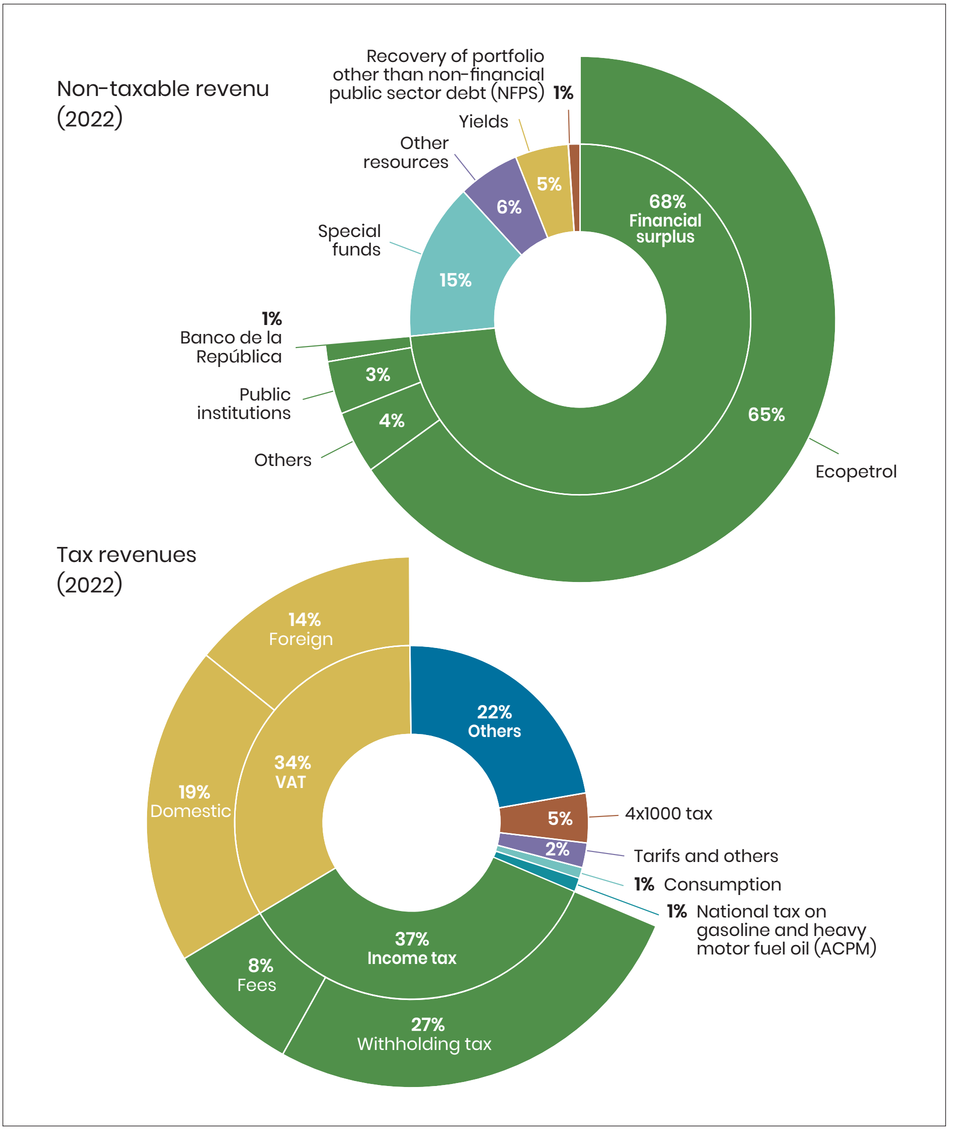
Figure 24. ***Central government income (2000–2022)***



Source: Authors base don data from the Ministerio de Hacienda y Crédito Público.

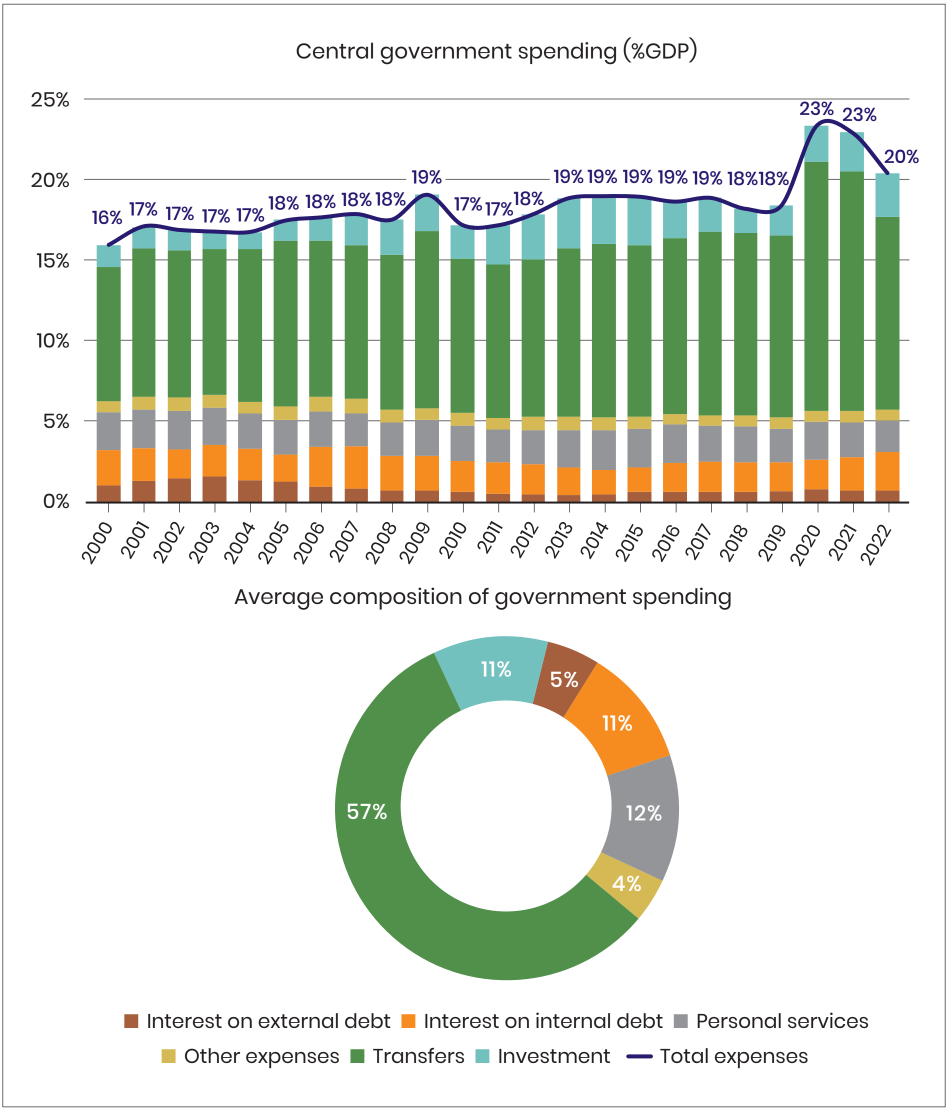
In 2022, the sum of the surpluses of all public companies represented 73% of total non-tax revenues. In the same year, most of the tax revenues came from value-added tax (VAT) (33%) and income tax (35%). The levy on financial transactions (known as 4x1000) contributed 5% of tax revenues. Thus, VAT, 4x1000, and income tax together accounted for 73% of tax revenues in Colombia (see Figure 25).

Graphique 25. ***Non-tax revenues and tax revenues in Colombia (2022)***



Source: Authors based on data from the Ministerio de Hacienda y Crédito Público.

Figure 26. ***Central government spending (2008–2022)***



Source: Authors based on data from the Ministerio de Hacienda y Crédito Público.

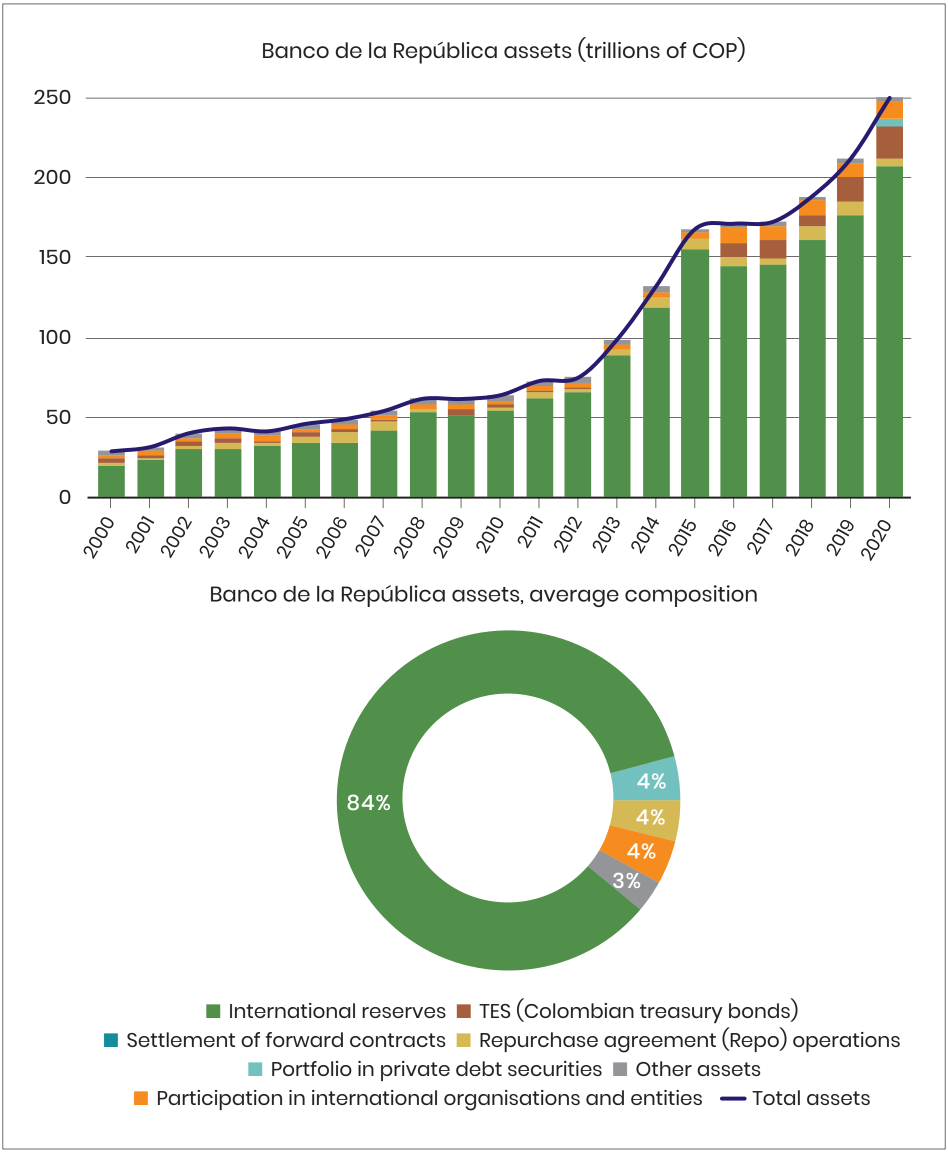
In 2022, Colombia's spending reached 20% of GDP (Figure 26). The average distribution of public spending between 2000 and 2022 is as follows: transfers (transfers to territorial entities for use in health, education, pensions, etc.), 57%; general expenses, 4%; personal services, 12%. These areas represent close to 74% of total average spending. Interest paid on internal and external debt represents 15% of spending, while investment financing accounts for the remaining 11%. A large part of public spending thus has fixed allocations, while investment spending remains autonomous, making it the usual adjustment variable to achieve certain fiscal deficit targets, particularly those associated with current regulations.[14]

2.7. Monetary policy performance profile

The main objective of Colombia's monetary policy is to preserve the purchasing power of the currency[15] while achieving general economic policy objectives, such as economic growth and full employment (Figure 27). However, with the exception of inflation control, Colombia's central bank, Banco de la República, has been very passive, playing practically no role in the achievement of other objectives.

14. Colombia implemented a fiscal rule on the behaviour of the current deficit through Law 1473 of 2011. The rule basically delimits the behaviour of the central national government with respect to the level of current indebtedness. The current fiscal deficit must meet targets recommended by the Fiscal Rule Advisory Committee, which calculates the current deficit targets based on estimates of the growth gap (current GDP with respect to potential GDP) and the behaviour of oil prices with respect to their historical values. Thus, the current deficit targets are assumed to be equivalent to the sum of the structural deficit and the cyclical deficit (resulting from the effects of the economic cycle). The application of Law 1473 was suspended during the COVID-19 pandemic, even though it did not include a suspension clause.
15. Articles 371, 372, and 373 of the Political Constitution of the Republic of Colombia.

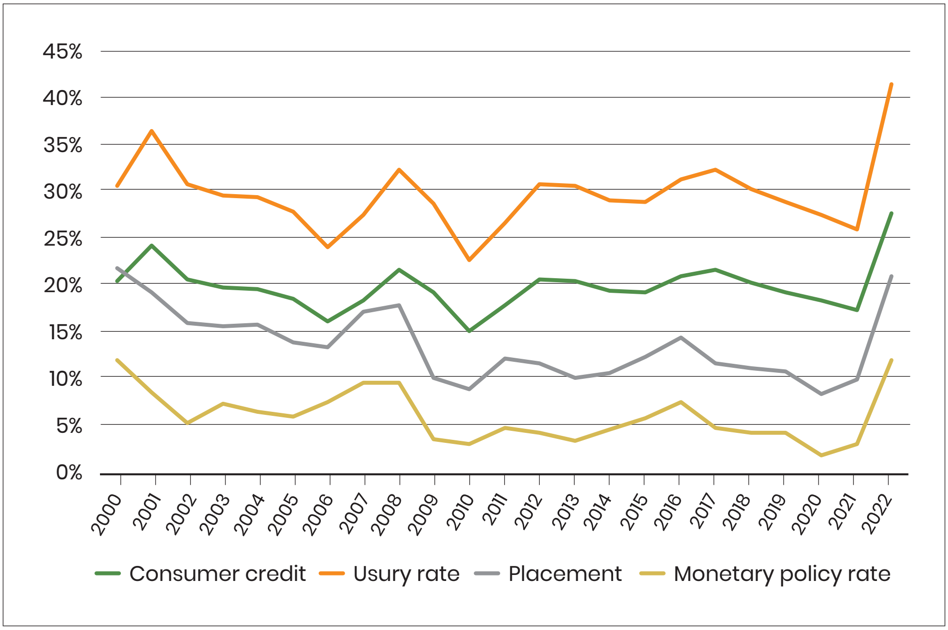
Figure 27. ***Banco de la República assets***



Source: Authors based on data from Banco de la República.

International reserves have become the main asset of Colombia's central bank, partly because the accumulation of these reserves is considered a "macro-prudential" policy in the face of external vulnerability. On average, international reserves represent 84% of the assets held by Banco de la República. Bonds issued by the Colombian government (TES) represent, on average, 4% of Banco de la República's assets, showing some interaction between the bank and the Ministerio de Hacienda y Crédito Público. These securities are acquired, however, through the secondary market, and they are treated as liquidity operations by Banco de la República, and not as financing through primary issuance. Repurchase agreement (repo) operations and assets in multilateral organisations make up the rest of the assets.

Figure 28. ***Interest rates, Colombia (2000–2022)***



Source: Authors base don data from Banco de la República and Superintendencia Financiera.

The interest rate management policy has a direct impact on consumer credit, and the placement rate of commercial banks follows the trend of the monetary policy interest rate. For the period 2000–2021, the average monetary policy interest rate was 5.8, while the average placement rate for the same period was 13.3%, a spread of 750 basis points. The gap in the consumer credit rate was 1,370 basis points above the central bank's intervention rate (Figure 28). In 2022, the rates values increased for inflation control policy of the monetary authorities.

3. Determinants of vulnerability to the transition to a low-carbon economy

3.1. The three transition gaps: Social, external, and environmental

By ratifying the Paris Agreement, Colombia explicitly committed to achieving a low-carbon economy by 2030 and a pattern of accumulation and growth decoupled from the production and consumption of fossil fuels. These commitments demand recognition of the set of constraints and tensions that will arise in the process of "ecological structural change," in which sunrise industries will surge and sunset industries will decline (Espagne *et al.*, 2021; Semieniuk *et al.*, 2020).

Major transformations are needed, and the outcome will depend on the chosen trajectory. What is certain is that the process will involve distributive conflicts, intersectoral tensions, and uncertainties. Progress, setbacks, slowdowns, and changes of course will be recurrent situations in the transition process. The state and the authorities must act as countervailing forces and manage societal conflicts.

Given the macroecological situation (see section 1.2), in both its institutional and biophysical dimensions, and the macroeconomic situation in its different perspectives (commercial, financial, and poverty and inequality) (see section 1.3), the methodology of the three gaps developed by ECLAC (2020*b*) is considered the most appropriate way to identify at an aggregate level the set of constraints and tensions of the energy transition in Colombia.

The three gaps are: (1) the social gap; (2) the environmental gap; and (3) the external sustainability gap.[16] The baseline for determining the three gaps in the growth rate is constrained by the balance of payments. This relationship is known as Thirlwall's law (Thirlwall, 1979). This law states that, in the long run, when the balance of payments is in equilibrium, i.e., its balance is equal to zero, the economy will be able to grow at a maximum rate, the value of which is determined by the structure of its foreign trade and the pattern of productive specialisation. Formally, it can be expressed as:

$$y_p = \frac{\varepsilon}{\theta} y_c \qquad (1)$$

16. For similar research on multiple policy objectives, see Valdecantos (2021).

where:

y_p = *rate of growth of the peripheral economy restricted by the balance of payments*

y_c = *the growth rate of the centre of the world*

ε = *world income elasticity of exports*

θ = *national income elasticity of imports*

We can determine the long-term growth rate of the Colombian economy (y_p) using the estimates of elasticities produced by ECLAC (2020*b*) and assuming that the world GDP growth rate maintains its average record for the period 1993–2020.

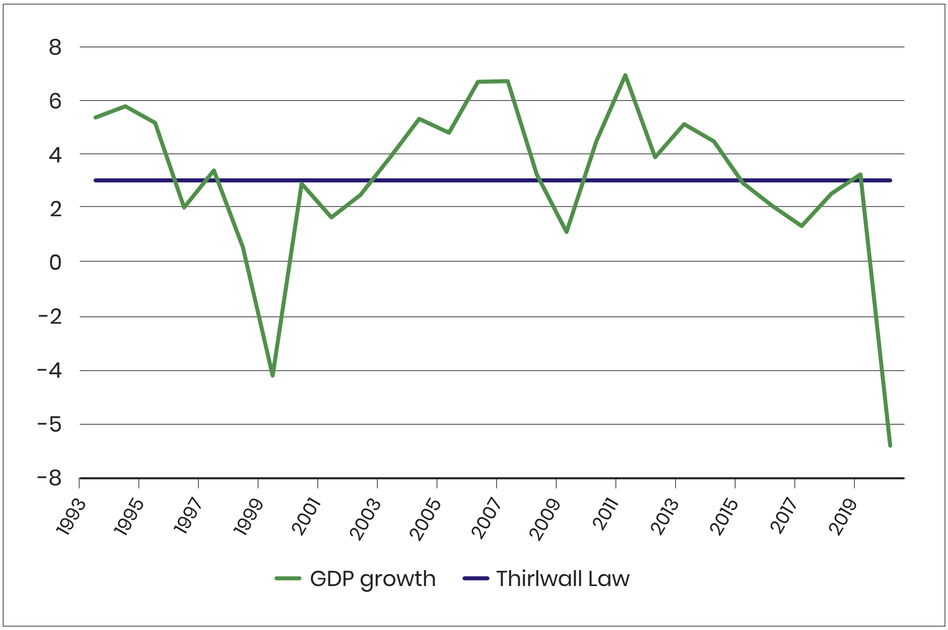
Table 1.

WORLD INCOME ELASTICITY OF EXPORTS	NATIONAL INCOME ELASTICITY OF IMPORTS	WORLD GROWTH RATE (1993–2020)	COLOMBIA'S LONG-RUN GROWTH RATE
1.7	1.6	2.9	3.1

Source: Authors, based on data from ECLAC (2020b) and the World Bank.

Figure 29 shows Colombia's long-run growth rate (Thirlwall's law) and the observed economic growth rate. Three periods can be distinguished. The first is the unsustainable boom at the beginning of the 1990s, when the economy grew above the rate consistent with the balance-of-payments equilibrium. This rate could not be maintained and led to a financial crisis at the end of the 1990s—the worst collapse of the country's real economy in the twentieth century. The second period is associated with the ensuing economic recovery and the boom in the prices of raw materials and commodities, hence easing external restrictions and allowing growth rates well above the rate consistent with the balance-of-payment equilibrium. However, these dynamics were only transitory; the resources of the boom were not used to lead a process of progressive structural change, as evidenced by the rapid fall in the growth rate, which overlapped with the public health crisis resulting from the COVID-19 pandemic (see section 1.3.2).

Figure 29. ***Growth constrained by the balance of payments***



Source: Authors based on data from the World Bank.

To determine the social gap, it is necessary to determine what ECLAC (2020*b*) calls the growth rate for equality (y_s). Samaniego and Alatorre (2022, 236) define it as "the minimum growth necessary to achieve equality objectives."[17] Other authors have called it the minimum growth rate for social inclusion (Gramkow & Porcile, 2022), i.e., the minimum rate that would make it possible to reach a particular objective, in terms of distribution of income or poverty level.

Following Samaniego and Alatorre (2022), the minimum growth rate for equality—in this case, a rate that guarantees to reduce the number of people below the monetary poverty line by half during the period 2020–2030—will be estimated. For this purpose, the following relationship between the poverty growth rate $\left(\frac{dP}{P}\right)$ and economic growth $\left(\frac{dY}{Y}\right)$ is assumed:

$$\frac{dP}{P} = \eta \frac{dY}{Y} \qquad (2)$$

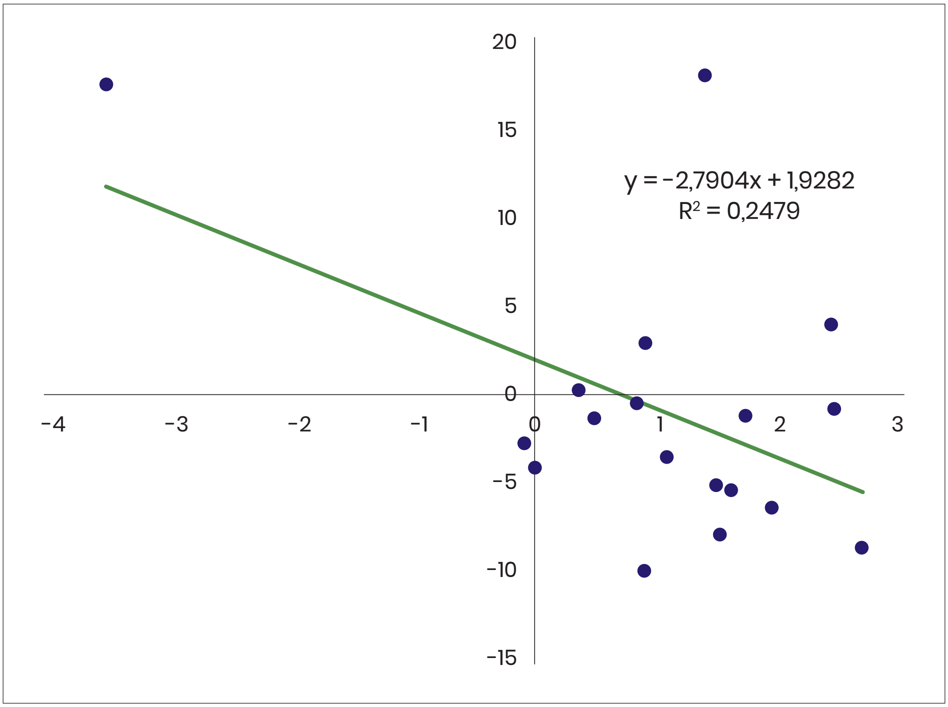
17. Our translation.

We use work by ECLAC (2020b), Gasparini, Cicowiez, and Sosa Escudero (2014), and Ravallion (2004; 1997) to estimate the growth elasticity of poverty reduction. The novelty of the approach lies in correcting the response of the poverty rate to economic growth using the Gini inequality index. The formal model to be estimated is as follows:

$$\frac{dP}{P} = c + \beta(1 - Gini) \cdot \frac{dY}{Y} + \epsilon \qquad (3)$$

The model postulates that there is a linear and constant relationship between poverty reduction and GDP growth rate. Figure 30 presents the simple estimation of equation (3) for the period 2002–2020.[18]

Figure 30. ***Model of equation (3) for the period 2002–2020***



Source: Authors, based on data from ECLAC.

18. The poverty rate, the Gini coefficient, and the economic growth data on which the estimate is based are annual.

The estimation of the constant is negative, and the R-squared yielded by the equation is standard in this type of exercise. Table 2 uses the estimated parameters and the level of inequality in Colombia in 2020, with a Gini=0.52 to determine the minimum growth rate for equality.

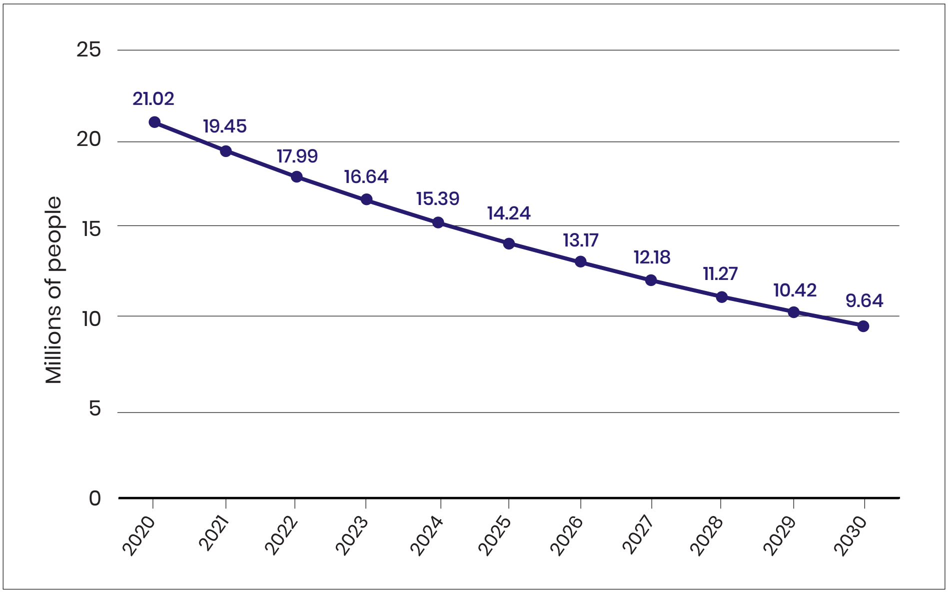
Table 2.

POVERTY VARIATION	COEFFICIENT	COEFFICIENT * $(\frac{dY}{Y})$	MINIMUM GROWTH FOR EQUALITY
$(\frac{dP}{P})$	-1.24992	-0.0749952	6%

Source: Authors based on data from ECLAC.

If we assume a poverty reduction target of 50% between 2020 and 2030, the estimated growth rate for equality is 6%. Figure 31 shows the trajectory of monetary poverty, associated with a minimum growth rate for equality of 6% per year between 2020 and 2030. The objective of reducing the population living below the monetary poverty line by 50% is met, due to the spillover effect of growth.

Figure 31. ***Projected monetary poverty, assuming a minimum growth rate for equality of 6% per year***



Source: Authors based data from DANE.

Finally, the maximum sustainable growth rate must be determined, consistent with the Nationally Determined Contributions (NDCs) that Colombia committed to under the Paris Agreement and that President Duque broadened in December 2020. ECLAC (2020b) calls it the green growth rate consistent with the sustainability frontier (y_e). To determine the maximum growth rate that complies with GHG emissions commitments in 2030, the following identity is assumed:

$$GHG^{19} = \frac{GHG}{Y}.Y \qquad (4)$$

Taking logarithms on both sides and finding the derivatives with respect to time, we can express the identity (4) in terms of growth rates:

$$\frac{dGHG}{GHG} = \frac{dZ}{Z} + \frac{dY}{Y} \qquad (5)$$

Where,

GHG = the rate of growth of GHG emissions

$\frac{dZ}{Z}$ = *energy efficiency growth rate*

$\frac{dY}{Y}$ = *growth rate of the economy's GDP*

The green growth rate (y_e)[20] compatible with the sustainability frontier can be obtained as:

$$y_e = \frac{dGEI}{GEI} - \frac{dZ}{Z} \qquad (6)$$

Colombia has officially committed to reducing its net GHG emissions by 51% by 2030. Thus, from a baseline of 291.3 million tonnes of CO_2 in 2020, the country must reduce its emissions to 169.4 million tonnes of CO_2 in 2030 (Ministerio de Ambiente y Desarrollo Sostenible, 2020, 28–32). According to these ambitious targets, the emissions reduction rate should be on average -5.3% per year for the period. Figure 32 shows the baseline scenario and the decarbonisation trajectory for 2020–2030.

19. This equation is a simplified form of the Kaya identity (Kaya & Yokobori, 1997):

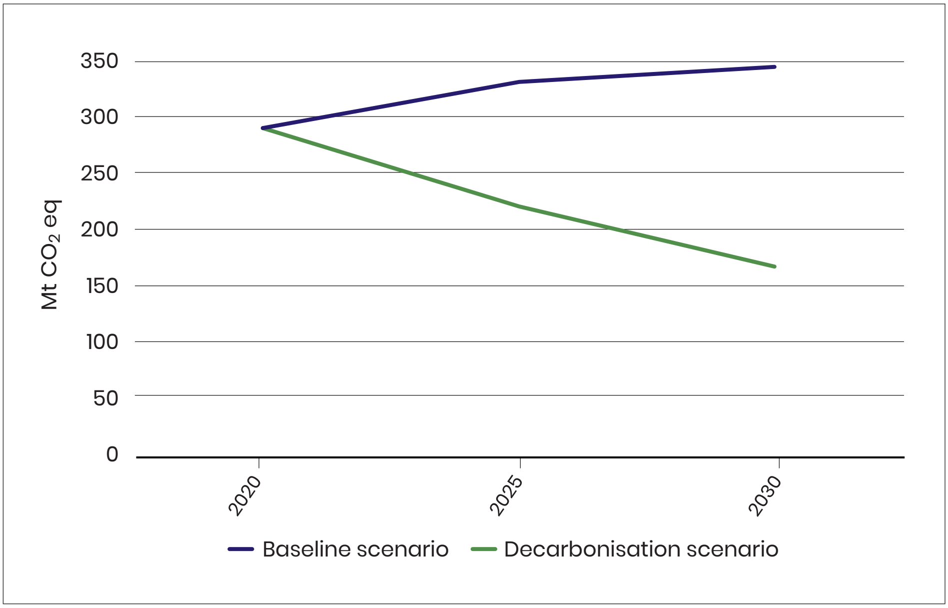
N = *Population*
Y = *Gross domestic product*
C^E = *Total energy consumption*
GHG = *Total GHG emissions.*

$$GHG = N.\frac{Y}{N}.\frac{C^E}{Y}.\frac{GHG}{C^E}$$

20. This is the maximum growth rate that the economy can achieve while still meeting its GHG emissions reduction target.

To obtain the green growth rate compatible with the sustainability frontier, an estimate of the energy efficiency growth rate $(\frac{dZ}{Z})$ is needed. Since it is practically impossible to make projections of such variables, due to the radical uncertainty of technological innovation processes, this analysis follows Bárcena *et al.* (2020) in assuming that the best estimate is the average energy efficiency growth rate for 1990–2014: -2.2%.

Figure 32. ***Projection of GHG emissions (2020–2030)***



Source: Authors, base don data from the Ministerio de Ambiente y Desarrollo Sostenible.

Table 3 presents the estimate of the ecological growth rate compatible with the sustainability frontier. Finally, Table 4 presents the three energy transition gaps in Colombia between 2020 and 2030.

Table 3.

GHG TARGET GROWTH RATE (2020–2030)	ENERGY EFFICIENCY GROWTH RATE $(\frac{dZ}{Z})$	GREEN GROWTH RATE (y_e)
-5.3%	-2.2%	-3.1%

Source: Authors based on data from Bárcena et al. (2020).

Table 4.

	SOCIAL GAP $y_s - y_p$	ENVIRONMENTAL GAP $y_p - y_e$	SUSTAINABILITY GAP $y_s - y_e$
Colombia	2.9%	6.1%	9.1%
Latin America	1.1%	3.5%	4.6%

Source: Authors.

The results of the estimation of the three gaps for Colombia show clearly the great difficulties in reconciling the three rates, i.e., in achieving convergence of the ecological growth rate, the external constraint growth rate, and the social growth rate, i.e., $y_e = y_p = y_s$. The magnitude of Colombia's three gaps far exceeds those estimated by ECLAC (2020*b*), and the comparison with Latin America in Table 4 shows that Colombia faces a bigger challenge than other countries in the region, on average. The new commitments in terms of GHG reduction by 2030 may be generating a problem of dynamic inconsistency in the energy transition, given the conditions and patterns of structural change, energy efficiency improvement, and social conflict in the country. We could call it the "transition impossibility theorem."

Conclusions

In this chapter, the macroecological (biophysical and institutional) and macroeconomic conditions of Colombia have been reviewed, in order to describe the country's context in the face of the challenge of complying with its NDC. On the production side, the responsibilities of the different institutional actors in the transition to a low-carbon economy have been evaluated, both in terms of the use of biophysical resources and in terms of GHG emissions. Frequently, it is non-financial corporations that bear the greatest responsibility for improving efficiency levels (unit of resource/unit of product, and unit of GHG emissions/unit of product). Even compared to the responsibility of the rest of the world (in terms of the total supply of the Colombian economy), the production of non-financial corporations is more inefficient. Thus, in the production sector, structural change is needed.

Next, the challenges of complying with the NDC have been analysed, considering the behaviour of the three financial balances of the economy (private, public, and external). The conclusion of this analysis is that the GHG emissions reduction targets are incompatible with the projections of fiscal behaviour presented by the economic authorities, since the adjustment in the public financial balance would imply an unsustainable result in the private balance.

Finally, the three-gap perspective (external, social, environmental) has been used to estimate the growth rate needed to simultaneously pursue poverty reduction, ensure NDC compliance, and respect balance-of-payments constraints. The results show that reconciling the different objectives presents a significant challenge. Meeting the new NDC targets for GHG emissions could generate a scenario of dynamic inconsistency in the energy transition, which we call the "transition impossibility theorem" because without changing the patterns of the production regime and the associated socioeconomic conditions, meeting the NDC targets is unfeasible and pursuing them could lead to pressure on growth and social fragilities.

However, the energy transition could follow sustainable and consistent paths if the inherited structural patterns can be altered and the necessary changes are promoted and implemented to loosen or even eliminate the identified macroeconomic constraints associated with a peripheral economy.

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An open economy model for Colombia: theoretical considerations, empirical aspects

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Chapter 2

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Chapter 2

Vulnerabilities, constraints, and opportunities of energy transition in Colombia: a structuralist approach

Introduction

In the context of modern globalisation, peripheral economies are not only affected by international real business cycles but also by the financial dynamics of advanced economies. This, added to the internal and structural features of each economy, gives rise to a set of complexities and interrelationships between domestic and external actors that must be considered when characterising developing economies theoretically and empirically. Stock-flow consistent (SFC) models attempt to close the existing methodological gaps, analysing the real and financial spheres of economies in an integrated way through the study of the balance sheets and real and financial transactions of the different institutional sectors.

This chapter describes the process of adapting and calibrating an SFC model in continuous time for the Colombian economy, emphasising the theoretical considerations that favour this type of modelling approach to study small open economies. To this end, we proceed with a detailed description of the equations composing the model, the treatment of the data that enabled us to construct the transaction-flow matrix and the balance sheet of the institutional sectors, and the calibration process of the model parameters. Finally, we present the baseline scenario.

The main aim of this model is to serve as a tool for analysis and support for various academic and policy discussions. This model will, therefore, be used in the following chapters to analyse some of the macroeconomic and financial implications associated with a reduction in fossil fuel exports (Chapter 3), different financing strategies required to meet Colombia's Nationally Determined Contribution (NDC) to the Paris Agreement and close its green investment gap (Chapter 4), and an increase in the country risk premium and other external shocks (using a slightly different model in Chapter 5).

1. Methodology

1.1. Existing macro models for Colombia

According to Espinoza *et al.* (2017), the macroeconomic models developed in Colombia to date have two main characteristics. First, most follow a mainstream approach by drawing on computable general equilibrium (CGE) models, dynamic stochastic general equilibrium (DSGE) models, and more recently on New Keynesian semi-structural state-space models (see, for example, Guarin *et al.*, 2020). Second, they are usually developed by the technical macroeconomic departments of the Banco de la República (the central bank), the Departamento Nacional de Planeación (National Planning Department), and the Ministerio de Hacienda y Crédito Público (Ministry of Finance and Public Credit), as well as by researchers attached to universities, think tanks such as Fedesarrollo, and consultancy projects supported by multilateral organisations.

CGE models have been used extensively since the 1980s and are based on the social accounting matrices of the System of National Accounts (Suescún *et al.*, 2017), which track the supply, demand, and factor income distribution dimensions of the economy. The objective of these CGE models has been to analyse the effects of different macroeconomic and policy scenarios on the economy at the national, regional, sectoral, and even household levels. Nonetheless, they have focused mostly on the real side of the economy while ignoring financial considerations.

Among the most recent CGE models, Haddad *et al.* (2022) analysed the regional economic impacts of royalties, Velasco-Martínez and Cárdenas-Hurtado (2015) constructed long-run macroeconomic scenarios for the central bank, and Hernández (2012) analysed the effects of payroll taxes on the labour market. It is worth mentioning that these models have also been used in Colombia to analyse the distributional effects of carbon taxes (Romero *et al.*, 2018), the macroeconomic effects of Colombia's first Nationally Determined Contribution to the Paris Agreement (Álvarez-Espinosa *et al.*, 2017), and the economic impacts of climate change on agriculture (Tapasco *et al.*, 2015).

Regarding DSGE models, their application in Colombia started to grow in the late 1990s in line with computational advances and developments in the New Keynesian literature, regarding the introduction of nominal and real rigidities and other frictions to the classical real business cycle models (Rodríguez Revilla, 2011). These models have been developed mainly by central bank researchers to build monetary policy scenarios and simulate macroeconomic shocks, calibrated for a steady state aiming to represent on average the characteristics of the Colombian economy.

Among the main DSGE models, the Policy Analysis Tool Applied to Colombian Needs (PATACON) developed by González *et al.* (2011) stands out, which aims to support the monetary policy decisions of the central bank. Similarly, the DSGE Fiscal Model for Colombia (FISCO) developed by Rincón *et al.* (2017) intends to conduct fiscal analysis and understand its interactions with monetary policy. More recently, these models have also been used to introduce risk balance scenarios into the macroeconomic forecasts of the central bank, as done by Méndez *et al.* (2021), who couple a DSGE model (PATACON) and a New Keynesian semi-structural model (4GM). Finally, regarding semi-structural models, some relevant applications of the main central bank model (4GM) correspond to the analysis of the relationship between weather shocks and inflation expectations in a New Keynesian framework (Romero & Naranjo, 2023).

On the other hand, although there have been previous contributions to SFC modelling in Colombia (Escobar, 2016; Guevara Castañeda, 2015), the model presented here differs in several respects. First, it details the main features and interactions of all institutional sectors of the economy, while Guevara Castañeda (2015) analyses a closed economy and Escobar (2016) aggregates households and financial and non-financial corporations into a single private sector. Second, it is an empirical and continuous-time model with a high level of disaggregation and a significant number of real and financial transactions, while the aforementioned studies present rather stylised models with a small number of variables and in discrete time. Third, the calibration of the model, the construction of the matrices, and the analysis of the results are carried out based on observed data, while in the previous contributions such exercises are not carried out or not presented.

1.2. Stock-flow consistent modelling

The SFC approach follows a financial accounting methodology that considers that agents in an economy are connected to each other through monetary stocks and flows, de facto creating a multilayered network of financial stock and transactions. Therefore, each real or financial transaction has a counterpart for another agent and will be reflected in the change of its wealth at the end of a given period (Godley & Lavoie, 2006). As argued by Michell and Toporowski (2012, 2), any model that attempts to represent the main dynamics of a modern economy must comprehensively incorporate the real and financial flows that result from the production and exchange process.

Based on a tight accounting framework (see section 3 for a description of the different empirical matrices composing the framework), the approach comprehensively integrates agents' income and expenditure flows, identifies which sectors run deficits or surpluses and for what reason, and captures how deficits are financed and how savings are allocated across assets. In this way, it is possible to understand how changes in income and expenditure flows alter the indebtedness and wealth of different sectors and to analyse how changes in interest rates, exchange rates, and asset prices affect the real sphere of the economy. Similarly, it also allows us to better understand the effects of booms in financial and credit markets and the emergence of financial constraints on the economy, as well as to understand the factors that influence the debt (un)sustainability of different institutional sectors.

Within the advances in SFC modelling (see Godley & Lavoie, 2006, for a detailed description of the approach and Nikiforos & Zezza, 2017, and Caverzasi & Godin, 2015, for literature reviews), three important lines of development, which are relevant to our task, can be identified in recent years. First, the construction of empirical SFC models (see, for example, Zezza & Zezza, 2022; Zezza & Zezza, 2019; Zezza, 2018; Miess & Schmelzer, 2016; Papadimitriou *et al.*, 2020; Caverzasi & Godin, 2015; Kinsella & Tiou-Tagba Aliti, 2012). Second, the construction of open economy or multi-country models (see, for example, Yilmaz & Godin, 2020; Ioannou, 2018; Mazier & Valdecantos, 2015; Valdecantos & Zezza, 2015; Bortz, 2014; Lavoie & Daigle, 2011). Third, the construction of ecological or environmental SFC models (see, for example, Jackson & Victor, 2020; Deleidi *et al.*, 2020; Bovari *et al.*, 2018; Naqvi & Stockhammer, 2018; Dafermos *et al.*, 2017; 2018; Jacques *et al.*, 2023; Yilmaz *et al.* 2023).

The model presented in this chapter is based on the benchmark model of Yilmaz and Godin (2020). It combines a multisectoral production structure with the SFC framework and the continuous-time dynamic macrofoundations approach of the Bielefeld school of macroeconomics (Chiarella & Flaschel, 2006; Flaschel, 2008; Flaschel *et al.*, 2008; Charpe *et al.*, 2011; Chiarella *et al.*, 2012; 2013). We specifically focus on dynamic disequilibrium processes and emphasise the significance of capital inflows for small open economies like Colombia (Frankel, 2010; Borio & Disyatat, 2015). Furthermore, we analyse how these inflows affect the domestic economy through channels like international trade (Blecker, 2016), liquidity (Kaminsky *et al.*, 1997), and balance sheet effects (Bernanke & Gertler, 1995).

The model's stock-flow structure is well-suited for examining external imbalances and a country's susceptibility to financial crises, as well as the macro-environmental channels that can propagate the initial loss in fossil fuel exports. This is due to the fact that the model monitors not only the current account imbalances and the first-round negative effects of a global transition on the trade balance, but also the gross exposure to external financial risks, which is typically overlooked when evaluating external imbalances (Borio & Disyatat, 2011; 2015). The endogenous international investment position and the dynamics of available foreign exchange reserves explicitly monitor the latter. Additionally, the model's structure facilitates a thorough investigation of how such financial risks are distributed within a country through the accumulation of external debt in the balance sheets of all institutional sectors. The model also permits detailed feedback effects such as price effects through the evolution of interest rates and quantity effects such as quantity rationing in the foreign exchange market and the overall indebtedness of the Colombian economy.

2. Empirical stock-flow consistent model construction

This section describes the model developed for the Colombian economy, showing its accounting structure and the theoretical relationships between institutional sectors. The appendix at the end of this chapter contains the list of all variables' name, description, nature (real or monetary), and currency (when applicable).

2.1. Transaction-flow matrix and balance sheet

Table 1 shows the transaction-flow matrix (TFM) that characterises the Colombian model. Each column represents an institutional agent and each row represents a transaction. There are six institutional agents (one per column): non-financial corporations (NFCs), households, financial corporations (FCs), the central bank (CB), the government, and the rest of the world (RoW). Three of them (NFCs, FCs, and CB) are divided, for ease of presentation, into two columns representing the current and capital accounts of these sectors.

Table 1. ***Transaction-flow matrix of the Colombian model***

Variable	Non financial corporations Current	Non financial corporations Capital	Households	Financial corporations Current	Financial corporations Capital	Central bank Current	Central bank Capital	Government	RoW	Σ
Consumption of NFCs' products	$+C$		$-C_H$					$-C_G$		0
Public services								$+PS_G$ $-PS_G$		0
Consumption of FCs' services			$-(INS_H+COM_H)$	INS_H+COM_H						0
Interm. cons. of NFCs' products	$+IC$			$-IC_B$				$-IC_G$		0
Interm. cons. of FCs' services	$-(INS_F+COM_F)$			INS_F+COM_F						0
Gross fixed capital formation	$+I_K$	$-I_F^K$	$-I_H^K$		$-I_B^K$			$-I_G^K$		0
Change in inventories	$+I^V$	$-I^V$								0
Imports	$-IM$								$+IM$	0
Exports	$+EX$								$-EX$	0
Taxes on imports	$-T^{IM}$							$+T^{IM}$		0
Value-added tax	$-T^V$							$+T^V$		0
Other taxes on products	$-T^P$							$+T^P$		0
Wages	$-W_F$		$+W$	$-W_B$				$-W_G$		0
Employers' social contributions	$-SC_F$		$+SC$	$-SC_B$				$-SC_G$		0
Mixed-income distribution	$-MI_H$		$+MI_H$							0
GOS redistribution	$-GOS_F$		$+GOS_F^H$					$+GOS_F^G$		0
Net other taxes on production	$-T_F^Y$			$-T_B^Y$				$-T^Y$		0
Int. on deposits	$+IntD_F$		$+IntD_H$	$-IntD$				$+IntD_G$		0
Int. on domestic loans	$-IntL_F$		$-IntL_H$	$+IntL$						0
Int. on domestic FX loans	$-IntL_F^{FX,B}$			$+IntL_F^{FX,B}$						0
Int. on RoW FX loans	$-IntL_F^{FX,W}$			$-IntL_B^{FX,W}$					$+IntL^{FX,W}$	0
Int. on domestic public bonds				$+IntBg_B$				$-IntBg$	$+IntBg_W$	0
Int. on FX public bonds								$-IntBg^{FX}$	$+IntBg^{FX}$	0
Int. on FX public loans								$-IntLg^{FX}$	$+IntLg^{FX}$	0
Int. on advances				$-IntA$		$+IntA$				0
Int. on FX reserves				$+IntR_B^{FX}$		$+IntR_{CB}^{FX}$			$-IntR^{FX}$	0
Firms' dividends	$-Div_F$		$+Div_F^H$					$+Div_F^G$	$+Div_F^W$	0
Banks' dividends			$+Div_B^H$	$-Div_B$					$+Div_B^W$	0
Royalties	$-Roy$							$+Roy$		0
Taxes on income	$-T_F^I$		$-T_H^I$	$-T_B^I$				$+T^I$		0
Workers' social contributions			$-WSC$	$+WSC_B$				$+WSC_G$		0
Social transfers			$+ST$	$-ST_B$				$-ST_G$		0
Remittances			$+Rem \cdot e^N$						$-Rem \cdot e^N$	0
Central bank profits						$-F_{CB}$		$+F_{CB}$		0
Other transfers	$-O_F$		$+O_H$	$-O_B$				$-O_G$	$-O_W$	0
Retained earnings	$-RE_F$	$+RE_F$		$-RE_B$	$+RE_B$					0
[Capital]		$[\dot{K}_F]$	$[\dot{K}_H]$		$[\dot{K}_B]$			$[\dot{K}_G]$		$[\dot{K}]$
[Inventories]		$[\dot{V}]$								$[\dot{V}]$
Foreign direct investment		$+FDI_F$			$+FDI_B$				$-FDI$	0
Cash and deposits		$-\dot{D}_F$	$-\dot{D}_H$		$+\dot{D}$			$-\dot{D}_G$		0
Gov. deposits at the CB							$+\dot{D}_{CB}$	$-\dot{D}_{CB}$		0
FX deposits		$-\dot{D}_F^{FX} \cdot e^N$			$-\dot{D}_B^{FX} \cdot e^N$			$-\dot{D}_G^{FX} \cdot e^N$	$+\dot{D}^{FX} \cdot e^N$	0
Domestic currency loans		$+\dot{L}_F$	$+\dot{L}_H$		$-\dot{L}$					0
Domestic FX loans		$+\dot{L}_F^{FX,B} \cdot e^N$			$-\dot{L}_F^{FX,B} \cdot e^N$					0
RoW FX loans		$+\dot{L}_F^{FX,W} \cdot e^N$			$+\dot{L}_B^{FX,W} \cdot e^N$				$-\dot{L}^{FX,W} \cdot e^N$	0
Domestic public bonds					$-\dot{Bg}_B$			$+\dot{Bg}$	$-\dot{Bg}_W$	0
FX public bonds								$+\dot{Bg}^{FX} \cdot e^N$	$-\dot{Bg}^{FX} \cdot e^N$	0
FX public loans								$+\dot{Lg}^{FX} \cdot e^N$	$-\dot{Lg}^{FX} \cdot e^N$	0
Insurance, pensions, and SGS			$-\dot{IPS}_H$		$+\dot{IPS}_H$					0
Domestic currency reserves					$-\dot{Rd}$		$+\dot{Rd}$			0
FX reserves					$-\dot{R}_B^{FX} \cdot e^N$		$-\dot{R}_{CB}^{FX} \cdot e^N$		$+\dot{R}^{FX} \cdot e^N$	0
Advances					$+\dot{A}$		$-\dot{A}$			0
Σ	0	0	0	0	0	0	0	0	0	0

The transactions (i.e., the rows) of the TFM are divided into three main blocks, separated by solid lines. The first part of the TFM presents the non-financial transactions, for which a positive sign (+) represents receipts and a negative sign (-) represents outflows. The second part of the TFM shows the accumulation of non-financial assets, i.e., capital and inventories, represented as memo items (hence within square brackets). The third part of the TFM represents the flow of financial funds for each institutional agent. A positive sign (+) indicates an accumulation of liabilities (i.e., a source of funding) and a negative sign (-) indicates an accumulation of assets (i.e., a use of funds).

As in the System of National Accounts (SNA), the sequence of non-financial transactions is grouped into different accounts, delimited by dotted lines. The first account is the goods and services one, containing the main components of demand and production of goods and services. It is followed by the income generation (consisting mostly of wages, mixed income, and profits) and primary income distribution (interest and dividends payments) accounts. The last account is the secondary income distribution one (income taxes, social, and other types of transfers). The sum of all these transactions by institutional agents leads to the net lending/saving position, represented only for the three agents for which there is an explicit distinction between the current and capital accounts (represented by the retained earnings line). For the three other agents (households, government, and rest of the world), the savings/borrowing needs are implicit.

The TFM highlights a tight accounting structure by showing that, on the one hand, each line sums up to zero, ensuring that each expenditure by an institutional agent is matched by an income for an institutional agent (possibly the same). Note that the only transaction where this rule is not respected refers to the memo items of non-financial assets accumulation (capital and inventories). On the other hand, the sum of each column, including the current and capital ones, is also equal to zero, representing the budget constraints faced by all the institutional agents.

Table 2 displays the balance sheet of each institutional sector resulting from the accumulation of financial and non-financial flows shown in the bottom part of the TFM.[21] The first part of the balance sheet shows the stock of capital and inventories, constituting the stock of non-financial assets and resulting from investment decisions, precautionary reasons, and unsold merchandise. The second part of the balance sheet presents the stocks of financial assets where each asset (+) is a liability (-) for someone else; the sum of the financial assets for all the sectors is hence equal to zero. Finally, the wealth or net worth is equal to the sum of net financial and non-financial assets for each agent.

Table 2. ***Balance sheet of the Colombian model***

Variable	NFCs	Households	FCs	CB	Government	RoW	$+\sum$
Capital stock	$+K_F$	$+K_H$	$+K_B$		$+K_G$		K
Inventories	$+V_F$						V
[Non-financial assets]	$+NFA_F$	$+NFA_H$	$+NFA_B$	$+NFA_{CB}$	$+NFA_G$	$+NFA_W$	NFA
Foreign equity	$-EQ_F^W$		$-EQ_B^W$			$+EQ^F$	0
Cash and deposits	$+D_F$	$+D_H$	$-D$		$+D_G$		0
Gov. deposits at the CB				$-D_{CB}$	$+D_{CB}$		0
FX deposits	$+D_F^{FX} \cdot e^N$		$+D_B^{FX} \cdot e^N$		$+D_G^{FX} \cdot e^N$	$-D^{FX} \cdot e^N$	0
Domestic currency loans	$-L_F$	$-L_H$	$+L$				0
Domestic FX loans	$-L_F^{FX,B} \cdot e^N$		$+L_F^{FX,B} \cdot e^N$				0
RoW FX loans	$-L_F^{FX,W} \cdot e^N$		$-L_B^{FX,W} \cdot e^N$			$+L^{FX,W} \cdot e^N$	0
Domestic public bonds			$+Bg_B$		$-Bg$	$+Bg_W$	0
FX public bonds					$-Bg^{FX} \cdot e^N$	$+Bg^{FX} \cdot e^N$	0
FX public loans					$-Lg^{FX} \cdot e^N$	$+Lg^{FX} \cdot e^N$	0
Insurance, pensions, and SGS		$+IPS_H$	$-IPS_H$				0
Domestic currency reserves			$+Rd$	$-Rd$			0
FX reserves			$+R_B^{FX} \cdot e^N$	$+R_{CB}^{FX} \cdot e^N$		$-R^{FX} \cdot e^N$	0
Advances			$-A$	$+A$			0
[Financial assets]	$+FA_F$	$+FA_H$	$+FA_B$	$+FA_{CB}$	$+FA_G$	$+FA_W$	0

21. Although this is not done for Colombia, the value of the stocks of financial and non-financial assets changes not only because of the accumulation of the corresponding flows but also because of capital gains and losses resulting from changes in asset prices. These capital gains and losses are captured in a revaluation matrix not presented here.

2.2. Model equations

2.2.1. Production, aggregate demand, and GDP

The market for goods and services produced by non-financial corporations (NFCs) exhibits disequilibrium dynamics, and what is produced is not necessarily demanded. Firms form their sales expectations (1) based on the gap between real aggregate demand ($Y^{D,r}$) and real expected sales (Y^e) and a forward-looking trend proxied by their fixed capital accumulation rate (g_k).

$$\dot{Y}^e = \beta_y \cdot (Y^{D,r} - Y^e) + g_k \cdot Y^e \qquad (1)$$

g_K (2) depends on the real investment of the firm sector (I_F^K) and greenfield FDI (FDI_F^G) less the depreciation of the capital stock

$$g_K = \frac{I_F^K + {FDI_F^G}/{p^K}}{K_F} - \delta_F \qquad (2)$$

We assume that firms have a desired level of inventories (V^d, 3) given by a constant inventory-to-expected sales ratio α_v. Therefore, the desired investment in inventory replacement ($I^{V,d}$, 4) is given by the gap between desired (V^d) and actual (V) inventories.

$$V^d = \alpha_v \cdot Y^e \qquad (3)$$

$$I^{V,d} = \beta_{IV} \cdot (V^d - V) \qquad (4)$$

The production of firms (Y^P, 5) depends on real expected sales (Y^e) and the desired investment in inventories ($I^{V,d}$).

$$Y^P = Y^e + I^{V,d} \qquad (5)$$

The disequilibrium in the goods market is absorbed by inventories, hence the change in the actual level of inventories ($\dot{V}$, 6) is given by the gap between real production (Y^P) and real aggregate demand ($Y^{D,r}$). This is equal, following the SNA accounting rules, to the actual investment in inventories (I^V).[22]

$$\dot{V} = Y^P - Y^{D,r} \qquad (6)$$

$$I^V = \dot{V} \qquad (7)$$

22. As briefly mentioned in the introduction, the structure of the production process follows Chiarella and Flaschel (2000) and Charpe *et al.* (2011).

Since we assume that all imports are imported via firms, domestic real production $(Y^{P,D}, 8)$ is equal to total real production (Y^P) minus real imports (M)

$$Y^{P,D} = Y^P - M \tag{8}$$

Aggregate demand, net of inventory accumulation, in nominal terms $(Y^D, 9)$ is given by the sum of final consumption, intermediate consumption, investment, and export expenditures. Accordingly, real aggregate demand $(Y^{D,r}, 10)$ can be found by deflating each term by its respective price index.

$$Y^D = C + IC + I^K + X \tag{9}$$

$$Y^{D,r} = \frac{C}{p^C} + \frac{IC}{p^{IC}} + \frac{I^K}{p^K} + \frac{X}{p^X} \tag{10}$$

Households and the government consume final consumption goods $(C, 11)$ produced by firms.

$$C = C_H + C_G \tag{11}$$

The intermediate consumption demand for goods produced bv NFCs $(IC, 12)$ is driven by the demand by firms themselves (IC_F), by FCs (IC_B), and by the government (IC_G).

$$IC = p^{IC} \cdot (IC_F + IC_B + IC_G) \tag{12}$$

Investment $(I^K, 13)$ is carried out by firms, the government, the household sector, FCs, and the rest of the world as greenfield FDI.

$$I^K = p^K \cdot (I_F^K + I_G^K) + I_H^K + I_B^K + FDI_F^G \tag{13}$$

Exports (X) are split into two groups: oil and coal (X_C) and non-oil/coal (X_{NC}) exports, as shown in (14).

$$X = X_C + X_{NC} \tag{14}$$

On the one hand, the nominal value of oil and coal exports $(X_C, 15)$ depends on the real exports of these commodities (x_C) and the international price index for these commodities (p_C^W), expressed in domestic currency using the nominal exchange rate (e^N). We assume that real oil and coal exports grow at the exogenous rate α_x as presented in (16).

$$X_C = x_C \cdot p_C^W \cdot e^N \tag{15}$$

$$\dot{x_C} = \alpha_x \cdot x_C \tag{16}$$

On the other hand, real non-oil/coal exports (X_{NC}, 17) are equal to a time-varying fraction (σ_{X_N}) of world GDP. This propensity to export (σ_{X_N}) adjusts towards its target value ($\sigma^T_{X_N}$, 18) at the speed β_{X_N} (19). The target propensity to export depends on the real exchange rate (e^R) and the foreign tariff rate (τ_W) as a measurement of price competitiveness and relative foreign (a_W) and domestic (a_D) labour productivity as a proxy of non-price competitiveness.

$$X_{NC} = \sigma_{X_N} \cdot GDP_W \cdot p^W \cdot e^N \tag{17}$$

$$\sigma^T_{X_N} = \sigma^X_p \cdot \left(\frac{e^R}{1 + \tau_W}\right)^{\epsilon^X_p} + \sigma^X_a \cdot \left(\frac{a_D}{a_W}\right)^{\epsilon^X_a} \tag{18}$$

$$\dot{\sigma}_{X_N} = \beta_{X_N} \cdot \left(\sigma^T_{X_N} - \sigma_{X_N}\right) \tag{19}$$

Nominal imports (IM, 20) are equal to real imports (M) multiplied by the import price index (p^W) and the nominal exchange rate. Real imports (M, 21) are determined by time-varying propensities to import out of consumption ($\sigma_{M,C}$), intermediate ($\sigma_{M,IC}$), and capital ($\sigma_{M,I}$) goods. As in the case of exports, these propensities adjust towards their target values ($\sigma^T_{M,i}$, 22 to 24) at the speed $\beta_{M,i}$ (25 to 27). Similar to the propensity to export, target import propensities are functions of the real exchange rate, the domestic tax rate on imports, and relative foreign and domestic labour productivity, where domestic labour productivity grows at a constant rate α_D (28).

$$IM = M \cdot p^W \cdot e^N \tag{20}$$

$$M = \sigma_{M,C} \cdot \left(\frac{C}{p^C}\right) + \sigma_{M,IC} \cdot \left(\frac{IC}{p^{IC}}\right) + \sigma_{M,I} \cdot \left(\frac{I^K}{p^K}\right) \tag{21}$$

$$\sigma^T_{M,C} = \sigma^M_{p,C} \cdot \left[e^R \cdot (1 + \tau^M)\right]^{-\epsilon^M_{p,C}} + \sigma^M_{a,C} \cdot \left(\frac{a_W}{a_D}\right)^{\epsilon^M_{a,C}} \tag{22}$$

$$\sigma^T_{M,IC} = \sigma^M_{p,IC} \cdot \left[e^R \cdot (1 + \tau^M)\right]^{-\epsilon^M_{p,IC}} + \sigma^M_{a,IC} \cdot \left(\frac{a_W}{a_D}\right)^{\epsilon^M_{a,IC}} \tag{23}$$

$$\sigma^T_{M,I} = \sigma^M_{p,I} \cdot \left[e^R \cdot (1 + \tau^M)\right]^{-\epsilon^M_{p,I}} + \sigma^M_{a,I} \cdot \left(\frac{a_W}{a_D}\right)^{\epsilon^M_{a,I}} \tag{24}$$

$$\dot{\sigma}_{M,C} = \beta_{M,C} \cdot \left(\sigma^T_{M,C} - \sigma_{M,C}\right) \tag{25}$$

$$\dot{\sigma}_{M,IC} = \beta_{M,IC} \cdot \left(\sigma^T_{M,IC} - \sigma_{M,IC}\right) \tag{26}$$

$$\dot{\sigma}_{M,I} = \beta_{M,I} \cdot \left(\sigma^T_{M,I} - \sigma_{M,I}\right) \tag{27}$$

$$\dot{a_D} = \alpha_D \cdot a_D \tag{28}$$

FCs produce financial services other than financial intermediation services indirectly measured (FISIM) on demand (Y^B, 29), which can be split into insurance services and commissions. Both of these services are demanded by firms and households; as intermediate consumption by the former and as final consumption by the latter.[23]

$$Y^B = INS_H + INS_F + Com_H + Com_F \qquad (29)$$

The government conducts non-marketed production (Y^G, 30), which refers to the goods and services provided by the public sector to households free of charge or at a price well below their market value, such as education and health. As in the SNA, we calculate the value of this non-marketed production at the cost of production, which is equal to the sum of wages and employers' social contributions, public sector intermediate consumption, and consumption of fixed capital.

$$Y^G = \left(1 + \tau_{W,G}\right) \cdot w_G \cdot L_G + p^{IC} \cdot IC_G + \delta_G \cdot p^K \cdot K_G \quad (30)$$

Following the SNA, the government demands its own non-marketed production as final consumption (G_C, 31).

$$G_C = Y^G \qquad (31)$$

GDP (32) is equal to the sum of final consumption of NFCs' and FCs' products, government market and non-market consumption, investment, and the trade balance.

$$GDP = C + I^K + INS_H + Com_H + G_C + X - IM \quad (32)$$

2.2.2. Pricing

Firms have a desired price level (p^d, 33), modelled as a time-varying mark-up over the historical unit cost. Prices are sticky, and the actual production price (p) slowly adjusts towards its target level at the speed β_p (34).

$$p^d = (1 + \mu) \cdot HUC \qquad (33)$$

$$\dot{p} = \beta_p \cdot (p^d - p) \qquad (34)$$

23. In essence, in the national accounts, the production of the financial sector includes FISIM, and this production is demanded by households/firms in the form of final consumption and intermediate consumption. Interest income is then recorded in the national accounts using a reference rate (see SNA, 2008). We do not pursue this method in our model, since it is very difficult to identify the reference rate used in the calculations by the national accounts. Instead, we record interest income directly using deposit/lending rates, as can be seen in the transaction-flow matrix above, and leave only commissions/insurance in the production of financial services.

The mark-up $(\mu, 35)$ reacts to the gap between the actual and target inventory-to-output ratio to capture demand pressures in the goods market.

$$\mu = \mu_0 - \mu_1 \cdot \left(\frac{V}{Y^e} - \alpha_v\right) \quad (35)$$

The historical unit cost (HUC) adjusts towards the unit cost of production (UC) at the speed β_{HUC} (36). See Yilmaz and Godin (2020) for a derivation of this equation in the presence of disequilibrium in the goods market. The unit cost is made up of wages and employers' social contributions, intermediate consumption, and taxes on production paid by firms (37).

$$H\dot{U}C = \beta_{HUC} \cdot (UC - HUC) \quad (36)$$

$$UC = \frac{\left(1 + \theta_{W,F}\right) \cdot w_F \cdot L_F + p^{IC} \cdot IC_F + \tau_F^Y \cdot Y^{P,D}}{Y^{P,D}} \quad (37)$$

The price indices for final consumption $(p^C, 38)$, intermediate consumption $(p^{IC}, 39)$, and investment $(p^K, 40)$ goods are linear combinations of domestic and foreign price levels, weighted by their respective propensities to import. For consumption goods, a value-added tax (τ^V) is levied on domestically produced demand and an import tax on imported consumption. For intermediate goods and investment goods, other indirect taxes are levied on domestically supplied demand and, as in consumption goods, an import tax on imported demand. So the composite price indices are given by:

$$p^C = (1 + \tau^V + \tau^P) \cdot \left[\left(1 - \sigma_{M,C}\right) \cdot p + (1 + \tau^M) \cdot \sigma_{M,C} \cdot p^W \cdot e^N\right] \quad (38)$$

$$p^{IC} = (1 + \tau^P) \cdot \left[\left(1 - \sigma_{M,IC}\right) \cdot p + (1 + \tau^M) \cdot \sigma_{M,IC} \cdot p^W \cdot e^N\right] \quad (39)$$

$$p^K = (1 + \tau^P) \cdot \left[\left(1 - \sigma_{M,I}\right) \cdot p + (1 + \tau^M) \cdot \sigma_{M,I} \cdot p^W \cdot e^N\right], \quad (40)$$

where τ^V is the VAT rate, τ^P is the other tax rate on products, and τ^M is the rate of tax on imports.

The export price index $(p^X, 41)$ is calculated as the ratio of nominal to real exports.

$$p^X = \frac{X}{x_C + \sigma_{X_N} \cdot GDP_W} \quad (41)$$

2.2.3. Non-financial corporations

Firms demand goods produced by themselves as intermediate consumption $(IC_F, 42)$, which is modelled as a constant fraction of real production.

$$IC_F = \theta_{IC,F} \cdot Y^P \quad (42)$$

Financial services other than FISIM demanded by firms are also intermediate consumption. Insurance services (INS_F, 43) depend on firms' capital stock, while commissions (Com_F, 44) depend on firms' stock of domestic currency loans.

$$INS_F = \theta_{INS,F} \cdot p^K \cdot K_F \tag{43}$$

$$Com_F = \theta_{Com,F} \cdot L_F^d \tag{44}$$

The target real investment (I_F^T, 45) of firms is a function of the profit rate net of inflation. Investment plans take time to materialise (Kalecki, 1935), hence firms' actual investment adjusts towards its target level at the speed β_{IF} (46) and drives the evolution of the capital stock as presented in (47).

$$I_F^{K,T} = \left[\kappa_0 + \kappa_1 \cdot \left(r_F - \frac{\dot{p}}{p}\right)\right] \cdot K_F \tag{45}$$

$$\dot{I}_F^K = \beta_{IF} \cdot \left(I_F^{K,T} - I_F^K\right) \tag{46}$$

$$\dot{K}_F = I_F^K + \frac{FDI_F^G}{p^K} - \delta_F \cdot K_F \tag{47}$$

The profit rate (r_F, 48) is defined as the ratio between net profits and the capital stock.

$$r_F = \frac{F_F}{p^K \cdot K_F} \tag{48}$$

The employment level in NFCs (L_F, 49) depends on real domestic production and labour productivity, following a Leontief production function.

$$L_F = \frac{Y^{P,D}}{a_D} \tag{49}$$

The average nominal wage paid by firms w_F grows as a function of the labour productivity growth rate, the difference between the employment rate and a reference rate of employment $\omega_{F,2}$, and the inflation rate (50). The employment gap term captures the tightness or slack in the labour market.

$$\dot{w}_F = \left(\omega_{F,0} \cdot \frac{\dot{a}_D}{a_D} + \omega_{F,1} \cdot \left(\frac{L}{pop} - \omega_{F,2}\right) + \omega_{F,3} \cdot \frac{\dot{p}}{p}\right) \cdot w_F \tag{50}$$

The gross operating surplus of NFCs (GOS_F, 51) is equal to aggregate demand after subtracting imports, indirect taxes (VAT, imports, and other taxes on products), taxes on production, intermediate consumption, wages, and employers' social contributions.

$$GOS_F = Y^D - IM - T^P - T^M - T^V - \tau^{Y,F} \cdot Y^{P,D} - p^{IC} \cdot IC_F - INS_F - Com_F \\ - \left(1 + \tau_{W,F}\right) \cdot w_F \cdot L_F \quad (51)$$

A share of firms' gross operating surplus is redistributed to households (52 and 53) and the government (54). We make the distinction in the former case between mixed-income (MI_H) and pure gross operating surplus ($GOS_{F,H}$). We follow this approach because in the model, unlike the SNA, NFCs carry out all production in the economy except for financial services and government non-market production.

$$MI_H = \theta_{MI} \cdot GOS_F \quad (52)$$

$$GOS_{F,H} = \theta_{GH} \cdot GOS_F \quad (53)$$

$$GOS_{F,G} = \theta_{GG} \cdot GOS_F \quad (54)$$

The gross profits of NFCs (GF_F, 55) are given by the gross operating surplus minus net interest payments, royalties, and mixed-income and gross operating surplus redistributed.

$$GF_F = GOS_F + i^D \cdot D_F - i_F^L \cdot L_F^d - i_F^{FX,B} \cdot L_F^{FX,B} \cdot e^N - i_F^{FX,W} \cdot L_F^{FX,W} \cdot e^N - Roy \\ - MI_H - GOS_{F,H} - GOS_{F,G} \quad (55)$$

The net profits of NFCs (F_F, 56) are equal to gross profits minus corporate income tax. Then, equation 57 shows net profits net of the accumulation of domestic and foreign currency deposits held as working capital (F_F^{ND}).

$$F_F = (1 - \tau_F^I) \cdot GF_F \quad (56)$$

$$F_F^{ND} = F_F - \dot{D}_F^{FX} \cdot e^N - \dot{D}_F \quad (57)$$

NFCs accumulate domestic currency deposits ($\dot{D}_F$, 58) in order to have the short-term liquidity to cover a fraction $\eta_{D,F}$ of the wage bill.

$$\dot{D}_F = \beta_{DF} \cdot \left(\eta_{D,F} \cdot \left(1 + \tau_{W,F}\right) \cdot w_F \cdot L_F - D_F\right) \quad (58)$$

On a similar basis, NFCs accumulate FX deposits ($\dot{D}_F^{FX}$, 59) to maintain in liquid form a fraction $\eta_{D,F}^{FX}$ of their stock of FX loans.

$$\dot{D}_F^{FX} = \beta_{DF}^{FX} \cdot \left(\eta_{D,F}^{FX} \cdot \left(L_F^{FX,B} + L_F^{FX,W}\right) - D_F^{FX}\right) \quad (59)$$

NFCs save a constant fraction of their net profits net of deposits accumulation and distribute the remaining as dividends (Div_F, 60).

$$Div_F = (1 - s_F) \cdot F_F^{ND} \tag{60}$$

Firms distribute dividends to the government ($Div_{F,G}$, 61), the rest of the world ($Div_{F,G}$, 62), and households ($Div_{F,H}$, 63). Dividend payments are sensitive to the ratio of oil and coal exports to GDP to account for the effect of Ecopetrol (the major state-owned oil company) and the fact that FDI is concentrated in the oil and mining sectors.

$$Div_{F,G} = \left[\zeta_{0G} + \zeta_{1G} \cdot \left(\frac{X_C}{GDP}\right)\right] \cdot Div_F \tag{61}$$

$$Div_{F,W} = \left[\zeta_{0W} + \zeta_{1W} \cdot \left(\frac{X_C}{GDP}\right)\right] \cdot Div_F \tag{62}$$

$$Div_{F,H} = Div_F - Div_{F,G} - Div_{F,W} \tag{63}$$

The retained earnings of NFCs (RE_F, 64) are given by the profits saved minus other transfers.

$$RE_F = s_F \cdot F_F^{ND} - O_F \tag{64}$$

The other transfers of NFCs (O_F, 65) are modelled as a constant fraction of domestic production. This item captures some minor SNA transactions not explicitly included in the model that affect the net lending/borrowing position of all the institutional sectors.

$$O_F = v_F \cdot p \cdot Y^{P,D} \tag{65}$$

Since retained earnings make it possible to self-finance a portion of firms' investment at the macroeconomic level, the total financing needs of NFCs (TFN_F, 66) are given by the difference between investment and retained earnings.

$$TFN_F = p^K \cdot I_F^K - RE_F \tag{66}$$

Firms cover a share of their financing needs by borrowing in foreign currency. They demand a fraction $\eta_F^{FX,B}$ of their total financing needs as FX loans with FCs (67). However, the desired FX loans demand ($L_F^{FX,B,d}$) is above the FX loans actually supplied ($L_F^{FX,B}$, 68), since global banks apply credit rationing to domestic banks ($rat_F^{FX,B}$, more details in (91)).

$$\dot{L_F^{FX,B,d}} = \eta_F^{FX,B} \cdot \frac{TFN_F}{e^N} \qquad (67)$$

$$\dot{L_F^{FX,B}} = \left(1 - rat_F^{FX.B}\right) \cdot \dot{L_F^{FX,B,d}} \qquad (68)$$

Firms also demand a fraction $\eta_F^{FX,W}$ of their total financing needs as FX loans directly from foreign banks. Similar to the previous case, the desired FX loans demand $(\dot{L_F^{FX,W,d}}, 69)$ is above the actual supply $(\dot{L_F^{FX,W}}, 70)$. Here, the credit rationing parameter $(rat_F^{FX.W}, 71)$ is modelled as a sigmoid sensitive to the country risk premium (rsk).

$$\dot{L_F^{FX,W,d}} = \eta_F^{FX,W} \cdot \frac{TFN_F}{e^N} \qquad (69)$$

$$\dot{L_F^{FX,W}} = \left(1 - rat_F^{FX.W}\right) \cdot \dot{L_F^{FX,W,d}} \qquad (70)$$

$$rat_F^{FX.W} = LB_F^{FX,W} + \frac{1}{1 + \exp\left(-\beta_F^{FX,W,} \cdot \left(rsk - \chi_F^{FX,W,}\right)\right)} \cdot \left(UB_F^{FX,W,} - LB_F^{FX,W}\right) \qquad (71)$$

Firms' demand for domestic currency loans $(\dot{L_F^d}, 72)$ acts as a buffer in the model. It is equal to the financing needs in excess of FX loans provided by domestic and foreign banks and non-greenfield FDI inflows in NFCs.

$$\dot{L_F^d} = TFN_F - \dot{L_F^{FX,B}} \cdot e^N - \dot{L_F^{FX,W}} \cdot e^N - FDI_F^{NG} \qquad (72)$$

2.2.4. Financial corporations

The gross operating surplus of FCs $(GOS_B, 78)$ is given by the production of financial services already shown in (29) net of intermediate consumption, taxes on production, wages, and employers' social contributions expenditures.

$$GOS_B = Y^B - p^{IC} \cdot IC_B - \tau_B^Y \cdot Y^B - \left(1 + \tau_{W,B}\right) \cdot w_B \cdot L_B \qquad (73)$$

The employment level in FCs $(\dot{L_B}, 74)$ grows at the constant rate η_B.

$$\dot{L_B} = \eta_B \cdot L_B \qquad (74)$$

We assume a constant technical relationship between labour and inputs in FCs. Hence, real intermediate consumption $(IC_B, 75)$ equals a constant fraction of the employment level.

$$IC_B = \theta_{IC,B} \cdot L_B \qquad (75)$$

The average nominal wage w_B paid by FCs grows (76) in response to the labour productivity growth rate and the domestic inflation rate.

$$\dot{w}_B = \left(\omega_{B,0} \cdot \frac{\dot{a}_D}{a_D} + \omega_{B,1} \cdot \frac{\dot{p}}{p}\right) \cdot w_B \tag{76}$$

Nominal investment (I_B, 77) is modelled as a constant fraction of FCs' production and drives the evolution of the real capital stock as shown in 78.

$$I_B = \kappa_B \cdot Y^B \tag{77}$$

$$\dot{K}_B = \frac{I^B}{p^K} - \delta_B \cdot K_B \tag{78}$$

Social transfers paid by FCs (ST_B, 79) represent a constant fraction of the total transfers received by households (see 158 for more details).

$$ST_B = \left(1 - \varsigma_{ST,G}\right) \cdot ST \tag{79}$$

The gross profits of FCs (GF_B, 80) equal the gross operating surplus minus net interest payments and social transfers paid to households. On the one hand, FCs receive interest on loans to households and NFCs, their holdings of government bonds, and their FX reserve assets. On the other hand, FCs pay interest on deposits, their FX loans with the rest of the world, and the liquidity advances received from the central bank.

$$\begin{aligned} GF_B = {} & GOS_B + i_H^L \cdot L_H^d + i_F^L \cdot L_F^d + i_F^{FX,B} \cdot L_F^{FX,B} \cdot e^N + i_G^B \cdot Bg_B + i_B^{FX,R} \cdot R_B^{FX} \\ & \cdot e^N - i^D \cdot D_G - i_H^D \cdot D_H - i_F^D \cdot D_F - i_B^{FX,W} \cdot L_B^{FX,W} \cdot e^N - i^P \cdot A \\ & - ST_B \end{aligned} \tag{80}$$

Then, net profits (F_B, 81) equal gross profits after paying corporate income tax.

$$F_B = \left(1 - \tau_B^Y\right) \cdot GF_B \tag{81}$$

FCs must have a certain amount of own funds to meet regulatory requirements (82), which are given by a constant capital adequacy ratio (car) to total loans granted. Consequently, they retain profits (RE_B, 83) in response to the difference between target and current own funds. These retained earnings allow them to raise their own funds (84).

$$OF_B^{car} = car \cdot \left(L_F^d + L_H^d + L_F^{FX,B} \cdot e^N\right) \tag{82}$$

$$RE_B = \beta_{OF} \cdot \left(OF_B^{car} - OF_B\right) \tag{83}$$

$$\dot{OF}_B = RE_B \tag{84}$$

Dividends distributed to households by FCs ($Div_{B,H}$, 85) equal net profits less retained earnings and other transfers.

$$Div_{B,H} = F_B - RE_B - O_B \tag{85}$$

As in the case of NFCs, the other transfers (O_B, 86) are modelled as a constant fraction of domestic production.

$$O_B = v_B \cdot p \cdot Y^{P,D} \tag{86}$$

FCs respect a liquidity ratio and thus accumulate liquid reserves at the central bank (87) as a constant fraction of the domestic deposits accumulated by NFCs, households, and the government (88).

$$\dot{Rd} = rrr \cdot \dot{D}^d \tag{87}$$

$$\dot{D}^d = \dot{D}_F + \dot{D}_H + \dot{D}_G \tag{88}$$

FCs have a desired demand for FX loans with foreign banks ($\dot{L}_B^{FX,W,d}$, 89), which depends on their own funds acting as collateral and the stock of FX loans granted to NFCs. As in the case of NFCs, the FX loans actually supplied by foreign banks ($\dot{L}_B^{FX,W}$, 90) are lower since they ration credit based on the country risk premium (91).

$$\dot{L}_B^{FX,W,d} = v_B^{FX,L} \cdot \frac{OF_B}{e^N} + \dot{L}_F^{FX,B} \tag{89}$$

$$\dot{L}_B^{FX,W} = (1 - rat_B^{FX}) \cdot \dot{L}_B^{FX,W,d} \tag{90}$$

$$rat_B^{FX} = LB_B^{FX} + \frac{1}{1 + \exp\left(-\epsilon_B^{FX} \cdot (rsk - \chi_B^{FX})\right)} \cdot (UB_B^{FX} - LB_B^{FX}) \tag{91}$$

FCs supply domestic currency loans ($\dot{L}^d$, 92) to NFCs and households on demand.

$$\dot{L}^d = \dot{L}_F^d + \dot{L}_H^d \tag{92}$$

FCs finance the government (93) by purchasing all domestic bonds issued that are available in the market after foreign investors have made their respective purchases.

$$\dot{Bg}_B = \dot{Bg} - \dot{Bg}_W \tag{93}$$

FCs accumulate FX deposits ($\dot{D}_B^{FX}$, 94) to keep in liquid form a constant share η_B^{FX} of the stock of FX loans borrowed from the rest of the world.

$$\dot{D}_B^{FX} = \beta_{DB}^{FX} \cdot \left[\eta_B^{FX} \cdot \dot{L}_F^{FX,W} - D_B^{FX}\right] \tag{94}$$

As a consequence of a strict no-open position rule, the desired accumulation of FX reserves by FCs (95) is equal to the desired demand for FX loans minus the FX deposits accumulated and the FX loans granted to NFCs.

$$\dot{R}_B^{FX,d} = \dot{L}_B^{FX,W,d} - \dot{D}_B^{FX} - \dot{L}_F^{FX,B} \tag{95}$$

To the extent that we account for credit rationing in the model, the actual FX reserves accumulated ($\dot{R}_B^{FX}$, 96) by FCs differ from those desired. Hence, in line with the balance of payments identity, the FX reserve assets accumulated by FCs equal the FX reserve assets accumulated by the whole economy minus those accumulated by the central bank.

$$\dot{R}_B^{FX} = \dot{R}^{FX} - \dot{R}_{CB}^{FX} \tag{96}$$

The total financing needs of FCs (TFN_B, 97) arise from the difference between accrued assets (use of funds) and liabilities (sources of funds) in domestic and foreign currency.

$$\begin{aligned} TFN_B = {} & \left[\dot{L}^d + \dot{Bg}_B + \dot{Rd} + I_B\right] - \left[(1+lr)\cdot \dot{D}^d + \dot{OF}_B + FDI_B + \dot{TIR}_H\right] \\ & + \left[\dot{D}_B^{FX}\cdot e^N + \dot{L}_F^{FX,B}\cdot e^N + \dot{R}_B^{FX}\cdot e^N - \dot{L}_B^{FX,W}\cdot e^N\right] \end{aligned} \tag{97}$$

The central bank acts as a lender of last resort in the way that it provides liquidity advances (98) whenever FCs are running positive financing needs.

$$\dot{A} = TFN_B \tag{98}$$

Regarding interest rates, the interest rate on domestic currency deposits (i^D, 99) is modelled as a mark-down over the monetary policy rate. This time-varying mark-down (md, 100) is sensitive to the ratio between the stock of advances and deposits collected as an indicator of liquidity in the banking sector.

$$i^D = (1 - md)\cdot i^P \tag{99}$$

$$md = \rho_0 - \frac{p_1}{1 + \exp\left(-\rho_2\left(\frac{A}{D^D} - \rho_3\right)\right)} \tag{100}$$

To better match the interest payments observed in the data for each sector, an additional constant mark-down over this rate is applied for households (101) and NFCs (102).

$$i_H^D = (1 - md_H)\cdot i^D \tag{101}$$

$$i_F^D = (1 - md_F)\cdot i^D \tag{102}$$

As we showed in Chapter 1, the lending rates to firms and households include large premiums over central bank policy rates in Colombia. Thus, we assume that the interest rate charged on domestic currency loans to NFCs (i_F^L, 103) is given by a premium ($prem_F$) over the domestic average funding costs of FCs (AFC, 104), which depends on the policy rate and deposit rates. This time-varying premium adjusts towards its target value ($prem_F^T$, 105) at the speed β_{Pr}^F (106). We model the target premium as sensitive to the ratio of firms' indebtedness to domestic production.

$$i_F^L = AFC \cdot (1 + prem_F) \qquad (103)$$

$$AFC = \frac{i^D \cdot D_G + i_H^D \cdot D_H + i_F^D \cdot D_F + i^P \cdot A}{D^d + A} \qquad (104)$$

$$prem_F^T = \phi_{F0}^{Pr} + \frac{\phi_{F1}^{Pr}}{1 + \exp\left(-\phi_{F2}^{Pr} \cdot \left(\frac{L_F^d + L_F^{FX,B} \cdot e^N + L_F^{FX,W} \cdot e^N}{p \cdot Y^{P,D}}\right)\right)} \qquad (105)$$

$$\dot{prem}_F = \beta_{Pr}^F \cdot (prem_F^T - prem_F) \qquad (106)$$

The interest rate charged on FX loans to NFCs ($i_F^{FX,B}$, 107) is modelled as a constant premium over the interest rate on FX loans that foreign banks charge to FCs ($i_B^{FX,W}$).

$$i_F^{FX,B} = i_B^{FX,W} \cdot \left(1 + \varrho_F^{FX,B} \cdot prem_F\right) \qquad (107)$$

As Chapter 1 showed, the interest rate charged on domestic currency loans to households (i_H^L, 108) is even higher than the lending rates to firms, so we model this rate as a premium ($prem_H$) over the interest rate on domestic loans to NFCs. This time-varying premium also follows its target value ($prem_H^T$, 109) at the speed β_{Pr}^H (110). The target premium is sensitive to households' debt-to-disposable income ratio.

$$i_H^L = i_F^L \cdot (1 + prem_H) \qquad (108)$$

$$prem_H^T = \phi_{H0}^{Pr} + \frac{\phi_{H1}^{Pr}}{1 + \exp\left(-\phi_{H2}^{Pr} \cdot \left(\frac{L_H^d}{YD_H}\right)\right)} \qquad (109)$$

$$\dot{prem}_H = \beta_{Pr}^H \cdot (prem_H^T - prem_H) \qquad (110)$$

2.2.5. Central bank

The Colombian central bank fundamentally emphasises inflation control over other policy objectives, as we mentioned in Chapter 1. Thus, in our model, we assume that the central bank has a target monetary policy rate ($i^{P,T}$, 111), which follows a simple inflation-targeting Taylor rule. Then, the actual policy rate follows its target value at the speed β_{ip}, as shown in (112).

$$i^{P,T} = \iota_0 + \iota_1 \cdot \left(\frac{\dot{p}}{p} - \iota_2\right) \tag{111}$$

$$\dot{i^p} = \beta_{ip} \cdot (i^{P,T} - i^P) \tag{112}$$

Central bank profits (F_{CB}, 113) are equal to the interest received on liquidity advances and FX reserve assets minus the interest paid to the government on their deposit holdings. The profits are fully transferred to the government.

$$F_{CB} = i^P \cdot A + i_{CB}^{FX,R} \cdot R_{CB}^{FX} - i_{CB}^D \cdot D_G^{CB} \tag{113}$$

The central bank has a target of FX reserves equal to a constant fraction $\theta_{FX,M}$ of imports. Therefore, when the actual stock of FX reserves is below this level, the central bank intervenes in the FX market to accumulate FX-denominated assets (114).

$$\dot{R}_{CB}^{FX} = max\left[\theta_{FX,M} \cdot M \cdot p^W - R_{CB}^{FX}, 0\right] \tag{114}$$

2.2.6. Households

Equation (115) describes the different components of households' disposable income, wage income, financial income, social contributions and social transfers, and remittances as income, and social contributions, interest payments, and financial consumption as expenses.

$$\begin{aligned} YD_H = (1 - \tau_W^I) \cdot wL + MI_H + GOS_H + ESC + ST + i^D \cdot D_H + Div_{F,H} \\ + Div_{B,H} + Rem \cdot e^N \cdot -WSC - i_H^L \cdot L_H^d - INS_H - Com_H + O_H \end{aligned} \tag{115}$$

The unemployment rate ($unem$, 116) depends on the level of employment relative to the labour force. Total employment equals the sum of employees in NFCs, FCs, and the government (117), while the labour force grows at the constant rate α_P (118).

$$unem = 1 - {}^{L}/_{pop} \tag{116}$$

$$L = L_F + L_B + L_G \tag{117}$$

$$\dot{pop} = \alpha_P \cdot pop \tag{118}$$

Accordingly, the total wage bill (wL, 119) and the total employers' social contributions (ESC, 120) received by the household sector are paid by NFCs, FCs, and the government.

$$wL = w_F \cdot L_F + w_B \cdot L_B + w_G \cdot L_G \tag{119}$$

$$ESC = \tau_{W,F} \cdot w_F \cdot L_F + \tau_{W,B} \cdot w_B \cdot L_B + \tau_{W,G} \cdot w_G \cdot L_G \tag{120}$$

Workers' social contributions (WSC, 121) are paid to the government. They equal employers' social contributions plus an additional levy charged to households as a fraction τ_{SC} of the total wage bill.

$$WSC = ESC + \tau_{SC} \cdot wL \tag{121}$$

As in previous cases, the other transfers of households (O_H, 122) are modelled as a constant fraction of total domestic production.

$$O_H = v_H \cdot p \cdot Y^{P,D} \tag{122}$$

Similar to what has been done for NFCs, households' demand for financial services is divided into insurance (INS_H, 123) and commissions (Com_H, 124). The first term depends on the capital stock and the second on the stock of loans.

$$INS_H = \theta_{INS,H} \cdot p^K \cdot K_H \tag{123}$$

$$Com_H = \theta_{Com,H} \cdot L_H^d \tag{124}$$

Households' target consumption (C_H^T, 125) depends on a time-varying propensity to consume out of disposable income, a time-varying propensity to consume out of wealth, and the flow of consumer credit. Then, the actual consumption level slowly moves towards its target level at the speed β_C as presented in (126).

$$C_H^T = m_1 \cdot YD_H + m_2 \cdot (D_H + TIR_H + p^I \cdot K_H^r) + L_H^{\dot{d},C} \tag{125}$$

$$\dot{C_H} = \beta_C \cdot (C_H^T - C_H) \tag{126}$$

The time-varying marginal propensities to consume, m_1 (127) and m_2 (128), are modelled as sigmoids sensitive to the real deposit rate.

$$m_1 = LB_H^{YD} + \frac{1}{1 + \exp\left(-\epsilon_H^{YD} \cdot \left(\left(i_H^D - \dot{p}/p\right) - \chi_H^{YD}\right)\right)} \cdot (UB_H^{YD} - LB_H^{YD}) \tag{127}$$

$$m_2 = LB_H^{W} + \frac{1}{1 + \exp\left(-\epsilon_H^{W} \cdot \left(\left(i_H^D - \dot{p}/p\right) - \chi_H^{W}\right)\right)} \cdot (UB_H^{W} - LB_H^{W}) \tag{128}$$

Households invest in residential buildings. Their target residential investment (I_H^T, 129) is modelled as a time-varying fraction (κ_H, 130) of disposable income. This fraction negatively depends on the interest rate and the unemployment rate, since they are indicators of borrowing costs and the business cycle, respectively. As in previous cases, the actual investment adjusts towards its target value at the speed β_{IH} (131) and drives the dynamic of the capital stock (132).

$$I_H^T = \kappa_H \cdot YD_H \tag{129}$$

$$\kappa_H = \kappa_{H,0} - \kappa_{H,1} \cdot i_H^L - \kappa_{H,2} \cdot unem \tag{130}$$

$$\dot{I_H} = \beta_{IH} \cdot (I_H^T - I_H) \tag{131}$$

$$\dot{K_H} = \frac{I_H}{p^K} - \delta_H \cdot K_H \tag{132}$$

We now define savings (S_H, 133) as the difference between disposable income and consumption.

$$S_H = YD_H - C_H \tag{133}$$

It can be seen in (134) that households will exhibit positive total financing needs whenever investment exceeds savings, while they will show a positive net lending position in the opposite case.

$$TFN_H = I_H - S_H \tag{134}$$

The demand of households for domestic currency loans (135) is split into consumer and mortgage loans. For the former (136), the demand for credit is adjusted to keep the ratio of consumer loans to disposable income stable. For the latter (137), demand is a constant fraction of housing investment.

$$\dot{L_H^d} = \dot{L_H^{d,C}} + \dot{L_H^{d,I}} \tag{135}$$

$$\dot{L_H^{d,C}} = \beta_{L,CH} \cdot \left(\eta_{LC} \cdot YD_H - L_H^{d,C}\right) \tag{136}$$

$$\dot{L_H^{d,I}} = \eta_{LI} \cdot I_H \tag{137}$$

Households allocate their savings in two assets: First, in the form of insurance, pensions, and standardised guarantee schemes (SGS), which is modelled as a constant fraction of the wage bill (138); and second, in the form of domestic currency deposits (139), the value of which is determined as the difference between the sources of funds (savings [or minus total financing needs] and loans) and the uses of funds (investment and insurance, pensions, and SGS).

$$\dot{TIR}_H = \eta_{TIR} \cdot wL \tag{138}$$

$$\dot{D}_H = -TFN_H + \dot{L}_H^d - \dot{TIR}_H \tag{139}$$

which can also be written as:

$$\dot{D}_H = \left(YD_H + \dot{L}_H^{d,C} - Ch\right) - (I_H - \dot{L}_H^{d,I}) - \dot{TIR}_H$$

2.2.7. Government

As we showed in detail in Chapter 1, a significant proportion of the fiscal revenues $(FR, 140)$ of the Colombian government is made up of tax revenues (T_T) and royalties (Roy). Analysis of the national accounts shows that the rest consists of gross operating surplus redistributed by NFCs, workers' social contributions, interest payments on deposit holdings, and dividends paid by NFCs. Thus, total fiscal revenues are given by:

$$FR = T_T + Roy + GOS_G + WSC + i^D \cdot D_G + i_{CB}^D \cdot D_G^{CB} + Div_{F,G} \tag{140}$$

Tax collection $(T_T, 141)$ is divided into five types of taxes.

$$T_T = T^I + T^M + T^V + T^P + T^Y \tag{141}$$

Taxes on income $(T^I, 142)$ are levied on the wage bill and gross profits of NFCs and FCs with differential tax rates.

$$T^I = \tau_W^I \cdot wL + \tau_F^I \cdot GF_F + \tau_B^I \cdot GF_B \tag{142}$$

Import taxes $(T^M, 143)$ are levied at a uniform tax rate on real imports.

$$T^M = \tau^M \cdot IM \tag{143}$$

VAT $(T^V, 144)$ is levied only on consumer goods at the τ^V rate.

$$T^V = \tau^V \cdot \frac{C \cdot \left[\left(1 - \sigma_{M,C}\right) \cdot p + (1 + \tau^M) \cdot \sigma_{M,C} \cdot p^W \cdot e^N\right]}{p^C} \tag{144}$$

The revenue of other taxes on products net of subsidies $(T^P, 145)$ depends on a uniform tax rate on final consumption, intermediate, and investment goods.

$$T^P = \tau^P \cdot \frac{C \cdot \left[\left(1 - \sigma_{M,C}\right) \cdot p + (1 + \tau^M) \cdot \sigma_{M,C} \cdot p^W \cdot e^N\right]}{p^C} + \tau^P \cdot \frac{IC \cdot \left[\left(1 - \sigma_{M,IC}\right) \cdot p + (1 + \tau^M) \cdot \sigma_{M,IC} \cdot p^W \cdot e^N\right]}{p^{IC}} + \tau^P \cdot \frac{I^K \cdot \left[\left(1 - \sigma_{M,I}\right) \cdot p + (1 + \tau^M) \cdot \sigma_{M,I} \cdot p^W \cdot e^N\right]}{p^K} \tag{145}$$

Taxes on production net of subsidies (T^Y, 146) are paid by NFCs and FCs.

$$T^Y = \tau_F^Y \cdot p \cdot Y^{P,D} + \tau_B^Y \cdot Y^B \tag{146}$$

Royalties collection (Roy, 147) is modelled as a constant fraction θ^R of oil and coal exports.

$$Roy = \theta^R \cdot X_C \tag{147}$$

Total government expenditure (G_T, 148) is divided into primary expenditure, interest payments on public debt, and other transfers.

$$G_T = G_P + G_{IP} + O_G \tag{148}$$

Primary expenditures (G_P, 149) consist of final market consumption, the wage bill, employers' social contributions, intermediate consumption, public investment, and social transfers paid to households.

$$G_P = C_G + \left(1 + \tau_{w,G}\right) \cdot w_G \cdot L_G + p^{IC} \cdot IC_G + p^K \cdot I_G + ST_G \tag{149}$$

The government has a target demand for final consumption goods (C_G^T, 150) that is modelled as a constant fraction $\theta_{G,C}$ of GDP. As in previous cases, the actual value of consumption moves towards the target at the speed β_{CG} as presented in (151).

$$C_G^T = \theta_{G,C} \cdot GDP$$

$$\dot{C}_G = \beta_{CG} \cdot (C_G^T - C_G) \tag{151}$$

Regarding the determinants of the wage bill, the nominal wage paid by the government (w_G) grows in relation to the labour productivity growth and the inflation rate (152). The level of public employment (L_G, 153) is determined as a constant fraction of the labour force.

$$\dot{w_G} = \left(\omega_{G,0} \cdot \frac{\dot{a_D}}{a_D} + \omega_{G,1} \cdot \frac{\dot{p}}{p}\right) \cdot w_G \tag{152}$$

$$L_G = \theta_{G,L} \cdot pop \tag{153}$$

We assume a constant technical relationship between real intermediate consumption (IC_G, 154) and employment in the government sector.

$$IC_G = \theta_{IC,G} \cdot L_G \tag{154}$$

The government has as a target to invest a constant fraction κ_G of the existing public capital stock K_G (155). As with NFCs, this target serves as an attractor for the actual level of investment, which converges at the speed β_{IG} (156) and, simultaneously, determines the dynamics of the capital stock (157).

$$I_G^T = \kappa_G \cdot K_G \tag{155}$$

$$\dot{I_G} = \beta_{IG} \cdot (I_G^T - I_G) \tag{156}$$

$$\dot{K_G} = I_G - \delta_G \cdot K_G \tag{157}$$

Total social transfers received by households (ST, 158) depend on population and unemployment dynamics. Of this amount, the government takes over the constant fraction ST_G (159), while the remaining part is paid by FCs as shown in (79).

$$ST = \varsigma_{ST} \cdot w_F \cdot (pop - L) \tag{158}$$

$$ST_G = \varsigma_{ST,G} \cdot ST \tag{159}$$

The government pays interest (G_{IP}, 160) on domestic currency bonds, FX bonds, and FX loans.

$$G_{IP} = i_G^B \cdot Bg + i_G^{B,FX} \cdot Bg^{FX} \cdot e^N + i_G^{L,FX} \cdot Lg^{FX} \cdot e^N \tag{160}$$

As in previous cases, the other transfers (O_G, 161) of the government are modelled as a constant fraction of total domestic production.

$$O_G = v_G \cdot p \cdot Y^{P,D} \tag{161}$$

At this point, we define the fiscal deficit (FD, 162) as the difference between total expenditures and revenues after taking into account central bank profits.

$$FD = G_T - FR - F_{CB} \tag{162}$$

Consequently, the total financing needs of the government (TFN_G, 163) are equal to the fiscal deficit plus the deposits accumulated as cash funds.

$$TFN_G = FD + \dot{D_G} + \dot{D_G^{CB}} + \dot{D_G^{FX}} \cdot e^N \tag{163}$$

The government accumulates domestic currency deposits at FCs (164) and the central bank (165) to hold in liquid form a fraction η_{DG} and η_{DG}^{CB} of its total expenditures, respectively.

$$\dot{D_G} = \beta_{DG} \cdot (\eta_{DG} \cdot G_T - D_G) \tag{164}$$

$$\dot{D_G^{CB}} = \beta_{DG}^{CB} \cdot (\eta_{DG}^{CB} \cdot G_T - D_G^{CB}) \tag{165}$$

Similarly, the government accumulates FX deposits (166) to retain in liquid form a constant fraction η_{DG}^{FX} of its FX-denominated debt

$$\dot{D_G^{FX}} = \beta_{DG}^{FX} \cdot (\eta_{DG}^{FX} \cdot (Bg^{FX} + Lg^{FX}) - D_G^{FX}) \qquad (166)$$

Domestic currency bonds issuance $(\dot{Bg}$,167) is determined as a residual from the difference between total financing needs and the FX financing raised from abroad via bonds and loans. The latter flows will be explained in the next section.

$$\dot{Bg} = TFN_G - \dot{Bg^{FX}} \cdot e^N - \dot{Lg^{FX}} \cdot e^N \qquad (167)$$

Domestic currency bonds pay the interest rate (i_G^B, 168), which depends on the monetary policy rate and a time-varying risk premium $(prem_G)$. The risk premium moves gradually towards its target value ($prem_G^T$,169) at the speed β_{Pr}^G (170). Lastly, the target premium is modelled as a sigmoid sensitive to the government debt-to-GDP ratio.

$$i_G^B = i^P + prem_G \qquad (168)$$

$$prem_G^T = \phi_{G0}^{Pr} + \frac{\phi_{G1}^{Pr}}{1 + \exp\left(-\phi_{G2}^{Pr} \cdot \left(\frac{Bg + Bg^{FX} \cdot e^N + Lg^{FX} \cdot e^N}{GDP}\right)\right)} \qquad (169)$$

$$\dot{prem_G} = \beta_{Pr}^G \cdot (prem_G^T - prem_G) \qquad (170)$$

2.2.8. Rest of the world

World real GDP grows (171) at the constant rate α_{GW}.

$$\dot{GDP_W} = \alpha_{GW} \cdot GDP_W \qquad (171)$$

World labour productivity (172) grows at the constant rate a_W.

$$\dot{a_W} = \alpha_W \cdot a_W \qquad (172)$$

In terms of prices, the foreign GDP deflator (p^W) and the price index for non-oil and non-coal exports in FX (p_X^W) have an inflation rate of α_p^W(173) and $\alpha_{P_X^W}$(174), respectively. Similarly, the international oil and coal price index (p_C^W) has an inflation rate of $\alpha_{P_C^W}$(175).

$$\dot{p^W} = \alpha_p^W \cdot p^W \qquad (173)$$

$$\dot{p_X^W} = \alpha_{P_X^W} \cdot p_X^W \qquad (174)$$

$$\dot{p_C^W} = \alpha_{P_C^W} \cdot p_C^W \qquad (175)$$

The current account deficit (CAD, 176) is given by the trade balance and the income account.

$$CAD = -(TB + IA) \tag{176}$$

The trade balance (TB, 177) equals exports minus imports.

$$TB = X - IM \tag{177}$$

The income account (IA, 178) is equal to receipts from remittances, interest on reserve assets, and other transfers minus outflows from interest payments on the bond holdings of foreign investors, interest payments on FX loans, and dividend payments.

$$\begin{aligned} IA = {} & Rem \cdot e^N + i_{CB}^{FX,R} \cdot R_{CB}^{FX} \cdot e^N + i_B^{FX,R} \cdot R_B^{FX} \cdot e^N - i_G^{B,FX} \cdot Bg^{FX} \cdot e^N - i_G^{L,FX} \\ & \cdot Lg^{FX} \cdot e^N - i_G^B \cdot Bg_W - i_F^{FX,W} \cdot L_F^{FX,W} \cdot e^N - i_B^{FX,W} \cdot L_B^{FX,W} \cdot e^N \\ & - Div_{F,W} - Div_{B,W} + O_W \end{aligned} \tag{178}$$

Remittances (Rem, 179) are modelled as a constant fraction θ_{REM} of nominal world GDP.

$$Rem = \theta_{REM} \cdot GDP_W \cdot p^W \tag{179}$$

Other transfers of the rest of the world (O_W, 180), as done for the other institutional sectors, are modelled as a constant fraction of total domestic production.

$$O_W = v_W \cdot p \cdot Y^{P,D} \tag{180}$$

To begin with the description of flows of funds with the rest of the world, FDI (181) is assumed to be a constant fraction ψ^{FDI} of the investment carried out by firms.

$$FDI = \psi^{FDI} \cdot p^K \cdot I_F \tag{181}$$

ψ_F^{FDI} represents the share of FDI allocated to the NFC sector (182). This flow can take the form of greenfield FDI (183), which adds to the capital stock, and non-greenfield FDI (184), which is only a source of funding.

$$FDI_F = \psi_F^{FDI} \cdot FDI \tag{182}$$

$$FDI_F^G = \psi_G^{FDI} \cdot FDI_F \tag{183}$$

$$FDI_F^{NG} = (1 - \psi_G^{FDI}) \cdot FDI_F \tag{184}$$

The remaining share $(1-\psi_F^{FDI})$ of total FDI inflows is allocated to FCs (185) as non-greenfield FDI:

$$FDI_B = (1-\psi_F^{FDI}) \cdot FDI \tag{185}$$

FDI allows the rest of the world to accumulate equities against NFCs (186) and FCs (187).

$$\dot{EQ}_F^W = FDI_F \tag{186}$$

$$\dot{EQ}_B^W = FDI_B \tag{187}$$

We assume that the rest of the world purchases domestic currency bonds ($\dot{Bg}_W$, 188) issued by the government on the basis of a constant relationship with the trade balance.

$$\dot{Bg}_W = \eta_{GW}^D \cdot -TB \tag{188}$$

We also assume that the government tends to seek more FX financing when the economy faces a stronger balance of payments imbalance as a way to cope with and ease the external constraint. More precisely, Ω_G^{FX} determines the percentage of the trade deficit that the government is willing to finance through FX public debt operations. This fraction moves towards its target value ($\Omega_G^{\mathrm{FX,T}}$, 189) at the speed $\beta_{FX,G}$ (190), which depends positively on the current account deficit as a percentage of GDP.

$$\Omega_G^{\mathrm{FX,T}} = \Omega_{G0} + \Omega_{G1} \cdot \frac{CAD}{GDP} \tag{189}$$

$$\dot{\Omega}_G^{\mathrm{FX}} = \beta_{FX,G} \cdot (\Omega_G^{\mathrm{FX,T}} - \Omega_G^{\mathrm{FX}}) \tag{190}$$

Hence, equation (191) shows the FX bonds issued by the government ($\dot{Bg}^{FX}$, 191), which are fully purchased by foreign investors. Meanwhile, equation (192) indicates the FX loans demanded by the government ($\dot{Lg}^{FX}$, 192), all of which are granted (i.e., no credit rationing) by foreign banks.

$$\dot{Bg}^{FX} = \phi_{BG}^{FX} \cdot \left(\Omega_G^{\mathrm{FX}} \cdot \frac{-TB}{e^N}\right) \tag{191}$$

$$\dot{Lg}^{FX} = (1-\phi_{BG}^{FX}) \cdot \left(\Omega_G^{\mathrm{FX}} \cdot \frac{-TB}{e^N}\right) \tag{192}$$

To simplify further our definitions, equation (193) shows the total flow of FX loans supplied by foreign banks ($\dot{L}^{FX,W}$, 193) to NFCs, FCs, and the government.

$$\dot{L}^{FX,W} = \dot{L}_F^{FX,W} + \dot{L}_B^{FX,W} + \dot{L}_G^{FX,W} \tag{193}$$

Conversely, equation (194) presents the total accumulation of FX deposits $\left(D^{\dot{F}X}\right)$ by these three sectors against the rest of the world.

$$D^{\dot{F}X} = D_F^{\dot{F}X} + D_B^{\dot{F}X} + D_G^{\dot{F}X} \tag{194}$$

The balance of payments identity is given by equation (195). Basically, it specifies that the economy will accumulate FX reserve assets when, in the balance of payments, FX inflows exceed outflows, while FX reserve assets will fall in the opposite case.

$$\dot{R}^{FX} = \frac{TB}{e^N} + \frac{IA}{e^N} + \frac{FDI}{e^N} + B\dot{g}^{FX} + L\dot{g}^{FX} + L^{F\dot{X},W} + \frac{B\dot{g}_W}{e^N} - D^{\dot{F}X} \tag{195}$$

In line with the above, the demand for foreign exchange $\left(D^{FX}\right.$, 196$\left.\right)$ is driven by the outflows in the current and financial accounts of the balance of payments.

$$D^{FX} = \frac{IM}{e^N} + i_G^{B,FX} \cdot Bg^{FX} + i_G^{L,FX} \cdot Lg^{FX} + \frac{i_G^B \cdot Bg_W}{e^N} + i_F^{FX,W} \cdot L_F^{FX,W} + i_B^{FX,W} \cdot L_B^{FX,W} + \frac{Div_{F,W}}{e^N} + \frac{Div_{B,W}}{e^N} + \dot{R}_B^{FX,d} \tag{196}$$

The supply of foreign exchange $\left(S^{FX}\right.$, 197$\left.\right)$, on the other hand, is given by the inflows in the current and financial accounts of the balance of payments.

$$S^{FX} = \frac{X}{e^N} + Rem + O_W + i_{CB}^{FX,R} \cdot R_{CB}^{FX} + i_B^{FX,R} \cdot R_B^{FX} + \frac{FDI}{e^N} + B\dot{g}^{FX} + L\dot{g}^{FX} + L^{F\dot{X},W} + \frac{B\dot{g}_W}{e^N} - \dot{R}_{CB}^{FX} \tag{197}$$

The dynamics of the nominal exchange rate $\left(e^N\right.$, 198$\left.\right)$ are driven by excess demand for foreign exchange. Thus, the exchange rate will increase (i.e., the currency will depreciate) with an excess FX demand, and it will decrease with an excess FX supply.

$$\dot{e^N} = \beta_{eN} \cdot \left(\frac{D^{FX} - S^{FX}}{S^{FX}}\right) \cdot e^N \tag{198}$$

Accordingly, the real exchange rate $\left(e^R\right.$, 199$\left.\right)$ is the ratio of the foreign price index expressed in domestic currency to the domestic price level.

$$e^R = \frac{p^W \cdot e^N}{p} \tag{199}$$

Now, before starting the description of interest rates on FX borrowing from abroad, it is important to mention that the country risk premium (rsk, 200) depends on the ratio of imports to FX reserve assets.

$$rsk = \xi_0 \cdot \left(\frac{M \cdot p^W}{R^{FX}}\right)^{\xi_1} \tag{200}$$

In turn, the country risk premium affects the overall premium on FX borrowing ($prem_{FX}$, 201), which affects the borrowing costs of all sectors, albeit to different magnitudes

$$prem_{FX} = \phi_0^{FX} + \phi_1^{FX} \cdot (rsk)^{\phi_2^{FX}} \tag{201}$$

The interest rate charged by foreign banks to FCs ($i_B^{FX,W}$, 202) depends on the international risk-free rate (i_W) and the overall premium ($prem_{FX}$) on FX borrowing.

$$i_B^{FX,W} = i_W + prem_{FX} \tag{202}$$

The interest rate charged by foreign banks to NFCs ($i_F^{FX,W}$), 203) also depends on the international risk-free rate and a multiple $\varrho_F^{FX,W}$ greater than one of the overall premium on FX borrowing. Our assumption is based on the fact that firms are normally charged higher borrowing costs in comparison to financial institutions when they borrow from abroad.

$$i_F^{FX,W} = i_W + \varrho_F^{FX,W} \cdot prem_{FX} \tag{203}$$

The interest rates on FX reserve assets held by the central bank (204) and FCs (205) are given by some constant premiums, $\varrho_B^{FX,R}$ and $\varrho_{CB}^{FX,R}$, over the international risk-free interest rate, respectively.

$$i_B^{FX,R} = i_W + \varrho_B^{FX,R} \tag{204}$$

$$i_{CB}^{FX,R} = i_W + \varrho_{CB}^{FX,R} \tag{205}$$

The interest rate on FX government bonds ($i_G^{B,FX}$, 206) also depends on the international risk-free rate and a multiple $\zeta_G^{B,FX}$ lower than one of the overall premium on FX borrowing. This is consistent with the fact that governments pay lower interest rates than the private sector in the absence of extreme default risks.

$$i_G^{B,FX} = i_W + \zeta_G^{B,FX} \cdot prem_{FX} \tag{206}$$

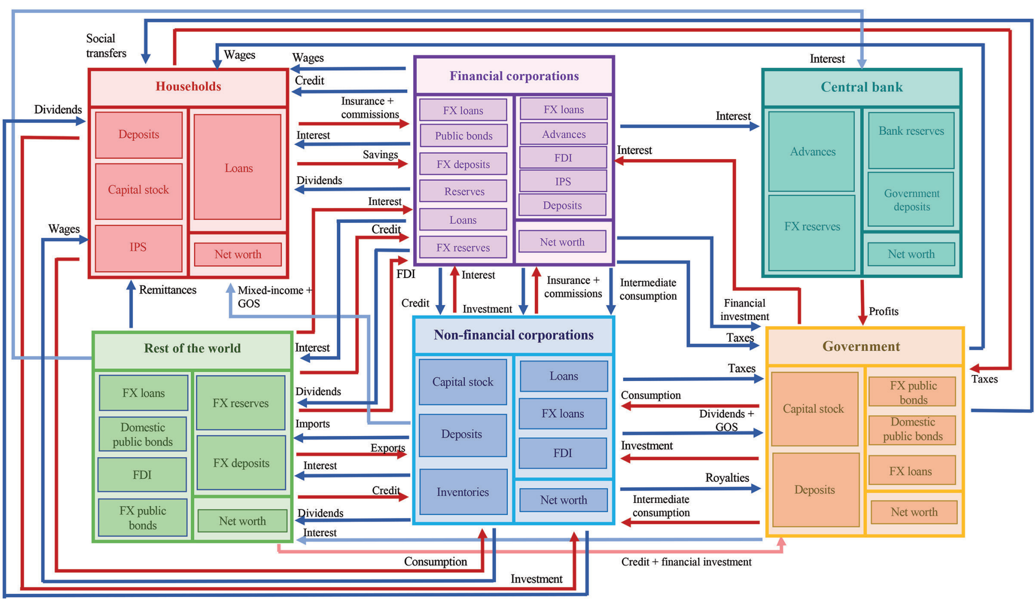
Last but not least, the interest rate on FX government loans ($i_G^{L,FX}$, 207) applies a mark-down $\zeta_G^{L,FX}$ over the FX bonds rate. We assume this since multilateral and development banks that typically provide FX loans tend to offer more favourable borrowing costs vis-à-vis raising FX financing in capital markets.

$$i_G^{L,FX} = \left(1 - \zeta_G^{L,FX}\right) \cdot i_G^{B,FX} \tag{207}$$

2.2.9. Summary

Figure 1 shows a diagram with the main real and financial flows incorporated in the model.

Figure 1. ***Real and financial flows in the Colombian model: Data sources***



3. Matching the data to the theoretical transaction-flow matrix

Moving from a theoretical to an empirical model requires first filling in the transaction-flow matrix (TFM) and the balance sheet (BS) with real data from the Colombian economy. This makes it possible to calibrate the parameters and set the initial conditions of the system of equations and to have some reference values to assess the accuracy of the model's simulations. We will now proceed to describe briefly each of these intermediate steps.

As can be seen in the accounting structure and the system of equations, the theoretical model attempts to capture a broad set of real and financial transactions and assets for the different institutional sectors. Therefore, developing an empirical SFC model is a data-intensive process that requires integrating multiple data sources while complying with the accounting consistency principles. Table 3 presents the main datasets used for the period 2005–2019.

The integrated economic accounts (IEA) dataset published by the Departamento Administrativo Nacional de Estadística (DANE) (National Administrative Department of Statistics) provides valuable information for constructing the real side of the TFM regarding goods and services, income generation, primary income distribution, secondary income distribution, and capital accounts. Along with the SNA guidelines, the flow of funds (FoF) and the financial account (FA) published by the central bank (Banrep) provide information on the flows and stocks of financial assets and liabilities for the different institutional sectors, respectively, which is a key input for the construction of the financial side of the TFM and the BS.

Although following a functional instead of the economic classification methodology of the SNA, the balance of payments (BoP) statistics published by the central bank also contain information on real and financial flows between residents and non-residents. Similarly, the international investment position (IIP) presents the stock of financial assets and liabilities of residents and non-residents. Colombia's financial regulator (Superfinanciera) compiles data on loans, deposits, and interest payments between the domestic banking sector and the private sector (i.e., households and NFCs). Finally, the Ministerio de Hacienda y Crédito Público provides detailed statistics on the public debt and the fiscal balance of the general government.

Table 3. ***Main datasets used to develop the SFC empirical model***

SOURCE	PIB
Departamento Administrativo Nacional de Estadística (DANE)	Integrated economic accounts (IEA) of the SNA
	Gross domestic product (GDP)
	Price deflators of the SNA
	Employment and unemployment
	Exports
	Imports
Banco de la República (Banrep)	Flow of funds (FoF) of the SNA
	Balance sheet (BS) of the SNA
	Balance of payments (BoP)
	International investment position (IIP)
	Central bank's balance sheet
	Central bank's financial income statements
	Foreign direct investment (FDI) by sector
	Nominal exchange rate
	Consumer price index (CPI)
	Monetary policy rate
Superintendencia Financiera de Colombia (Superfinanciera)	Household and NFC loans
	Aggregate deposits
	Interest payment on household and NFC loans
Ministerio de Hacienda y Crédito Público (MHCP)	Public debt of the general government
	Fiscal balance of the general government

Source: Authors.

3.1. Constructing the empirical matrices

Representing the theoretical TFM and BS with empirical data is neither a straightforward nor an automatic process. Even though the IEA, the FoF, and the FA of the SNA have an important correspondence with the accounting structure of the model and provide most of the information, in some cases their level of disaggregation is insufficient to fill in all transactions and assets, and in others, there are conceptual and methodological differences that create discrepancies between the real and the financial side of the economy. This requires the integration and harmonisation of complementary sources of information and the making of certain assumptions, while ensuring the accounting consistency of the matrices and reliably representing the main regularities of the institutional sectors.

One of the main challenges arising from the SNA is that it is not always possible to identify who pays whom and who owes whom, in contrast to what is envisaged in the model. Thus, the SNA does not always provide information on income and expenditure flows between institutional sectors or on intersectoral debt relationships. This required us to draw on complementary information compiled by the Superfinanciera, the Banco de la República, and the Ministerio de Hacienda y Crédito Público and harmonise it with the existing SNA information. This was done mainly to obtain disaggregated interest payments by agent and by asset type and to better identify loans, deposit holdings, and public debt holdings across institutional sectors.

Related to the above, the SNA divides the interest payments actually paid by the institutional sectors on loans and deposits into two components. On the one hand, as value added associated with the provision of financial intermediation services indirectly measured (FISIM) in the goods and services account and, on the other hand, as pure interest payments in the primary income distribution account. To the extent that the empirical TFM resorts to interest payments on loans and deposits from sources other than the SNA, it is necessary to recalculate GDP (supply and demand) to deduct FISIM and avoid double counting. In this sense, in the empirical TFM, FISIM is not treated as value added but as actual interest payments, as we also mentioned above.

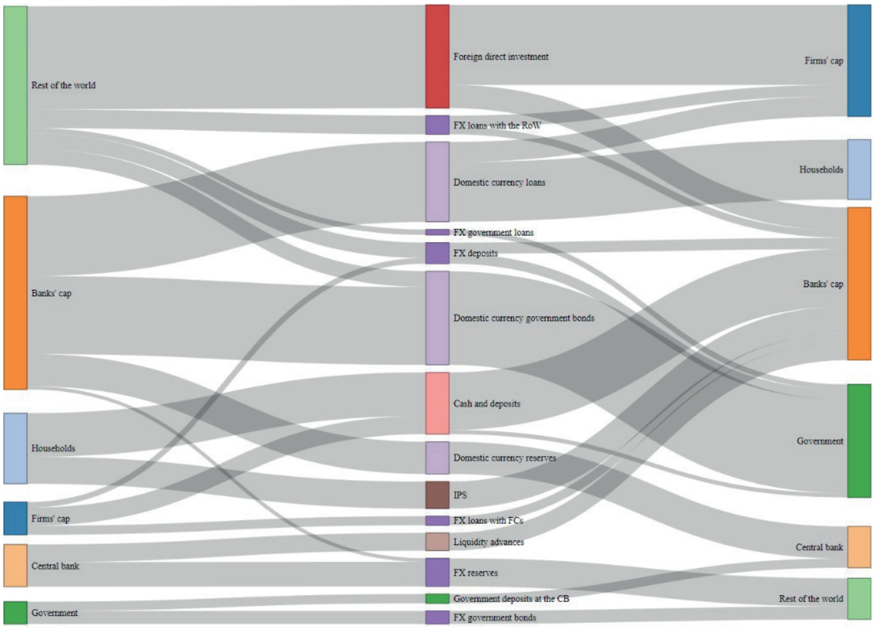
Although in the model, firms carry out most of the production in the economy, in the SNA both households and the government also produce and generate value added. To allow firms to receive almost all of the aggregate demand in the economy and to avoid the complexity of modelling each institutional sector as a productive sector, the production of households and the market production of the government was shifted to non-financial corporations. This also required shifting production-related flows such as intermediate consumption, taxes on production, and wages paid by households. However, to keep the net lending/borrowing position of these agents unchanged, non-financial corporations redistribute the corresponding value added back to households and the government.[24]

Finally, it was also necessary to deal with three additional issues that create discrepancies between theory and practice. First, the SNA includes non-profit institutions serving households (NPISHs) even though they are not analytically relevant to the model. Dealing with this required moving all their flows and stocks recorded in the SNA into the household sector. Second, the SNA also presents some income and expenditure flows that are neither analytically relevant nor large, but which affect the net lending/borrowing position of the agents and therefore cannot be eliminated. This implied the creation of an item called *other transfers* that aggregates the flows not explicitly modelled. Third, in the SNA there are discrepancies between the net lending/borrowing of institutional sectors calculated from the real data (i.e., IEA) and financial data (i.e., FoF) due to the use of different data sources and methodologies. As the model cannot have loopholes between the real and financial side of the TFM, the item other transfers also acts as a residual that helps to balance both sides.

With this in mind, the empirical appendix of this chapter shows the TFM and BS of the Colombian economy as a percentage of GDP for the year 2019, which will serve as a reference for the calibration of the parameters and the setting of the initial conditions of the model. However, to appreciate the size and type of interrelationships between the institutional sectors, Figure 2 presents a Sankey diagram representing the financial side of the empirical TFM, and Figure 3 shows a Sankey diagram representing the real side of the empirical TFM.

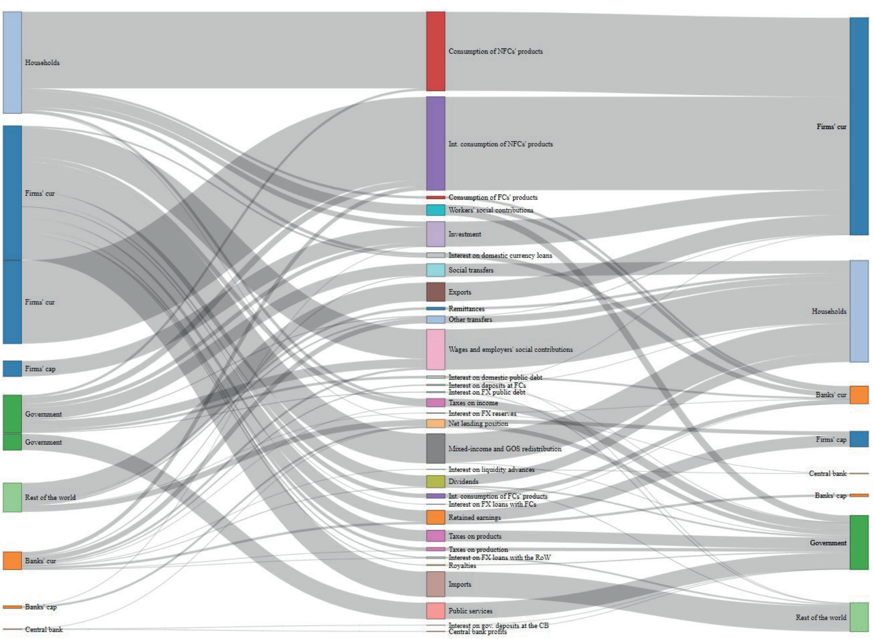
24. This procedure is behind the rows of mixed-income distribution and gross operating surplus redistribution shown in the TFM.

Figure 2. ***Sankey diagram of the financial side of the empirical TFM (%GDP)***



** On the left is the accumulation of assets (or the deaccumulation of liabilities), and on the right is the accumulation of liabilities (or the deaccumulation of assets).*

Figure 3. ***Sankey diagram of the real side of the empirical TFM (%GDP)***



On the left are uses and on the right are resources

Source: Own computations.

3.2. Model calibration and initial conditions

Once the TFM and the BS are filled with empirical data, the next step in the development of the empirical SFC model corresponds to the determination of the initial conditions and parameter values of the dynamic system of equations. This procedure will determine the accuracy of the model to reproduce, on average, the main macroeconomic and financial regularities of the Colombian economy underlying the accounting structure. We will now proceed to briefly explain the intuition behind each of these steps.

First, determining the initial conditions of the system of equations refers to assigning values to certain variables for a reference year that will serve as a starting point and mark the trajectory of the simulations. The variables requiring initial conditions are the stocks of financial and non-financial assets (e.g., loans, deposits, capital stock) and other state variables with an associated differential equation (e.g., prices, exchange rate, labour productivity, wages). Based on the information contained in tables 1 to 3, 2019 was chosen as the base year to avoid the COVID-19 shock in 2020–2021 and due to low data availability for 2022.

Second, given the starting point, the parameter set plays a major role in driving the system of equations since it determines the interrelationship between variables and their evolution over time. The parameter values were calculated based on the datasets presented in tables 1 to 3 for the period 2014–2019 for the same reasons mentioned previously. Here it is important to point out that some out-of-sample issues may arise, especially in very long-term simulations, since the parameters are set based on past information and cannot capture any type of structural change and policy regime shift. Nonetheless, this limitation is common to most macroeconomic models relying on past data.

With this caveat in mind, three approaches were followed to calibrate the parameters. In the case of variables that grow at a constant rate (e.g., labour productivity, foreign prices) or that are a ratio between two known variables (e.g., tax rates, public consumption to GDP), the associated parameters are calibrated as simple averages. For some parameters such as elasticities to country risk premium, firms' leverage, and public debt, reference values were taken from the literature. When possible, a numerical algorithm optimisation method known as CMA-ES[25],

25. Covariance matrix adaptation - evolution strategy (CMA-ES) is a numerical algorithm that optimises non-linear continuous-time dynamic systems (see Hansen & Auger, 2011, and Auger & Hansen, 2012 for further details). It determines the parameter values that minimise the distance between the observed variable and the simulated variable from a block of model equations. Nonetheless, the approach is not an estimation procedure since there is no statistical inference.

which minimises the distance between simulated variables and observed data, was used to calibrate some parameters (e.g., propensities to consume and import).

After setting the parameter values and the initial conditions of the system of equations, the numerical solution method Runge-Kutta of order 4 (RK4) was used to conduct numerical simulations for a given time horizon. Although RK algorithms do not provide analytical solutions due to the large number of variables and the non-linearity of the system of equations, fourth-order RK generate accurate simulation results in a computationally efficient way. Hence, this method provides a solution path for the model variables associated with each of the different macroeconomic scenarios described in this and the following chapters.

4. Baseline scenario

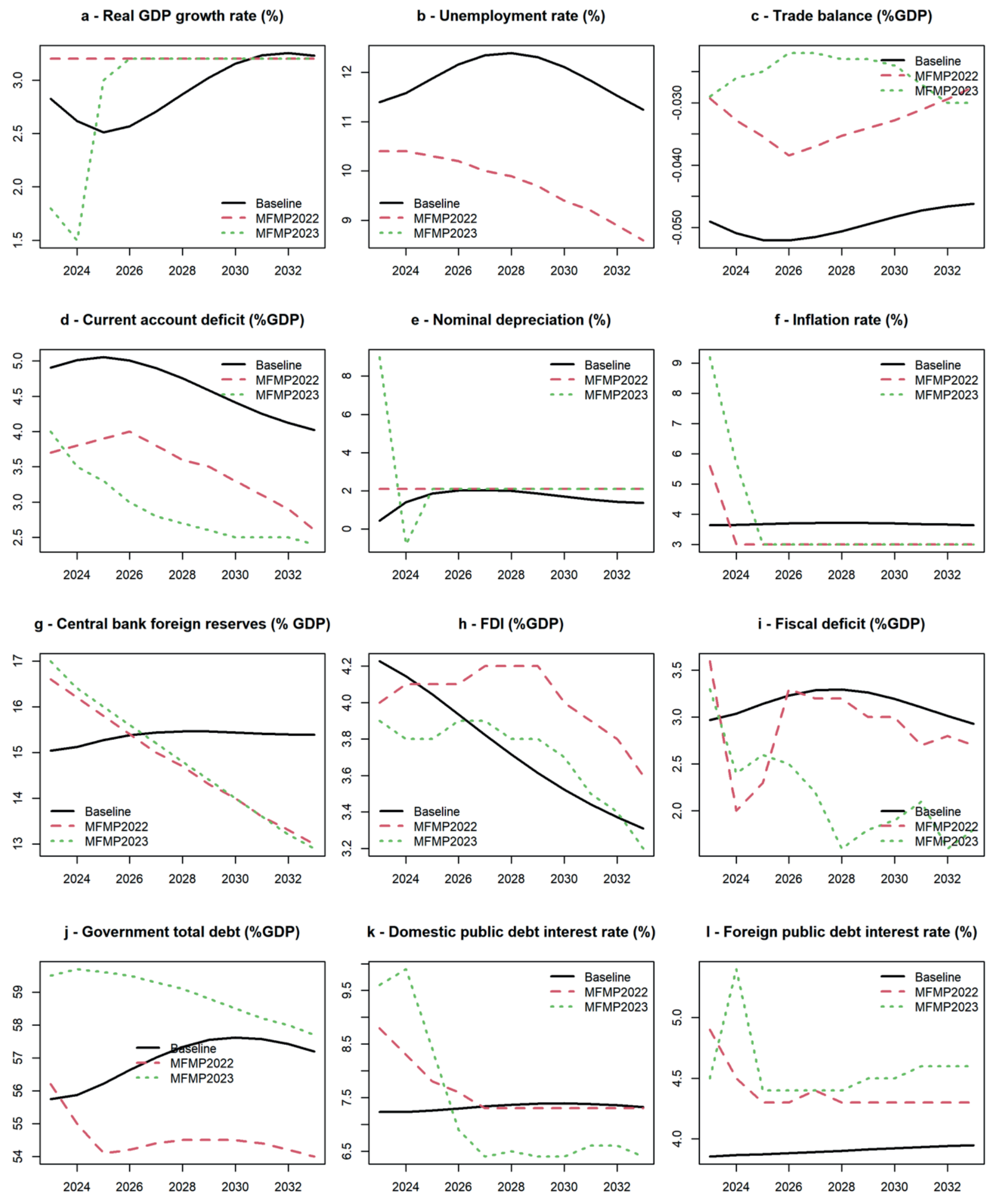
Aside from the calibration and initial value setting, it is necessary to determine paths for several other macroeconomic variables. The baseline scenario reflects the average medium- and long-term behaviour of the Colombian economy that the GEMMES model is able to represent based on the system of equations, the calibration of the parameters, and the setting of the initial values. Insofar as the GEMMES model is not a forecasting tool but rather an analytical framework to study counterfactual scenarios, the baseline scenario lacks domestic and external shocks, regime shifts, and fiscal and trade policy responses. In this sense, it does not consider the investment path in climate change mitigation and adaptation, nor does it consider a drop in fossil fuel exports in the context of a global low-carbon transition. This will allow the other scenarios to assess the macroeconomic impacts of the green investment commitments and the materialisation of some cross-border transition risks such as loss of fossil fuel exports.

In the baseline scenario, we thus assume the population to grow at a constant rate of 1%, domestic and world productivity to grow at a constant rate of 2% (hence assuming away any catching-up or lagging behind), world GDP in real terms to grow at a constant rate of 3%, and world inflation is set at 3%. We assume further that FDI inflows as a share of NFCs' investment slow down from their peak value in 2019, falling from 38% of investment (i.e., 4.5% of GDP) to 26% (3% of GDP) by 2050. We also assume a reversal in observed trends of propensity to export non-fossil fuel goods and services and revert it to its average over the last 15 years by slowly increasing the linear term in the export propensity equation by 20% between 2019 and 2050.

4.1. Medium-term outcomes

We now describe our baseline scenario and compare it with the baseline scenarios of the Ministerio de Hacienda y Crédito Público (MHCP) for the period 2023 to 2033. Figure 4 shows the projections for selected variables for the two scenarios: our baseline (black solid line) and the MHCP baseline (red dashed line for the MHCP's 2022 projections, and green dashed line for the MHCP's 2023 projections). Evidently, our scenarios seem to concur on most variables with both MHCP scenarios (noting that there are some differences between 2022 and 2023). Our baseline foresees slightly slower real GDP growth (Panel a) initially but converging values in the long run, a slightly higher unemployment rate (Panel b), a slightly higher trade deficit (Panel c), a slightly higher current account deficit (Panel d), a similar nominal depreciation rate (Panel e), slightly higher inflation (Panel f), more stable foreign reserves (Panel g), similar FDI growth rates (Panel h), a slightly higher fiscal deficit (Panel i), average public debt (Panel j), and similar interest rates on domestic (Panel k) and foreign (Panel l) public debt.

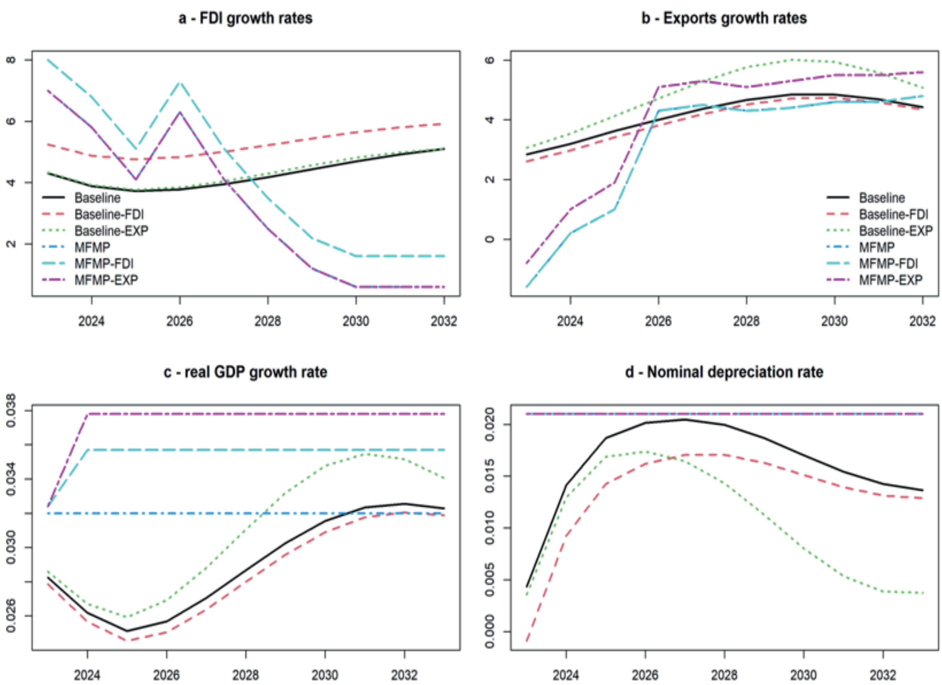
Figure 4. ***Simulated baseline scenario (black solid line), medium-term fiscal framework 2022 (MFMP 2022, red dashed line), and medium-term fiscal framework 2023 (MFMP 2023, green dashed line)***



Source: Ministerio de Hacienda y Crédito Público (2022; 2023) and own computations.

As a robustness test, we simulate the two external scenarios considered in Ministerio de Hacienda y Crédito Público (2022) in our model and compare them with their results. In Figure 5 below, "MFMP 2022 FDI" assumes higher levels of FDI inflows entering the economy relative to MFMP baseline, while "MFMP 2022 EXP" assumes an increase in export propensities due to a stronger integration in global value chains relative to MFMP baseline again (see Box 4.3 starting on page 132 of Ministerio de Hacienda y Crédito Público, 2022).[26] Panel a in Figure 5 compares the paths for FDI and exports under our FDI and EXP scenarios with the MFMP's FDI and EXP scenarios with these assumptions.

Figure 5. ***Baseline (black solid line), FDI scenario (red dashed line), EXP scenario (green dotted line), Ministerio de Hacienda y Crédito Público (2022) baseline (blue dash-dotted line), the MHCP's FDI scenario (cyan long-dashed line), and the MHCP's EXP scenario (pink dash-dotted line).***



Source: Ministerio de Hacienda y Crédito Público (2022; 2023) and own computations.

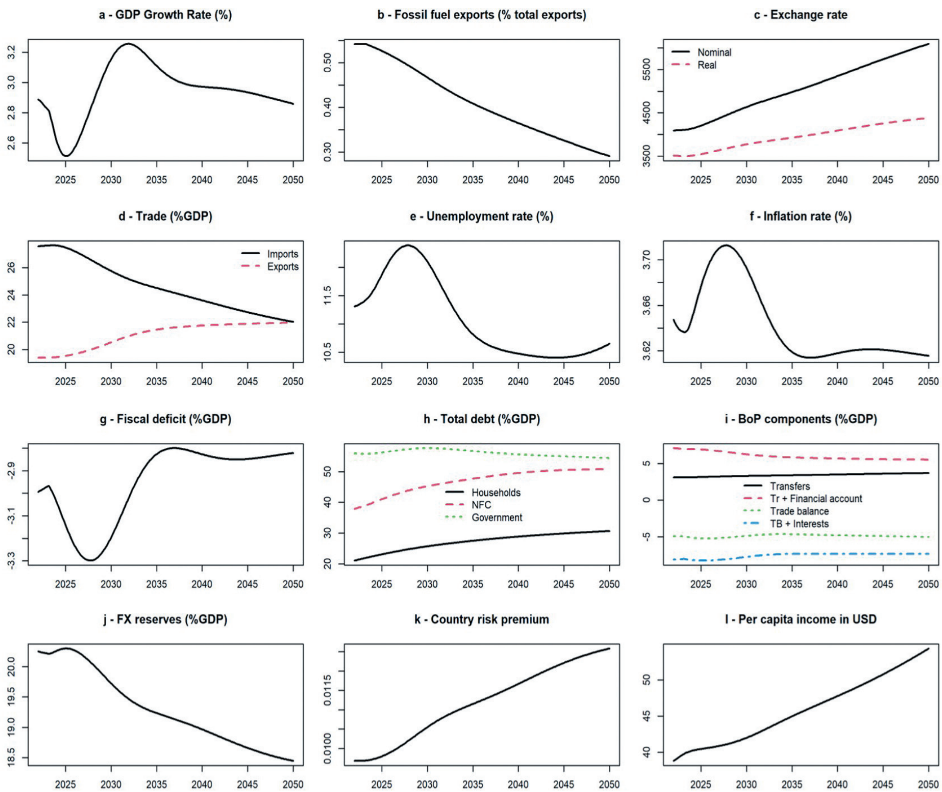
26. Note that in Panel a, MFMP baseline and MFMP EXP have the same FDI growth rates, so the two curves coincide, while in Panel b, MFMP baseline and MFMP FDI have the same export growth rates, so the two curves coincide again. In Panel d, the three MFMP scenarios have the same depreciation rate so that the three curves coincide as well.

Panels c and d display the dynamics of the growth rate and the nominal depreciation rate of the Colombian peso from our model and MHCP (2022). The effects in terms of GDP growth are lower for the export scenarios (the difference between the red dashed line and the black line vs. the difference between the pink line and the cyan line) and very small and of opposite sign for FDI in our simulations, contrary to MHCP (2022). This is because in our model only 48% of FDI investment leads to capital accumulation (in other words, greenfield FDI), while the rest only provides financing of investment for NFCs, and because in our demand-driven model, FDI investment only has a positive demand effect, i.e., it does not necessarily lead to higher production as in the supply-driven model of MHCP, where capital stock determines production. Furthermore, the increase in FDI leads to a lower depreciation rate (Panel d), which increases imports and reduces exports (Panel b), overcoming the positive effect that FDI has on investment and hence leading to a lower growth rate of GDP. On the other hand, the increase in exports leads to a fall in the depreciation rate in our model, hence reducing the drop in imports observed in the baseline scenario and causing lower growth rates in real terms. This highlights the importance of having a fully integrated model with financial feedback loops.

4.2. Long-term outcomes

Figure 6 presents the long-term outcomes of our baseline scenario from 2023 to 2050 for selected variables. We can see that the real GDP growth rate settles at 2.8% (Panel a). It is important to note that our baseline scenario encompasses a profound structural change induced by fixed fossil fuel exports, hence leading to a reduction of their share in total exports (Panel b). As a result, the economy experiences a strong depreciation of its currency, both in nominal and real terms (Panel c). Imports thus decrease as a share of real GDP, while exports increase. Note that because fossil fuel exports remain constant in real terms, the aggregate growth rate of exports increases less fast than imports fall (Panel d). As a consequence, both consumption and investment see a decrease of their share in real GDP (not shown).

Figure 6. ***Long-term properties of the baseline scenario for selected variables***



Source: Own computations.

Unemployment (Panel e) and inflation (Panel f) are relatively stable. The fiscal deficit (Panel g) decreases and stabilises at around 2.8% of GDP. NFC total debt decreases to stabilise at around 50% of GDP, while households' debt pursues its historical growth to reach more than 30% of GDP (Panel h). On the other hand, public debt, after a slight increase, starts decreasing and reaches around 50% of GDP in 2050, which is in line with the target set by the government (see Chapter 1).

Panel i shows different components of the balance of payments where all components remain fairly constant, notwithstanding the Colombian peso's depreciation. Interest payments to the rest of the world remain relatively constant as a share of GDP because while depreciation increases the domestic currency value of FX debt, the deleveraging of both firms and government compensates for this negative effect. Finally, the reduction in financial inflows, partly due to the exogenous reduction in FDI flows and partly due to the general deleveraging, leads to a lower supply of foreign exchange, and as a consequence the economy experiences a constant excess demand in foreign exchange markets, maintaining the depreciation of the Colombian peso over the entire simulation. Moreover, FX reserves decline as a share of GDP (Panel j), leading to an increase in the country risk premium (Panel k). Finally, per capita income in USD (Panel l) displays a constant increase until 2050, indicating increasing living standards for the Colombian population.

Table 4 summarises average values for the baseline and their historical counterpart. The model will be used in the subsequent chapters while testing for alternative scenarios.

Table 4. ***Simulated and reference values for selected macroeconomic variables***

VARIABLE	SIMULATED VALUE	REFERENCE VALUE	SOURCE
Real GDP growth rate (%)	3.0%	3.2%	CARF long-term reference. Source: CARF
Unemployment rate (%)	11.1%	10.7%	Average 2005–2019. Source: DANE
Inflation rate (%)	3.6%	3.9%	Average 2010–2019*. Source: BanRep
Nominal depreciation rate (%)	1.5%	3.1%	Average 2005–2019. Source: BanRep
Final consumption (%GDP)	82.3%	81.6%	Average 2005–2019. Source: DANE
Investment (%GDP)	22.6%	22.0%	Average 2005–2019. Source: DANE
Imports SNA (%GDP)	22.1%	20.6%	Average 2005–2019. Source: DANE
Exports SNA (%GDP)	17.3%	16.8%	Average 2005–2019. Source: DANE
Trade balance SNA (%GDP)	-4.9%	-3,7%	Average 2005–2019. Source: DANE
Current account SNA (%GDP)	-4.1%	-4.3%	Average 2005–2019. Source: DANE
Transfers BoP (%GDP)	3.4%	2.3%	Average 2015–2019. Source: BanRep
Primary income account BoP (%GDP)	-2.7%	-2.6%	Average 2015–2019. Source: BanRep
Foreign direct investment BoP (%GDP)	3.3%	4.0%	Average 2005–2019. Source: DANE
Portfolio and other investment inflows BoP (%GDP)	1.9%	2.6%	Average 2005–2019. Source: BanRep
Public investment SNA (%GDP)	3.8%	3.5%	Average 2015–2019. Source: DANE
General gov. expenditure SNA (%GDP)	31.4%	31.6%	Average 2015–2019. Source: DANE
General gov. revenue SNA (%GDP)	28.5%	27.0%	Average 2015–2019. Source: DANE
General gov. balance (%GDP)	3.0%	2.6%	Average 2008–2019. Source: MHCP
General gov. interest payments (%GDP)	3.3%	3.0%	Average 2008–2019. Source: MHCP
General gov. primary balance (%GDP)	0.4%	0.4%	Average 2008–2019. Source: MHCP
General gov. public debt (%GDP)	56.3%	55.0%	Debt anchor for the Central National Government
General gov. implied public debt interest rate (%)	5.9%	6.2%	Average 2008–2019. Source: MHCP
Household deposits (%GDP)	48.2%	17.8%	2019. Source: DANE
Household loans (%GDP)	27.5%	21.0%	2019. Source: Superfinanciera
NFCs' loans (%GDP)	47.4%	36.4%	2019. Source: Superfinanciera and BanRep
Gross external debt (%GDP)	42.2%	45.2%	2019. Source: Superfinanciera and Banrep
FX reserve assets (%GDP)	19.3%	22.2%	2019. Source: BanRep
Monetary policy rate (%)	6.1%	5.5%	Average 2005–2019: Source: BanRep

** The inflation target was set at 3.0% in 2010.*
Source: Authors.

5. Concluding remarks

This chapter presented a detailed account of the empirical macroeconomic model developed for the case of Colombia, capturing most of the institutional characteristics of the country. The model is able to capture relevant economic dynamics of the past and seems to agree in the short to medium term with the econometric model of the Ministerio de Hacienda y Crédito Público. We have however shown how its financial and monetary nature sheds a different light when considering specific shocks such as export or FDI increases.

The model will be used in the coming chapters to analyse the macroeconomic and financial outcomes of different global transitions and their impact on Colombia's fossil fuel exports (Chapter 3), of different scenarios for financing Colombia's NDC (Chapter 4), and of different international shocks (Chapter 5, but based on a different version of the model).

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Appendix: Nomenclature

Variable name and description

VARIABLE	DESCRIPTION	TYPE	CURRENCY
Y^e	Expected sales	Real	
g_k	NFCs' capital stock growth rate	Real	
Y^P	Production of NFCs	Real	
$I^{V,d}$	Desired investment in inventories	Real	
V^d	Desired inventories	Real	
V	Inventories	Real	
I^V	Actual investment in inventories	Real	
$Y^{P,D}$	Domestic production of NFCs	Real	
Y^D	Nominal aggregate demand	Nominal	Domestic
$Y^{D,r}$	Real aggregate demand	Real	
C	Final consumption of goods	Nominal	Domestic
IC	Intermediate consumption	Nominal	Domestic
I^K	Total investment	Nominal	Domestic
X	Total exports	Nominal	Domestic
X_C	Nominal oil and coal exports	Nominal	Domestic
x_C	Real oil and coal exports	Real	
X_{NC}	Non-oil and coal exports	Nominal	Domestic
$\sigma^T_{X_N}$	Target propensity to export non-commodity exports		
σ_{X_N}	Propensity to export non-commodity exports		
GDP_W	Foreign gross domestic product	Real	
IM	Nominal imports	Real	
M	Real imports	Real	
$\sigma^T_{M,C}$	Target propensity to import consumption goods		
$\sigma_{M,C}$	Propensity to import consumption goods		
$\sigma^T_{M,IC}$	Target propensity to import int. consumption goods		

VARIABLE	DESCRIPTION	TYPE	CURRENCY
$\sigma_{M,IC}$	Propensity to import int. consumption goods		
$\sigma_{M,I}^{T}$	Target propensity to import investment goods		
$\sigma_{M,I}$	Propensity to import investment goods		
a_D	Domestic productivity	Real	
a_W	Foreign productivity	Real	
Y^B	Production of FCs	Nominal	Domestic
Y^G	Non-market production of the government	Nominal	Domestic
G_C	Non-market consumption of the government	Nominal	Domestic
GDP	Gross domestic product	Nominal	Domestic
UC	Unit cost of production	Nominal	Domestic
HUC	Historical unit cost of production	Nominal	Domestic
p^d	Desired production price level	Nominal	Domestic
μ	Mark-up on historical unit cost		
p	Production price level	Nominal	Domestic
p^C	Price of consumption goods	Nominal	Domestic
p^{IC}	Price of intermediate consumption goods	Nominal	Domestic
p^K	Price of investment goods	Nominal	Domestic
p^X	Price of export goods	Nominal	Domestic
p^W	Foreign price level	Nominal	Foreign
IC_F	Intermediate consumption of NFCs	Real	
INS_F	Insurance services paid by NFCs	Nominal	Domestic
COM_F	Financial commissions paid by NFCs	Nominal	Domestic
$I_F^{K,T}$	Target investment of NFCs	Real	
I_F^K	Investment of NFCs	Real	
K_F	Capital stock of NFCs	Real	
r_F	Profit rate	Nominal	
u	Utilisation rate of capital		

VARIABLE	DESCRIPTION	TYPE	CURRENCY
u^e	Expected utilisation rate of capital		
L_F	Employment in NFCs		
w_F	Wage paid by NFCs	Nominal	Domestic
GOS_F	Gross operating surplus of NFCs	Nominal	Domestic
MI_H	Mixed income	Nominal	Domestic
$GOS_{F,H}$	Gross operating surplus redistributed to households	Nominal	Domestic
$GOS_{F,G}$	Gross operating surplus redistributed to the government	Nominal	Domestic
GF_F	Gross profits of NFCs	Nominal	Domestic
F_F	Net profits of NFCs	Nominal	Domestic
F_F^{ND}	Net profits of NFCs net of deposits accumulation	Nominal	Domestic
D_F^{FX}	FX deposits of NFCs	Nominal	Foreign
D_F	Domestic deposits of NFCs	Nominal	Domestic
Div_F	Dividends paid by NFCs	Nominal	Domestic
$Div_{F,G}$	Dividends paid by NFCs to the government	Nominal	Domestic
$Div_{F,W}$	Dividends paid by NFCs to the RoW	Nominal	Domestic
$Div_{F,H}$	Dividends paid by NFCs to households	Nominal	Domestic
RE_F	Retained earnings of NFCs	Nominal	Domestic
TFN_F	Total financing needs of NFCs	Nominal	Domestic
$L_F^{FX,B,d}$	Desired FX loans of NFCs with FCs	Nominal	Foreign
$L_F^{FX,B}$	FX loans of NFCs with FCs	Nominal	Foreign
$L_F^{FX,W,d}$	Desired FX loans of NFCs with the RoW	Nominal	Foreign
$L_F^{FX,W}$	FX loans of NFCs with the RoW	Nominal	Foreign
L_F^d	Domestic currency loans of NFCs	Nominal	Domestic
$rat_F^{FX.B}$	Rationing of FCs to NFCs' FX loans demand		
$rat_F^{FX.W}$	Rationing of the RoW to NFCs' FX loans demand		
GOS_B	Gross operating surplus of FCs		
L_B	Employment in FCs		

VARIABLE	DESCRIPTION	TYPE	CURRENCY
IC_B	Intermediate consumption of FCs	Real	
w_B	Wage paid by FCs	Nominal	Domestic
ST_B	Social transfers paid by FCs	Nominal	Domestic
I_B	Investment of FCs	Real	
K_B	Capital stock of FCs	Real	
GF_B	Gross profits of FCs	Nominal	Domestic
F_B	Net profits of FCs	Nominal	Domestic
OF_B^{CAR}	Capital required to comply with leverage regulations	Nominal	Domestic
RE_B	Retained earnings of FCs	Nominal	Domestic
OF_B	Own funds of FCs	Nominal	Domestic
Div_B	Dividends paid by FCs	Nominal	Domestic
$Div_{B,H}$	Dividends paid by FCs to households	Nominal	Domestic
$Div_{B,W}$	Dividends paid by FCs to the RoW	Nominal	Domestic
L^d	Domestic currency loans	Nominal	Domestic
D^d	Domestic currency deposits	Nominal	Domestic
Rd	Domestic currency reserves	Nominal	Domestic
Bg_B	Government bonds held by FCs	Nominal	Domestic
$L_B^{FX,W,d}$	Desired FX loans of FCs with the RoW	Nominal	Foreign
$L_B^{FX,W}$	FX loans of FCs with the RoW	Nominal	Foreign
$rat_B^{FX.W}$	Rationing of the RoW to FCs' FX loans demand		
D_B^{FX}	FX deposits of FCs	Nominal	Foreign
$R_B^{FX,d}$	Desired FX reserves of FCs	Nominal	Foreign
R_B^{FX}	FX reserves held by FCs	Nominal	Foreign
TFN_B	Total financing needs of FCs	Nominal	Domestic
A	Liquidity advances	Nominal	Domestic
i^D	Interest rate on domestic deposits	Nominal	Domestic
md	Mark-down on monetary policy rate	Nominal	Domestic

VARIABLE	DESCRIPTION	TYPE	CURRENCY
i_F^L	Interest rate on loans to NFCs	Nominal	Domestic
AFC	Average funding cost of FCs	Nominal	Domestic
$prem_F^T$	Target interest rate premium on loans to NFCs	Nominal	Domestic
$prem_F$	Interest rate premium on loans to NFCs	Nominal	Domestic
i_H^L	Interest rate on loans to households	Nominal	Domestic
$prem_H^T$	Target interest rate premium on loans to households	Nominal	Domestic
$prem_H$	Interest rate premium on loans to households	Nominal	Domestic
$i_B^{FX,W}$	Interest rate on FX loans of FCs with the RoW	Nominal	Foreign
$prem_{FX}$	Premium on FX loans	Nominal	Foreign
$i_F^{FX,B}$	Interest rate on FX loans of NFCs with FCs	Nominal	Foreign
$i_F^{FX,W}$	Interest rate on FX loans of NFCs with the RoW	Nominal	Foreign
$i_B^{FX,R}$	Interest rate on FX reserves of FCs	Nominal	Foreign
$i^{P,T}$	Target monetary policy rate	Nominal	Domestic
i^P	Monetary policy rate	Nominal	Domestic
F_{CB}	Central bank profits	Nominal	Domestic
R_{CB}^{FX}	FX reserves held by the central bank	Nominal	Foreign
$i_{CB}^{FX,R}$	Interest rate on FX reserves of the central bank	Nominal	Foreign
YD_H	Disposable income of households	Nominal	Domestic
L	Total employment		
$unem$	Unemployment rate		
pop	Labour force		
wL	Wage income	Nominal	Domestic
ESC	Employers' social contributions	Nominal	Domestic
WSC	Workers' social contributions	Nominal	Domestic
INS_H	Insurance services paid by households	Nominal	Domestic
COM_H	Financial commissions paid by households	Nominal	Domestic
C_H^T	Target final consumption of households	Nominal	Domestic

VARIABLE	DESCRIPTION	TYPE	CURRENCY
C_H	Final consumption of households	Nominal	Domestic
m_1	Propensity to consume out of disposable income		
m_2	Propensity to consume out of wealth		
I_H^T	Target investment of households	Nominal	Domestic
I_H	Investment of households	Nominal	Domestic
γ_{IH}	Households' investment to disposable income ratio		
K_H	Capital stock of households	Real	
S_H	Households' savings	Nominal	Domestic
TFN_H	Total financing needs of households	Nominal	Domestic
L_H^d	Domestic currency loans of households	Nominal	Domestic
$L_H^{d,C}$	Consumption loans of households	Nominal	Domestic
υ_{LC}^T	Target consumption credit to disposable income ratio		
υ_{LC}	Consumption credit to disposable income ratio		
$L_H^{d,I}$	Mortgage loans of households	Nominal	Domestic
TIR_H	Technical insurance reserves	Nominal	Domestic
D_H	Domestic currency deposits of households	Nominal	Domestic
FR	Fiscal revenue	Nominal	Domestic
T_T	Tax revenue	Nominal	Domestic
T^I	Taxes on income	Nominal	Domestic
T^M	Taxes on imports	Nominal	Domestic
T^V	Value-added taxes	Nominal	Domestic
T^P	Other net taxes on products	Nominal	Domestic
T^Y	Taxes on production	Nominal	Domestic
Roy	Royalties	Nominal	Domestic
G_T	Total expenditures of the government	Nominal	Domestic
G_P	Primary expenditures of the government	Nominal	Domestic
C_G	Final consumption of the government	Nominal	Domestic

VARIABLE	DESCRIPTION	TYPE	CURRENCY
w_G	Wage paid by the government	Nominal	Domestic
L_G	Employment in the government		
IC_G	Intermediate consumption of the government	Real	
I_G^T	Target investment of the government	Real	
I_G	Investment of the government	Real	
K_G	Capital stock of the government	Real	
ST	Social transfers received by households	Nominal	Domestic
ST_G	Social transfers paid by the government	Nominal	Domestic
G_{IP}	Interest payments on public debt	Nominal	Domestic
FD	Fiscal deficit	Nominal	Domestic
D_G^T	Target domestic currency deposits of the government	Nominal	Domestic
D_G	Domestic currency deposits of the government	Nominal	Domestic
$D_G^{CB,T}$	Target deposits of the government at the central bank	Nominal	Domestic
D_G^{CB}	Deposits of the government at the central bank	Nominal	Domestic
D_G^{FX}	FX deposits of the government	Nominal	Foreign
TFN_G	Total financing needs of the government	Nominal	Domestic
Bg^{FX}	FX bonds issued by the government	Nominal	Foreign
Lg^{FX}	FX loans of the government	Nominal	Foreign
$\Omega_G^{FX,T}$	Target share of FX debt in new public debt issued		
Ω_G^{FX}	Share of FX debt in new public debt issued		
Bg	Domestic currency bonds issued by the government	Nominal	Domestic
i_G^B	Interest rate on domestic government bonds	Nominal	Domestic
$prem_G^T$	Target int. rate premium on domestic government bonds	Nominal	Domestic
$prem_G$	Interest rate premium on domestic government bonds	Nominal	Domestic
$i_G^{B,FX}$	Interest rate on FX government bonds	Nominal	Foreign
$i_G^{L,FX}$	Interest rate on FX government loans	Nominal	Foreign
CAD	Current account deficit	Nominal	Domestic

VARIABLE	DESCRIPTION	TYPE	CURRENCY
TB	Trade balance	Nominal	Domestic
IA	Income account of the balance of payments	Nominal	Domestic
Rem	Remittances	Nominal	Foreign
FDI	Foreign direct investment	Nominal	Domestic
FDI_F	Foreign direct investment in NFCs	Nominal	Domestic
FDI_B	Foreign direct investment in FCs	Nominal	Domestic
FDI_F^G	Greenfield foreign direct investment in NFCs	Nominal	Domestic
FDI_F^{NG}	Non-greenfield foreign direct investment in NFCs	Nominal	Domestic
Bg_W	Domestic government bonds held by the RoW	Nominal	Domestic
$L^{FX,W}$	FX loans with the RoW	Nominal	Foreign
D^{FX}	FX deposits	Nominal	Foreign
R^{FX}	FX reserves	Nominal	Foreign
S^{FX}	Foreign exchange supply	Nominal	Foreign
D^{FX}	Foreign exchange demand	Nominal	Foreign
e^N	Nominal exchange rate	Nominal	Domestic
$e^{N,e}$	Expected nominal exchange rate	Nominal	Domestic
e^R	Real exchange rate		
rsk	Country risk	Nominal	Foreign
i_W	International reference interest rate	Nominal	Foreign

Understanding the macroeconomic and financial vulnerabilities associated with the global low-carbon transition for Colombia

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Chapter 3

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Chapter 3

Understanding the macroeconomic and financial vulnerabilities associated with the global low-carbon transition for Colombia

Introduction

One of the key points for achieving the objectives established in the Paris Agreement is to rapidly initiate a decarbonisation pathway for global consumption and production patterns, especially in high-income countries. Despite the slow pace of this process due to moderate ambition and political constraints affecting global mitigation actions, the reduction in global demand for fossil fuels will emerge as one of the main outcomes of this forthcoming structural change. While this global low-carbon transition could benefit net fossil fuel-importing countries, other economies with export, financial, productive, and/or fiscal dependencies on fossil fuel industries will have to cope with the negative impacts (see for example Daumas, 2023; Cahen-Fourot *et al.*, 2021; and Van der Ploeg & Rezai, 2020).

Colombia is a good example of such adversely affected countries; a middle-income country for which coal and oil exports accounted for 51% of the export basket of goods for the period 2015–2022. The oil and mining sector has also been an important source of foreign exchange for the economy, both via high levels of exports and as the recipient of 24% of foreign direct investment (FDI) during this period. In terms of production, the oil and coal mining industry contributed around 5% to the total value added between 2015 and 2022. Finally, the industry has also been an important source of fiscal revenues: royalties, dividends from Ecopetrol (the majority state-owned oil company), and income tax contributed at an average level of 1.4% of GDP per year for the period 2015–2021.

This chapter seeks to analyse some of the implications that the global low-carbon transition may have for the Colombian economy over the period 2023–2050. Based on the model and its calibration presented in Chapter 2, we simulate different scenarios of oil and coal exports projections and analyse their respective medium- and long-term impacts. Then, we consider the effects of an industrialisation policy that contributes to diversifying the export basket in order to assess policy alternatives to reduce the vulnerabilities arising from the decline of fossil fuel exports.

This chapter thus contributes to the literature on macroeconomic and financial vulnerabilities that may emerge in developing economies in the context of the global low-carbon transition. Semieniuk *et al.* (2021), Bolton *et al.* (2020), and Bernal and Ocampo (2020), among others, have examined the potential effects that moving to a low-carbon economy may have on financial stability using a more qualitative approach without resorting to modelling tools to explore cross-channel interactions. Magacho *et al.* (2023) have quantified the macroeconomic exposure of countries to the global low-carbon transition using input-output analysis and clustering techniques. While this approach allows for a deeper exploration of multisectoral issues, its static nature and emphasis on the real side of the economy omit financial dynamics and stock-flow relationships relevant to a more holistic view of vulnerability. Bernal-Ramírez *et al.* (2022) have estimated the effects of physical and transition risks on a set of macroeconomic and financial variables in Colombia based on the Network for Greening the Financial System's scenarios. Although it is a pioneering study for the country, the use of partial equilibrium methodologies and accounting projections omits interactions and adjustment mechanisms within and between the real and financial spheres of the economy that may affect the simulated paths.

Hence, unlike previous studies, this chapter empirically analyses the consequences of such a structural change using a fully integrated stock-flow consistent (SFC) approach that simultaneously models the real and financial dynamics of an economy under different scenarios, while allowing for dynamics of disequilibrium and endogenous responses of institutional sectors to changes in their budget constraints and balance sheets. In this way, by capturing the interactions and feedback loops between both spheres over time, we can obtain more accurate and realistic diagnoses of the risks and opportunities that the low-carbon transition may bring for developing countries like Colombia.

Our results indicate that a decline in fossil fuel exports would lead Colombia to greater macroeconomic and financial fragility. More precisely, the widening trade deficit and lower FDI inflows induce a sharp depreciation of the Colombian peso, which, depending on the timing of the transition and policy responses, could lead to a currency crisis. In turn, the economy exhibits a lower growth rate, resulting in higher unemployment and higher inflation due to the exchange rate pass-through.

Falling oil and coal exports, currency depreciation, and higher inflation widen the fiscal deficit and lead to a higher level of public debt, while the deterioration in public finances and the dis-accumulation of international reserves increases the country risk premium. In the long run, the economy's ability to mitigate or reverse these impacts will depend on the magnitude of the favourable response of the trade balance to peso depreciation, on the implementation of industrialisation policies, and on the integration into global value chains that would diversify the export basket. However, it is a priority to start implementing such policies early, because such structural transformations take time to materialise, and they require multiple bottlenecks to be overcome in order to be effective.

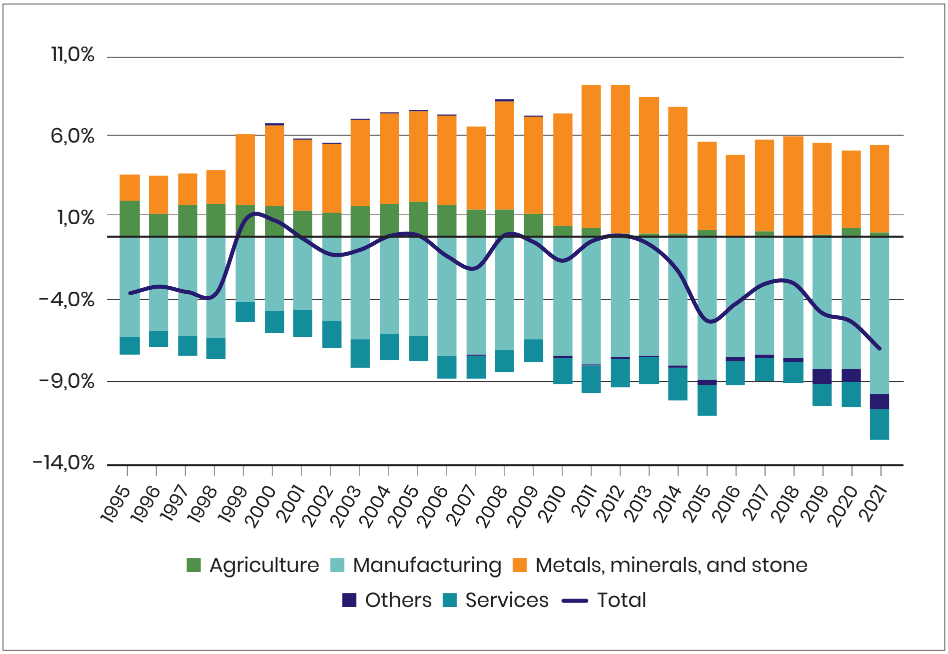
This chapter is structured as follows. After this introduction, section 2 presents a brief background of the Colombian economy. Section 3 describes the scenarios that will be simulated. Section 4 then presents the results of the model simulations for some of the scenarios, shows the possibility of a currency crisis, and discusses some policy responses. Last but not least, section 5 presents the final reflections of this chapter and concludes.

1. A forthcoming global low-carbon transition

As expressed in the introduction, if the world economy follows a global decarbonisation trajectory, the coming decades are expected to be accompanied by a structural change in global energy consumption and production patterns. To embark on a global path towards carbon neutrality, countries will start reducing their demand for fossil fuels and substitute them with cleaner and renewable energy sources. In this regard, coal– and oil-exporting countries would likely experience a decline in prices and real demand for fossil fuels and would be pushed to adjust their supply downwards in response to the transition. This may not only turn fossil fuel reserves and related infrastructure into stranded assets, but also have wide-ranging productive, fiscal, external, and financial implications based on countries' dependencies.

Accordingly, the global low-carbon transition and subsequent decline of demand for fossil fuels will entail risks for the Colombian economy. A recent report by Willis Towers Watson (2023) points out that the country would face material downside risks in exports equal to 27% of 2019 GDP between 2022 and 2050 if there is no change in Colombian export composition. The study also points out implications for employment and fiscal revenues, which, although significant at the national level, also display a high degree of heterogeneity at the regional level. Finally, firms in the sector will be exposed to financial risks due to balance sheet deterioration and loss of capitalisation.

Figure 1. ***Trade balance of goods by type of product (% GDP)***

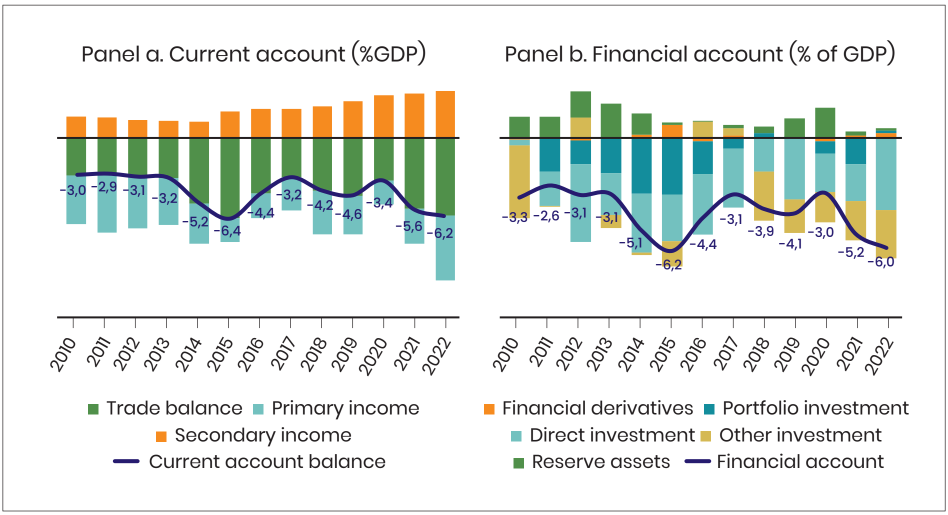


Source: Atlas of Economic Complexity – Authors.

Against this backdrop, Colombia stands out as an exporter of commodities with low value added and technological complexity, on which the country has become increasingly reliant over time. For instance, the share of metals, minerals, and stone products in total exports rose from 40.6% in 2000 to 50.9% in 2021. Figure 1 shows that the sector most exposed to the low-carbon transition is the only one that currently generates a trade surplus of goods for Colombia. By contrast, the trade surplus of agricultural products has been gradually declining to zero, and the trade balance of manufacturing goods shows a growing deficit consistent with the premature deindustrialisation of the country (for more details, see for example Caldentey & Vernengo *et al.*, 2021; Hoyos, 2017; Botta *et al.*, 2016).

The dynamics of the trade balance extend to the current account, which shows a deficit trajectory over the last decade (see Figure 2a). More precisely, the country is currently in a tight external position since the current account deficit rose to 6.2% of GDP in 2022, a historic level comparable to that observed in 2015 after the terms-of-trade shock (6.4% of GDP). Although this increases the external constraint to growth and the vulnerability to international financial conditions, the financing of the deficit has relied on a stable source such as foreign direct investment (FDI, see Figure 2b). However, in the face of the global low-carbon transition, this foreign exchange inflow may decrease, since 24% of FDI targeted the oil, coal, and mining sectors between 2018 and 2022.

Figure 2. ***Balance of payments of Colombia 2010–2022 (% GDP)***

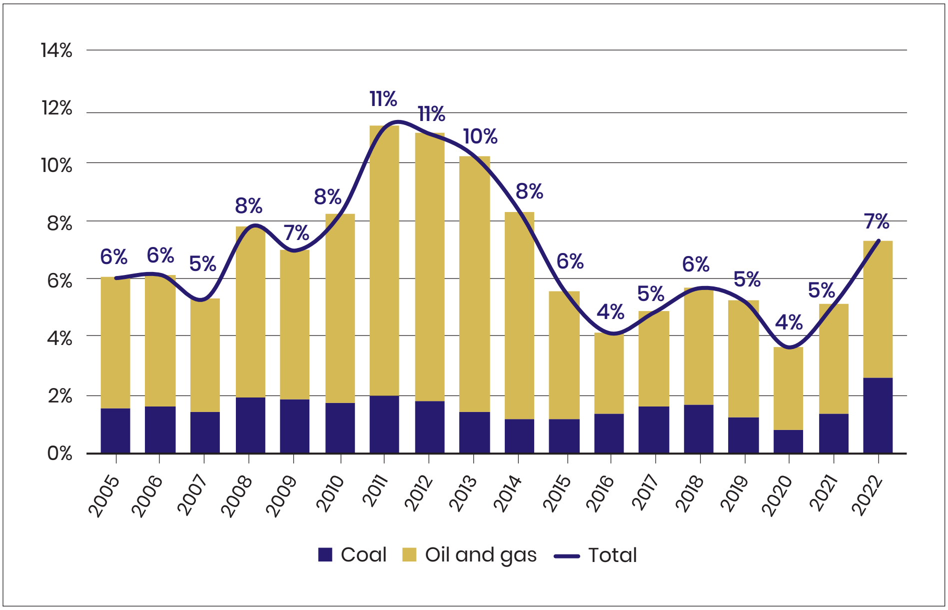


Source: Banco de la República – Own calculations.

This global decarbonisation path would also feed through to the real sphere of the economy given that the oil, gas, and coal sector accounted for about 5.3% of gross value added between 2015 and 2022. The main channel will be due to a fall in production and investment (including greenfield FDI) in response to falling demand and prices for fossil fuels. In turn, even though local content intermediate goods and industrial processing of these raw materials is low, this will spill over to other sectors through backward and forward linkages and subsequently affect both direct and indirect jobs. It is worth noting that these impacts will differ geographically and will be particularly greater in departments such as La Guajira, Cesar, Casanare, Meta, Arauca, and Santander due to their greater dependence on these industries in terms of production and employment (see Hernández *et al.*, 2023).

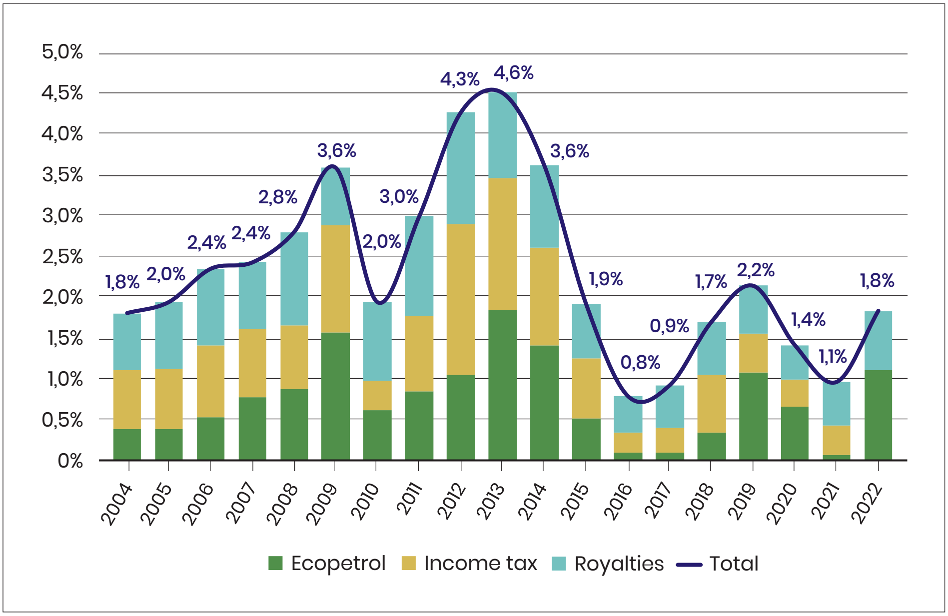
While all economic activities have an influence on public finances through tax revenues, this relationship is stronger in the case of extractive industries in Colombia. Figure 4 shows that over the last two decades, general government revenues associated with oil and coal extraction have ranged between 0.8% and 4.6% of GDP, averaging 1.5% between 2015 and 2022. These resources correspond to the national level in the case of Ecopetrol dividends (the majority state-owned oil company) and corporate income taxes, while they belong to the regional level in the case of royalties. In the latter case, a large percentage of royalties are specifically earmarked to finance public investment projects in municipalities and departments.

Figure 3. ***Share of the coal, oil, and gas sector in gross value added (%)***



Source: DANE – Authors.

Figure 4. ***Fossil fuel revenue of the general government (% GDP)***



Note: It does not include corporate income revenue data for 2022.
Source: Ministerio de Hacienda y Crédito Público, Authors.

As a result of the fall in fossil fuel exports, and even though Ecopetrol has started to diversify its investment portfolio, the associated decline in fiscal revenues would a priori have as a counterpart a higher fiscal deficit and debt path. While the latter does not consider potential impacts on financing conditions and fiscal policy responses (e.g., transfers, public spending cuts, and tax increases), it would undoubtedly result in an additional constraint on the policy space needed to facilitate investments in biodiversity protection, climate adaptation, and mitigation. It is worth noting that the current fiscal policy space is already tight following the higher level of indebtedness left by the COVID-19 pandemic, the current contractionary monetary policy at the domestic and global level, and the fiscal consolidation path set by the fiscal rule over the medium term.

2. Scenarios

The model is described at length in Chapter 2, along with the baseline scenario; we will concentrate on describing the scenarios constructed for the exercises related to global transition dynamics.

As a reminder, we assume the population to grow at a constant rate of 1%, domestic and world productivity to grow at a constant rate of 2% (hence assuming away any catching-up), world GDP in real terms to grow at a constant rate of 3%, and world inflation is set at 3%. We assume further that FDI inflows as a share of NFC investment slow down from their peak value in 2019, falling from 38% of investment (i.e., 4.5% of GDP) to 26% (3% of GDP) by 2050. We also assume a reversal in observed trends of propensity to export non-fossil fuel goods and services and revert it to its average over the last 15 years by slowly increasing the linear term in the export propensity equation by 20% between 2019 and 2050.

We construct three scenarios for fossil fuels exports in Colombia, based on various existing scenarios for petrol and coal exports. One of the key issues when designing a baseline scenario for Colombia relates to the evolution of exports in general and so-called traditional exports (oil and coal mainly) in particular. This section will present the different scenarios found in the literature, concentrating first on fossil fuel exports and then addressing total exports.

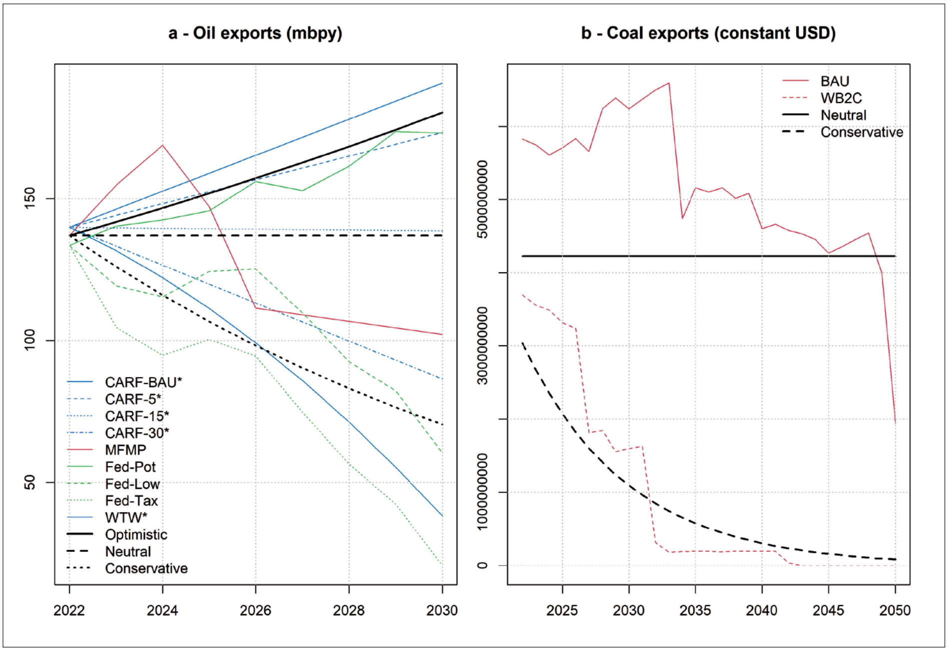
2.1. Oil exports

We present here four different exercises regarding projections of oil exports:

1. The one presented in the latest (2022) medium-term fiscal framework (Marco Fiscal de Mediano Plazo) produced by the finance ministry (Ministerio de Hacienda y Crédito Público, 2022), consisting of one scenario labelled “MFMP”;
2. The one presented in a report written by the Autonomous Committee on the Tax Rule (Comité Autónomo de la Regla Fiscal) on the macroeconomic and fiscal effects of an exploration policy and the 2022 tax reform in the hydrocarbon sector (Comité Autónomo de la Regla Fiscal, 2023), consisting of four scenarios assuming no reduction in petrol production investment, labelled “CARF-BAU,” and three scenarios assuming a linear reduction in oil extraction investment of 5% (CARF-5), 15% (CARF-15), and 30% (CARF-30);

3. The one presented in a report written by Fedesarrollo, the largest Colombian economic think tank, on the economic effects of the impact of the tax reform on the mining and energy sector (Fedesarrollo, 2022), consisting of three scenarios: one with potential oil production (Fed-Pot), one with little exploration (Fed-Low), and one with little exploration and a tax reform (Fed-Tax); and
4. The one presented in a report by Willis Towers Watson and the University of the Andes on “Understanding the Impact of a Low Carbon Transition on Colombia” (Willis Towers Watson, 2023), consisting of one scenario labelled “WTW.”

Figure 5. ***Oil and coal exports projections***



Source: Ministerio de Hacienda y Crédito Público (2022); Comité Autónomo de la Regla Fiscal (2023); Fedesarrollo (2022); Willis Towers Watson (2023), and own elaboration.

Figure 5 Panel a shows the different oil exports projections in millions of barrels per year (mbpy) as presented in the different scenarios. One can see three different types of outcomes:

1. An increase in exports (CARF-BAU, CARF-5, and Fed-Pot), with average annual growth rates ranging between 3% (CARF-5) and 5% (CARF-BAU);

2. A stable export level (CARF-15); and
3. A decrease in exports (CARF-30, MFMP, Fed-Low, Fed-Tax, and WTW), with average annual reduction rates ranging between 3% (MFMP) and 11% (Fed-Tax).

The goal of our scenario building is not to project exact values but rather to design representative scenarios. We thus propose to use three scenarios: an optimistic scenario with an increase in value of oil exports of 4%; a neutral scenario with no growth in oil exports; and a conservative scenario with a reduction in value of oil exports of 6%, also shown in Panel a.

The value of these exports scenarios will of course depend on future oil prices, which are complex to project. We will thus assume a constant price, for the sake of simplicity, acknowledging that there is an intricate co-dependency between supply, demand and global oil price.

2.2. Coal exports

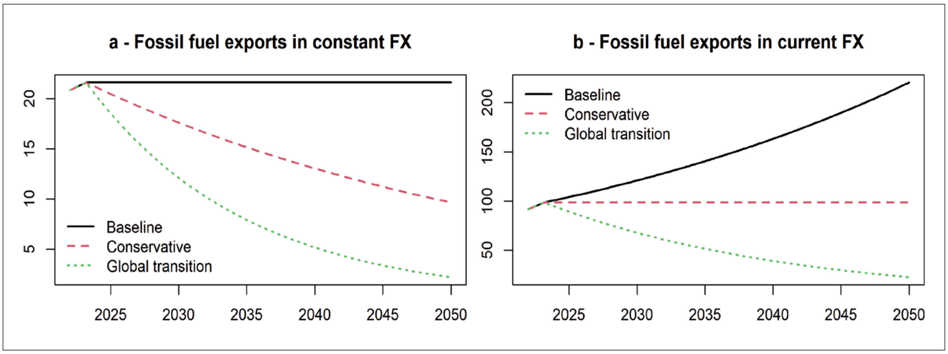
There are fewer scenarios analysing future exports of coal in the long term. We thus rely only on the Willis Towers Watson (2023) study proposing two scenarios for coal exports in Colombia (in millions of USD): a Business as Usual (BAU) scenario and a World Below 2 Degrees Celsius (WB2C) scenario, see Figure 5 - Oil and coal exports projections. Source: Ministerio de Hacienda y Crédito Público Panel b. The BAU scenario sees first an increase in exports until 2034, and then a decrease in exports leading to a value of exports in 2048 similar to that in 2021, followed by a further rapid decrease. We approximate this scenario by a neutral scenario seeing no growth in coal exports. The WB2C scenario sees a rapid decrease of coal exports until 2032, followed by a plateau for the next decade, and then no exports afterwards. We approximate that scenario by a conservative scenario characterised by a constant decline of coal exports of 12% year on year.

2.3. Fossil fuel exports

We thus have three scenarios for oil exports (optimistic, neutral, and conservative) and two for coal exports (neutral and conservative). Combining all of these would lead to six scenarios for the export of fossil fuels in Colombia. We however discard two improbable combinations (the conservative coal scenario with either the optimistic or neutral oil scenarios), leading to four scenarios for the export of fossil fuels in Colombia. The optimistic scenario sees an increase in oil exports and constant coal exports, leading to a constant 2.5% annual increase in fossil fuel sectors. The neutral scenario sees no increase in either fossil fuels. The conservative scenario sees no increase in coal exports and a reduction in oil exports, leading to a constant 3% annual reduction in fossil fuel exports. Finally, the global transition scenario sees a decrease in oil and coal exports, leading to a constant 8.5% decrease in fossil fuel exports.

In this chapter, we will consider only the last three scenarios (neutral, conservative, and global transition, see Panel a of Figure 6), because the optimistic scenario would entail further investments to open new oil fields, with the likely outcome of generating stranded assets. Using a constant price inflation of 3% for fossil fuels, we obtain three scenarios of fossil fuel exports in nominal terms (see Panel b).

Figure 6. ***Oil and coal exports projections***



Source: Authors.

Apart from any policy responses, which we will describe in section 5, we thus have three scenarios:

- A baseline scenario encompassing all previous assumptions and the neutral scenario regarding fossil fuel exports (i.e., constant fossil fuel exports from 2023). This scenario is very similar to the baseline scenario of the Ministerio de Hacienda y Crédito Público's medium-term fiscal framework of 2022.
- A conservative scenario encompassing all previous assumptions and the conservative scenario regarding fossil fuel exports (i.e., a constant decrease of 3% of fossil fuel exports from 2023).
- A global transition scenario encompassing all previous assumptions and the conservative scenario regarding fossil fuel exports (i.e., a constant decrease of 8.5% of fossil fuel exports from 2023).

We run the model from 2019 to 2050 and present the results starting from 2023, since the model presents some volatility due to the initial point calibration. All scenarios start in 2023 except for the policy response, which starts in 2024.

3. Results

We next move on to analyse the outcome of our two alternative exports scenarios with respect to our baseline, before considering the policy responses that could be implemented.

3.1. Loss of fossil fuel exports with no export diversification

Figure 7 displays the simulation results under the three different scenarios we described in detail in section 3 (baseline, conservative, and global transition—hereinafter GT), where fossil fuel exports start decreasing in 2024. Both scenarios exhibit similar dynamics, with larger magnitudes for the GT scenario. While the long-term consequences in terms of real growth seem to converge for all scenarios (Panel a), this is not the case for most of the other variables. Furthermore, the model displays the consequences of a non-equilibrium exchange rate determination. Since it is based on an excess demand approach (Yilmaz and Godin ,2020), the exchange rate does not converge to a predetermined value, implying that import and export propensities will also not converge to predetermined values. The different scenarios hence leave the Colombian economy in very different positions, depending on how much the peso depreciated or not.

As exports of fossil fuels start falling in real terms, this adds immediate pressure on the trade balance (Panel b) and the exchange rate (Panel c). The trade balance deteriorates rapidly, reaching its lowest point three years after the shock, before beginning to recover in the medium term due to the real depreciation impacting the propensities to import and export. In the conservative scenario, however, the trade balance remains slightly below the baseline in the long term. In contrast, the recovery is stronger in the GT scenario because the sharp currency depreciation further reduces import demand and increases the competitiveness of non-fossil fuel exports.

The nominal depreciation of the peso leads to inflationary pressures for production prices (Panel d) and consumer prices (Panel e) due to increases in the domestic currency price of imported goods. This leads to a reduction both in consumption (via the reduction in marginal propensities to consume, Panel f) and in investment (due to the reduction of real profit rates, Panel g). The fall in consumption, investment, and exports is not compensated fully by the fall in imports, leading to a reduction in real growth and an increase in unemployment (Panel h).

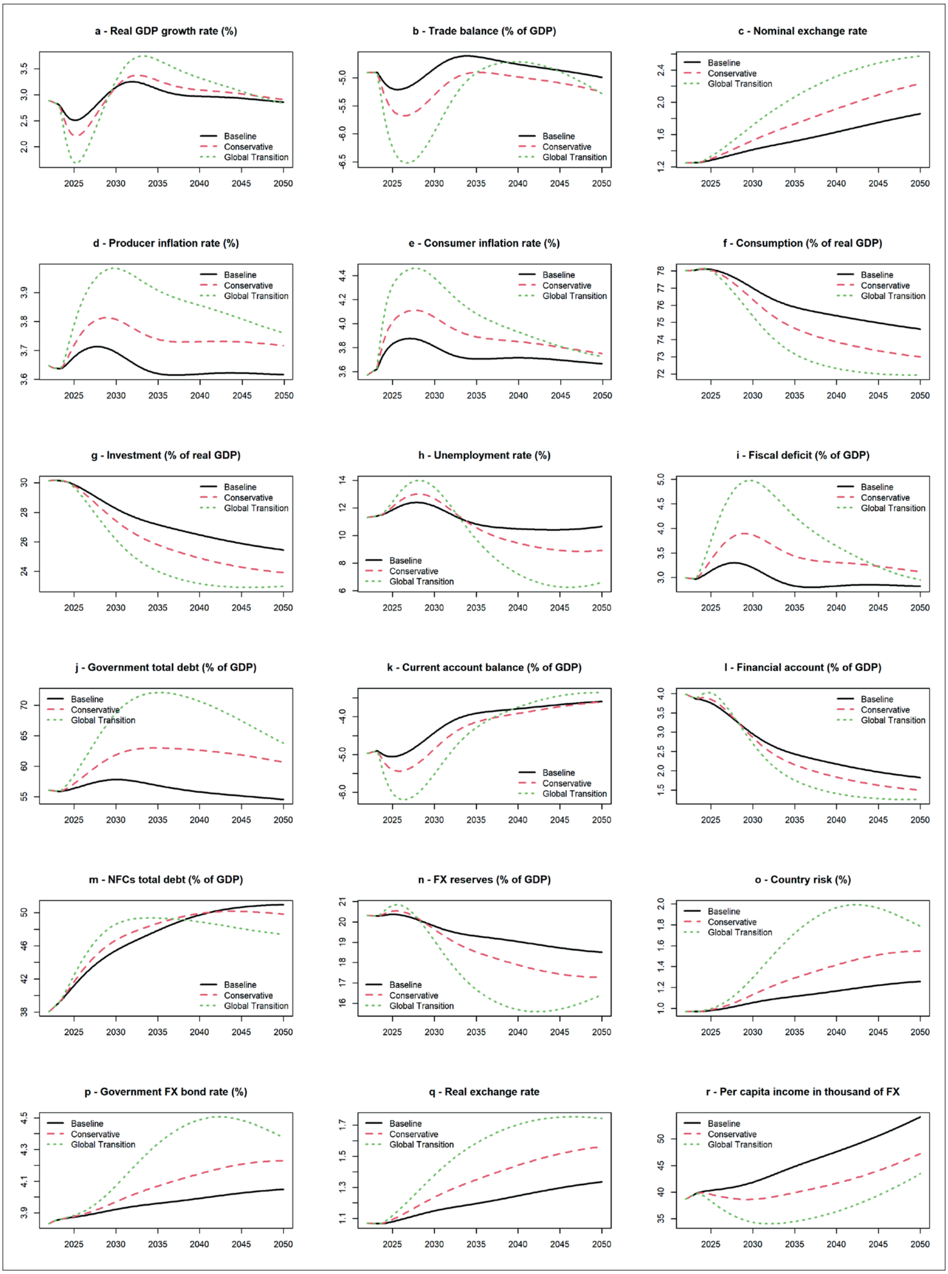
The increase in unemployment leads to an increase in social transfers, while inflationary pressures push up public expenditure (both market and non-market) and investment. On the revenue side, despite tax revenue slightly increasing due to inflation and currency depreciation, the larger drop in royalties and dividends ensures a decline in total fiscal revenue, especially in the long run.[27] Both forces lead to a worseing of the fiscal deficit (Panel i) and an increase in public debt (Panel j), further amplifying these dynamics via interest payments.

The current account of the balance of payments (Panel k) worsens in the short and medium term following the deterioration of the trade balance before recovering and converging to the baseline scenario path in the long term. The main driver of this recovery is the currency depreciation, which not only supports an improvement in net exports, as noted above, but also ensures that the increase in transfers in pesos, especially remittances, more than offsets the worsening of interest payments to foreign creditors. On the other hand, the financial account surplus (Panel l) falls due to two driving forces also observed in the baseline scenario: the reduction in FDI flows, and the deleveraging of firms reducing their demand for FX loans (Panel m). The two scenarios however exacerbate these dynamics via the initial reduction in investment and via stronger depreciation. We thus have three dynamics at hand: a constant reduction in fossil fuel exports, an overall reduction in financial inflows, and an improvement of the income account. The first two dynamics tend to increase the depreciation of the peso, while the last one is not sufficient to overcome the first two, at least at the beginning of the simulations.

These tensions on the peso slowly disappear as the trade balance improves and as remittances play an increasing role in covering for imports (from 12% in the baseline to more than 15% in the GT scenario by 2050). All of these dynamics lead to a reduction in foreign reserve accumulation (Panel n), hence leading to a worsening of the country risk (Panel o) and an increase in interest premiums (Panel p), along with higher rationing on international financial flows.

27. These results could be modified by taking into consideration the latest tax reform, in which the mining and oil sectors will pay more taxes. The consequence will be a strong loss in total revenues, which would further aggravate the fiscal deficit.

Figure 7. ***Baseline (black solid line), conservative (red dashed line), and global transition (green dotted line) scenarios for selected variables.***



Source: Own computations.

The reversal of dynamics is due to the income effect of remittances, leading to an increase in consumption on the one hand and to investment picking up due to public and household investment on the other. Once both consumption and investment recover, unemployment starts decreasing, further fuelling the recovery.

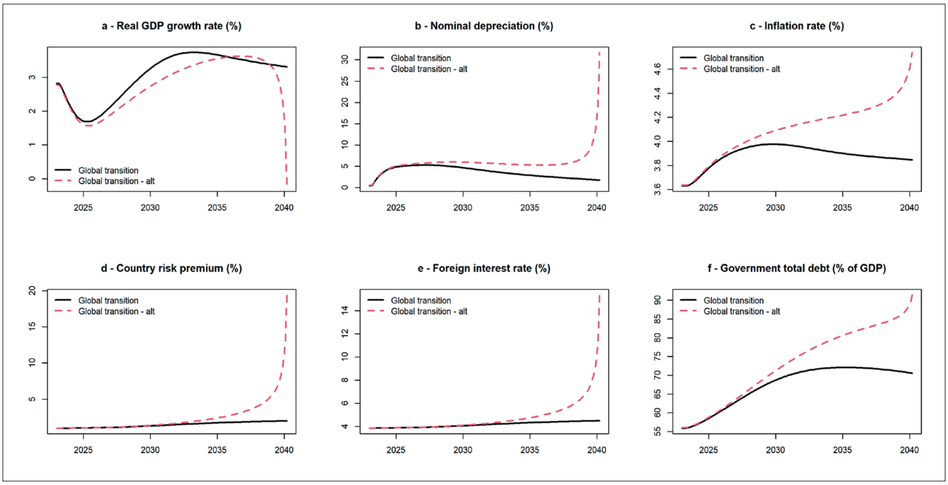
As observed in the graph, there are long-term differences for each scenario. Stronger real depreciation (Panel q) leads to more structural change via import reduction and export boost.[28] Furthermore, prolonged and more acute deficits lead to greater debt accumulation. All in all, it is easy to see that the GT leads to a more severe recession and to a more fragile economy either from a public finance or an international finance perspective. An interesting indicator to look at is per capita income in USD[29] (Panel r). It reflects the fact that even if the economy is growing in real terms, this does not compensate for real depreciation, indicating that all international consumption goods start becoming very expensive, hence leading to lower standards of living. In the GT scenario, it takes more than 20 years to recover the standard of living of 2023.

3.2. Currency crisis

It is worth noting that the GT scenario can lead to a currency crisis by the end of 2039 if the assumption, made in section 3, that export propensity reverts to its last decade average does not hold up. Figure 8 shows these simulations. In this scenario, the trade balance deterioration is so strong that it leads to an accelerating depreciation (Panel b). This currency crisis leads to strong inflationary pressure (Panel c), and to country risk (Panel d), foreign interest rates (Panel e), and public debt (Panel f) exploding.

28. This result should be mitigated by questions regarding whether only the price effect leads to structural change. It would be interesting to connect the actual increase in exports and reduction in imports to capital accumulation in related sectors. This is outside the scope of this chapter, as it would require a multisectoral model.
29. Per capita income was calculated in the model with respect to the labour force rather than the total population.

Figure 8. ***Currency crisis for selected variables.***



Source: Own computations.

3.3. Export diversification

In order to respond to the dramatic impacts of a global transition and avoid a potential currency crisis, we consider a policy response in the form of an increase of the propensity to export via the integration of the Colombian economy into global value chains (GVCs), see Del Carpio *et al.* (2022). This is simulated via a gradual increase in the linear term of the propensity to export non-fossil fuels, starting from 2024. We assume that this outcome is achieved via public or private investment.[30] We thus build two new scenarios based on the GT one: GT private investment and GT public investment, representing each investment possibility.

Figure 9 shows the results of these two scenarios along with the baseline and the GT. Both policies lead to a reduction of the pressure exerted on the Colombian peso (Panel c) via an increase in exports. The overall long-term effect on the trade balance (Panel b) is however small compared to the GT scenario because the gain in export propensity is compensated for by a lower real depreciation (Panel q). The increase in investment has a multiplier effect, which leads to a lower decline in real growth and a quicker and stronger recovery (Panel a). The immediate increase in

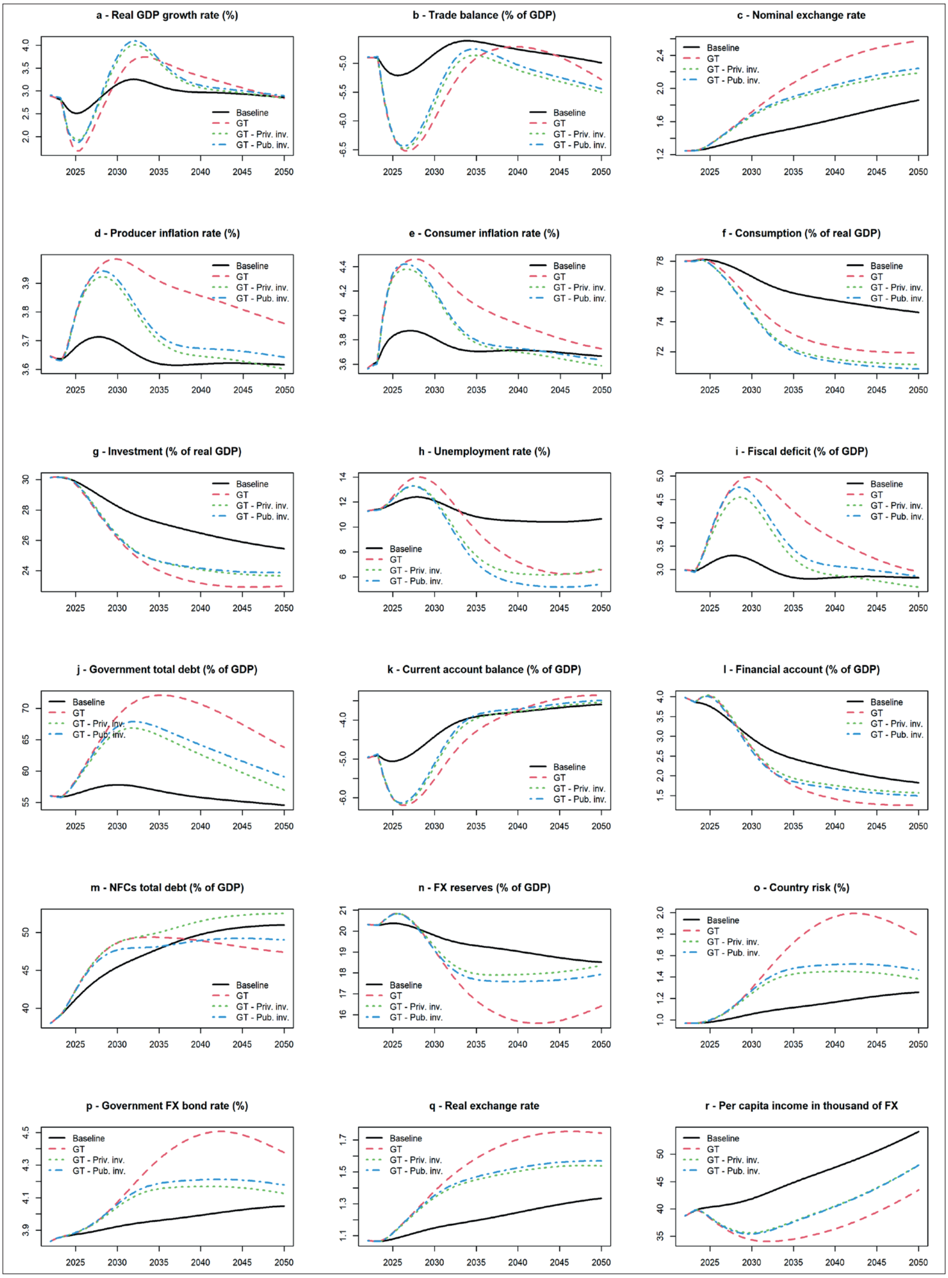
30. We do not have any estimation of what such investment would be worth, so we assumed an arbitrary 0.5% increase in the growth rate of private or public capital accumulation.

demand due to extra exports and extra investment leads to slightly higher inflation, but this is quickly compensated for by the reduction in import-driven inflation (Panel d and Panel e). Both scenarios lead to a restructuring of aggregate demand towards exports and investment, leading to a lower share of consumption and a higher share of investment in GDP (Panel f and Panel g). The extra demand leads to a significant reduction in unemployment.

This fall in unemployment leads to lower social transfers, and the higher growth rates of the economy increase tax revenues, hence reducing the fiscal deficit (Panel i). Note that in the GT public investment scenario, the fiscal deficit barely changes from the GT scenario due to the increase in public investment compensating for lower social transfers and higher tax revenues. This is temporary, however, and quickly the decrease in social transfers and increase in tax revenues more than compensate for the extra investment. It is important to highlight that the public deficit is lower in the long term when the extra investment is fully carried out by the private sector. Lower fiscal deficits mechanically amount to lower public debt (Panel j). In the GT private investment scenario, the extra investment by NFCs leads to higher NFC debt (Panel m). The extra debt coming from firms leads to higher international financial flows (Panel l) in the form of FDI and cross-border lending, helping to further reduce the pressure on the Colombian peso. Note that the current account (Panel k) starts recovering faster in both diversification scenarios notwithstanding the extra debt incurred by firms and the government. However, the long-term recovery is weaker in comparison to the GT scenario, as in this latter case the Colombian peso depreciates more. Since a stronger currency depreciation is accompanied by higher inflation, there is a long-term trade-off between gains in the current account, particularly driven by the trade balance, and the real per capita income of households.

The extra financial inflows along with a lower current account deficit lead to a greater accumulation of foreign reserves (Panel n), which then decrease at a slower pace, particularly for the GT private investment scenario. As a consequence of these improved macroeconomic conditions, the country risk (Panel o) does not rise as much as in the GT scenario. The premium paid on foreign interest (Panel p) is hence lower and almost converges to the baseline values. While the economy performs better under both publicly and privately financed export diversification, Colombia still goes through a general impoverishment of its population in USD terms (Panel r). The scenarios make it possible to speed up the recovery of GDP per capita in USD by six years, but the crisis still lasts more than 15 years.

Figure 9. ***Baseline (black solid line), GT (red dashed line), GT private investment (green dotted line), and GT public investment (blue dash-dotted line) scenarios for selected variables***



Source: Own computations.

4. Discussion and conclusion

We developed an empirical SFC model for the Colombian economy to analyse the medium- to long-term consequences of different scenarios of fossil fuel exports over the period 2023–2050. On the basis of three scenarios (baseline, conservative, and global transition), we envisage that the decline in oil and coal exports will have deep impacts on the real and external sectors of the Colombian economy and will deteriorate its fiscal and financial conditions. Precisely, the feedback between these dimensions that is fully captured in the model does not rule out the possibility of a crisis whenever the productive system and policy responses do not adequately respond to the challenges and constraints imposed by a global low-carbon transition.

Important results to highlight in the conservative and global transition scenarios include a slowdown in economic growth and a consequent increase in unemployment in the medium term, a rise in the inflation rate, the fiscal deficit, public debt levels, and risk premiums over the long term, and a permanent currency depreciation leading to a fall in international reserves. It is worth noting that the depreciation of the peso comes from two connected but distinct dynamics: a worsening of the trade balance (given by the scenarios) and a worsening of the financial account surplus (given by the reduction in FDI, which is likely to be worse in the case of a reduction in fossil fuel exports).

Colombia hence needs to respond to both dynamics by diversifying its exports and reducing its import dependency (not simulated) but also by ensuring a constant stream of international inflows. This can be done by means of industrialisation strategies and attracting FDI, with Colombia having a good record in the latter respect.

Our results thus highlight that while finance helps in mitigating the negative impacts of the global transition in the long term, the main driver of a recovery lies in industrial policies aiming at reducing import dependencies and increasing the export base with more sophisticated and higher value-added goods and services. However, integration into global value chains is not an easy task, as highlighted in Del Carpio *et al.* (2022), and will require coordinated actions between industry, finance, and the government, while the current lack of certain productive and technological capabilities may hinder the country's competitiveness in green or sunrise industries (see Mealy and Teytelboym, 2022).

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Financing a domestic transition in Colombia, in the context of a global transition

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Chapter 4

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Chapter 4

Financing a domestic transition in Colombia, in the context of a global transition

Introduction

In the face of a low-carbon and climate-resilient transition, Colombia faces multiple challenges in climate change mitigation and adaptation and biodiversity protection that require significant investments by the public and private sectors. While these investments have multiple social, economic, and environmental returns, they will also generate short-to-medium-term fiscal and external sector pressures. In particular, the sustainability and feasibility of these investment commitments will be conditioned not only by how they are financed but also by the capacity of the economy to respond to the decline in fossil fuel exports over the coming decades.

With this in mind, the aim of this chapter is to understand some of the macroeconomic, fiscal, and external sector impacts of Colombia's mitigation and adaptation investments for the period 2023–2050. It explores how these impacts change in the face of different financing strategies concerning interest rates, green taxes, grants, and green debt instruments. Additional impacts are analysed when considering a simultaneous fall in fossil fuel exports and an export diversification policy that moderates their effects. To this end, different scenarios are constructed and various simulations are carried out based on the empirical stock-flow consistent model developed for the Colombian economy and presented in Chapter 2. The aim is to point out the opportunities that transitions can bring for Colombia and to discuss some transition risks and policy actions to address them.

1. The Colombian economy in a time of transitions

This section presents some of the transition scenarios that the Colombian economy will face over the coming decades and some of the macroeconomic, fiscal, and external challenges that they may imply.

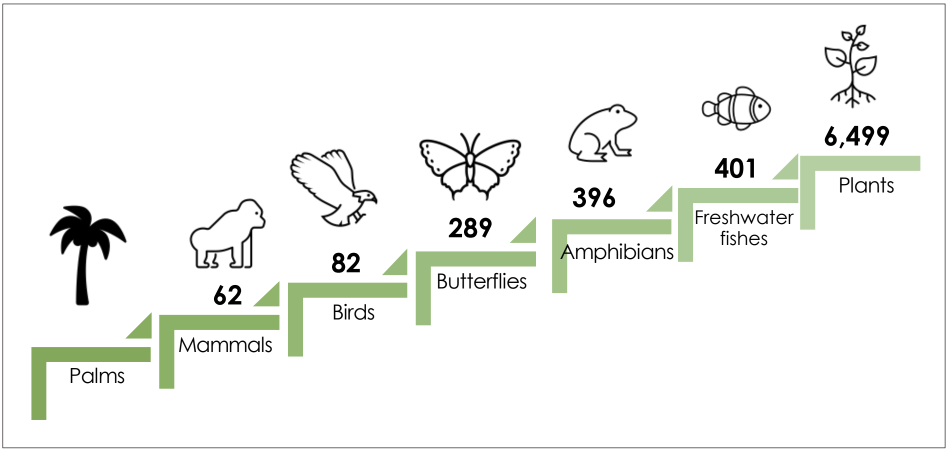
1.1. Three commitments for the coming decades

In discussions on the medium- and long-term prospects for Colombia, there is an acceptance that the development path must guarantee and accelerate the improvement in the population's living standards while being circumscribed within certain environmental sustainability criteria. Although the concept of "sustainability" is in itself a normative and multidimensional notion, making it impossible for it to have a single definition (Godin *et al.*, 2022), three of its elements institutionalised by Colombia in a series of commitments are presented below: the protection of biodiversity, the reduction of greenhouse gas (GHG) emissions, and adaptation to climate change.

To begin with, Colombia is the second most biodiverse country in the world due to a variety of watersheds and climatic, geographical, and geological conditions. This is reflected in the 91 types of ecosystems, including moorlands, swamps, wetlands, savannahs, reefs, seagrasses, mangroves, and countless types of natural forests. In particular, about 41.6% of the country's continental territory is part of the Amazon region – even though it accounts for just 6.4% of the total Amazon biome (CEPAL, 2013). Thus, Colombia also plays a major role in preserving the Amazon rainforest, which is key to regulating the regional climate, the global water cycle, and carbon storage.

These numerous and diverse ecosystems host around 75,000 species of flora and fauna according to observations of the Colombian Biodiversity Information System (SiB, 2023). Of these observed species, which represent around 10% of the total number of species recorded worldwide, around 7,800 are endemic (Figure 1). However, SiB (2023) figures also show that in Colombia, 339 species are critically endangered, 578 are endangered, and 604 are vulnerable. As nature is a complex system of interactions between organisms and between organisms and the environment, the loss of species and the destruction of habitats jeopardise the stability and functioning of entire ecosystems (Mace, G. M., Norris, K., and Fitter, A. H., 2012).

Figure 1. ***Endemic species of fauna and flora observed in Colombia***

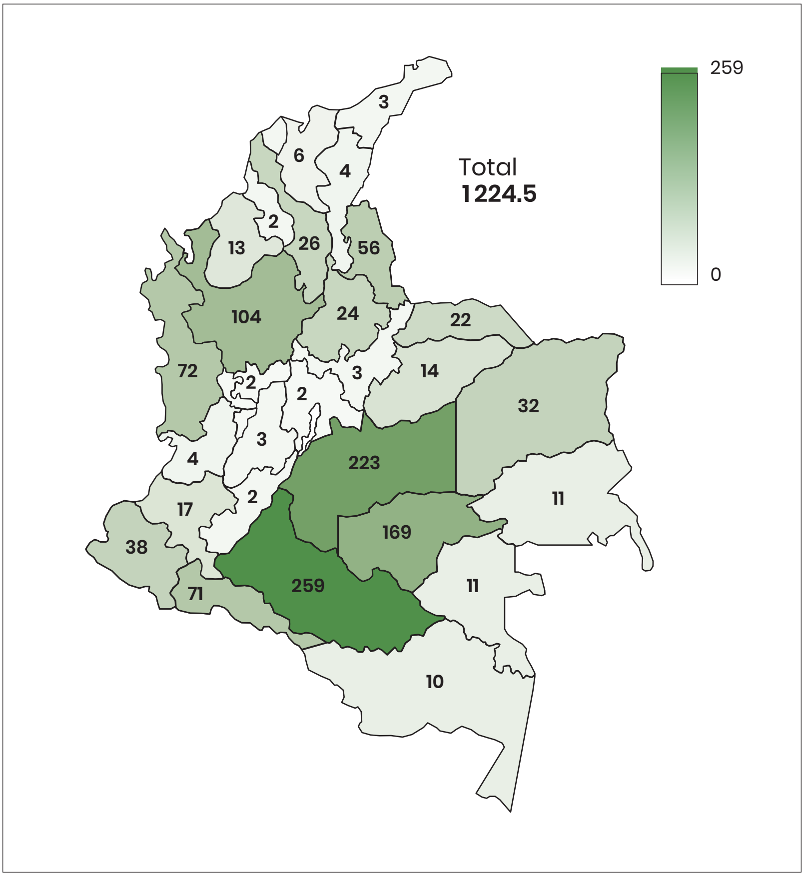


Source: SiB (2023). Authors

Records of endangered species of fauna and flora reflect the increasing loss and deterioration of the country's biodiversity. Although it is a multi-causal phenomenon, the main drivers of this trend include land grabbing, the unregulated expansion of the agricultural and livestock frontier, illegal mining, species and timber trafficking, illegal crops, and multiple conflicts over land use. It is worth noting that these drivers are favoured by the socio-political context in Colombia. This includes armed conflict, the low institutional capacity of the state in terms of land use, planning, and the definition of property rights, the high inequality in land ownership, and a model of raw materials and agricultural exports development (see for example Arias *et al.*, 2021; Cantillo and Garza, 2022; López *et al.*, 2020).

The deforestation of more than 1.22 million hectares in Colombia between 2015 and 2021, (about 1.1% of the country's continental territory), is the epitome ecosystems' destruction. As can be seen in Figure 2, deforestation has mostly taken place in biodiversity hotspots such as the Pacific region, the Amazon region, and the wildlife corridor between the Amazon region, the Eastern Plains, and the Andes. Partly motivated by these trends, Colombia has established a series of commitments and lines of action to preserve biodiversity, including the Belém Declaration for the protection of the Amazon in 2023, the Kunming-Montreal Agreement in the United Nations Convention on Biological Diversity in 2022, and the National Biodiversity Action Plan in 2017.

Figure 2. ***Deforestation in Colombia between 2015 and 2021 (thousands of hectares)***

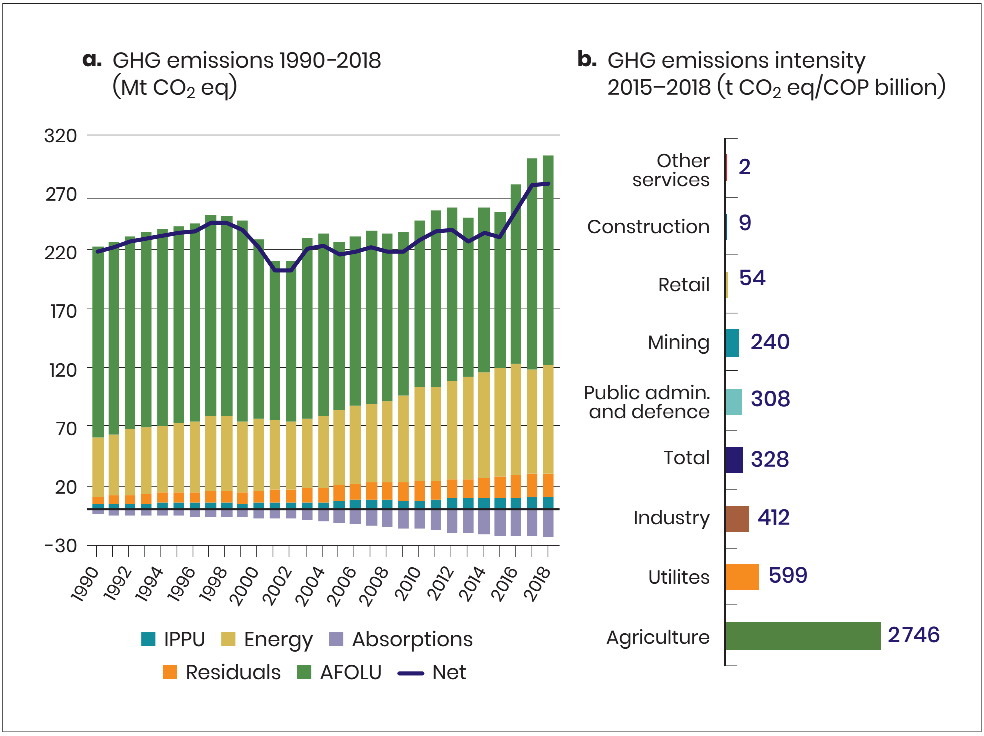


Source: Ministerio de Ambiente y Desarrollo Sostenible (2022). Authors

Aside from the challenges of biodiversity protection, Colombia also needs to take action to mitigate climate change even though its contribution to cumulative global emissions has been historically low. Domestically, the country's GHG emissions have shown an upward trend in the last decade, mainly attributed to the agriculture forestry and other land use (AFOLU) module and to the energy module from fuel combustion and fugitive emissions in electricity generation (see Figure 3a). This pattern of GHG emissions is consistent with the fact that the agricultural, utilities (especially power generation), and industrial sectors have a higher GHG emissions intensity per unit of value added than the average of the whole economy (see Figure 3b).

With this context in mind, Colombia has institutionalised its mitigation commitments along two main lines. Firstly, the 2020 update of the Nationally Determined Contribution (NDC) to the Paris Agreement establishes a GHG emissions reduction target of 51% compared to projected emissions for 2030. It is worth noting that the updated NDC is much more ambitious than the first version presented in 2015 insofar as it places the GHG emissions ceiling at 169.4 million tonnes of CO_2 equivalent (Mt CO_2eq) instead of 268.5 Mt CO_2eq. In addition, the Colombia 2050 Long-Term Climate Strategy submitted to the United Nations Framework Convention on Climate Change targets to achieve carbon neutrality by 2050, among other considerations.

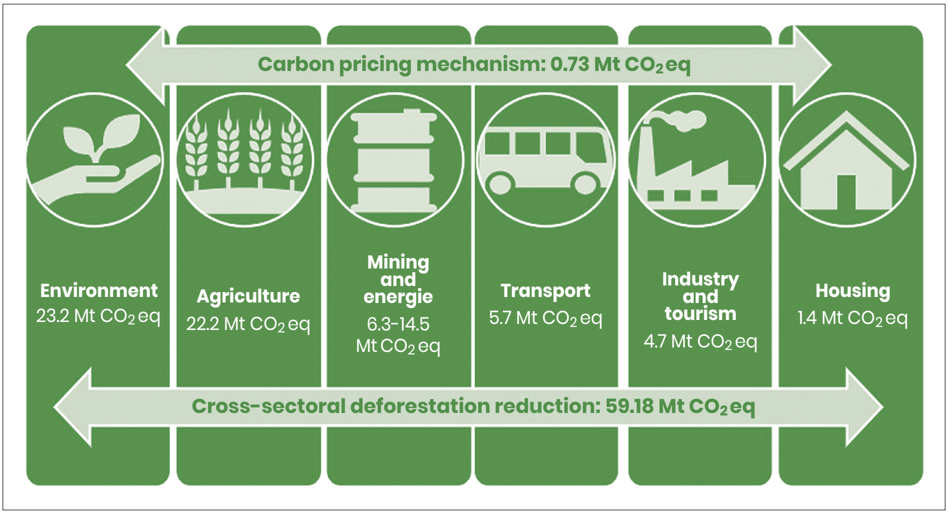
Figure 3. ***Pattern of GHG emissions in Colombia***



Source: IDEAM and DANE. Own calculations. The agriculture sector includes AFOLU emissions. See Annex 1 for further details on the economic sector classification.

Figure 4 shows the mitigation potential in the actions of Colombia's updated NDC, which closely relates to investment needs by sector. The fight against deforestation, aiming to reduce it to 50,000 hectares per year by 2030, stands out as one of the crosscutting actions. Investments in the environment and agriculture sectors are mainly oriented towards reforestation and environmental restoration, livestock, forestry, and sustainable agriculture. In the mining and energy sector, investments aim at expanding electricity generation from renewable sources, reducing fugitive emissions in mining, and increasing energy efficiency in the electricity sector. Finally, the transport sector requires investment in the electrification and modernisation of public, private, and freight transport, while investments in industry should be geared towards electrification and increased energy efficiency.

Figure 4. ***GHG emissions reduction potential in the updated Colombia NDC***



Source: Own calculations based on Ministerio de Ambiente y Desarrollo Sostenible (2020).

Even though the mitigation commitments represent an important effort for the country, Colombia is a "climate taker" highly dependent on the mitigation actions of other countries, especially high-income ones. In this sense, as pointed out in the IPCC's Sixth Assessment Report (2023), the insufficiency of current worldwide efforts to avoid a temperature increase above the critical threshold of 2.0°C by 2100 and the current materialisation of climate change make adaptation actions a pressing need for the country. This is particularly relevant for coming decades, when global temperatures, the intensity and frequency of extreme weather events such as droughts, heat waves, storms, cyclones, and hurricanes, and the occurrence of natural disasters such as floods, landslides, and forest fires are expected to continue rising.

It should be noted that the dynamics of the Colombian climate will not only be determined by global trends, but also by the preservation of the Amazon biome as a regulator of regional temperature and precipitation, and by the response of the main climate variability phenomena already affecting the country (e.g., El Niño and La Niña). In this context, Colombia exhibits high vulnerability to climate change due to its geographical and socioeconomic conditions. According to IDEAM (2017), all municipalities in Colombia present some degree of vulnerability to climate change in the dimensions of food security, water resources, biodiversity, health, human habitat, and infrastructure, with 59% of them at medium to very high risk and 25% at high to very high risk.

The socioeconomic impacts of climate change are expected to be multiple but unevenly distributed across regions, economic activities, and individuals (i.e., according to income and wealth levels). These include damage to infrastructure, housing, and productive capital stock, reduced yields and destruction of farms, fisheries, and agricultural holdings, and reduced labour productivity. Aside from food security risks due to higher food prices and reduced production for self-consumption, health will be affected by heat-related morbidity and increased occurrence of vector-borne and water-based diseases. Increased water stress, energy prices, internal displacement and migration, and damage to ecosystems will also affect the quality of life, especially in rural communities.

Therefore, adaptation actions are increasingly necessary to reduce the economy's sensitivity and enhance people's capacities to prepare for, cope with, and recover from isolated and cascading climate events. While there are limits to adaptation that prevent climate risks from being reduced to zero, which become more binding as global temperatures rise, investing in adaptation has high social, economic, and environmental returns, especially in the medium and long term. Even though adaptation actions are sector- and geography-specific, investing in resilient infrastructure and agriculture, diversifying productive activities, land-use planning, strengthening social safety nets, and ecological restoration are relevant examples for Colombia.

While there is no official statement on the amount of investment required to address the challenges of biodiversity protection and climate change mitigation and adaptation, Table 1 presents some estimates published in various documents over the last few years. Roughly, the amount ranges between 1% and 2% of GDP per year and tends to be closer to the upper limit when commitments other than mitigation are included. Similarly, considering that climate-related investments have averaged 0.16% of GDP per year between 2013 and 2021 (Departamento Nacional de Planeación and Fedesarrollo, 2022), it is clear that to meet these targets Colombia needs to close a considerable investment and financing gap. This gap is even more significant when considering that, for the same period, total public investment in Colombia was around 3.3% of GDP.

Table 1. ***Estimated value of green investments required by Colombia***

AMOUNT	COMMITMENTS	SOURCE
1.5% of GDP until 2030 and 1.1% of GDP from 2031 to 2050	Mitigation and adaptation	World Bank (2023)
Between 1.6% of GDP and 2.3% of GDP annually	Mitigation, adaptation, and biodiversity protection	Departamento Nacional de Planeación and Ministerio de Ambiente y Desarrollo Sostenible (forthcoming)
2.0% of GDP annually	Mitigation, adaptation, and biodiversity protection	Ministerio de Hacienda y Crédito Público (2023)
1.2% of GDP annually	Mitigation	Departamento Nacional de Planeación and Fedesarrollo (2021)
1.1% of GDP annually for upper-middle-income countries	Mitigation and adaptation	World Bank (2022)

Source: Authors.

From a macroeconomic perspective, closing this investment gap would have positive implications in terms of growth and employment in different regions of the country and would represent a window for structural change to modernise and diversify the productive structure. In turn, the reduced vulnerability to climate shocks resulting from adaptation measures would reduce future losses in terms of poverty, income and assets, reconstruction expenditures, and contingent liabilities. In parallel, the co-benefits associated with improved air quality by reducing particulate matter, increased provision of public goods such as transport, and preserved biodiversity for its contribution to people are also significant. Finally, mitigation actions would gradually disincentivise the development of high-carbon infrastructure that could become stranded assets and block the transition in the future by increasing its cost.

Keeping these positive impacts in mind allows us to envision these investments beyond a cost narrative. However, these investments may also generate certain pressures at the macroeconomic level that are important to consider in assessing their sustainability and viability. On the fiscal side, while the private sector plays a key role, many of these investments should be financed by the government, thus leading to higher fiscal deficits and a higher debt path. From the external sector perspective, many of the goods required for the transition to electrify, reduce emissions intensity, and increase the energy efficiency of the economy are not produced domestically and must be imported (e.g., solar panels, wind turbines, batteries, electric vehicles, machinery, etc.), increasing the trade deficit and reducing the domestic investment multiplier.

1.2. A forthcoming global low-carbon transition

In light of the structural changes anticipated in global energy consumption and production, Colombia faces significant risks associated with the ongoing global low-carbon transition (see Chapter 3). The country's heavy reliance on exports of low value-added commodities, particularly in the mining sector, makes it vulnerable to a drop in global demand for these goods. The recent report by Willis Towers Watson (2023) indicates a potential 27% reduction in exports as a percentage of 2019 GDP between 2022 and 2050 if there is no shift in the composition of Colombian exports. This shift not only jeopardises employment and fiscal revenues at the national level, but also introduces a high degree of regional heterogeneity. Firms in the sector are exposed to financial risks, with the possibility of balance sheet deterioration and loss of capitalisation, further complicating the economic landscape.

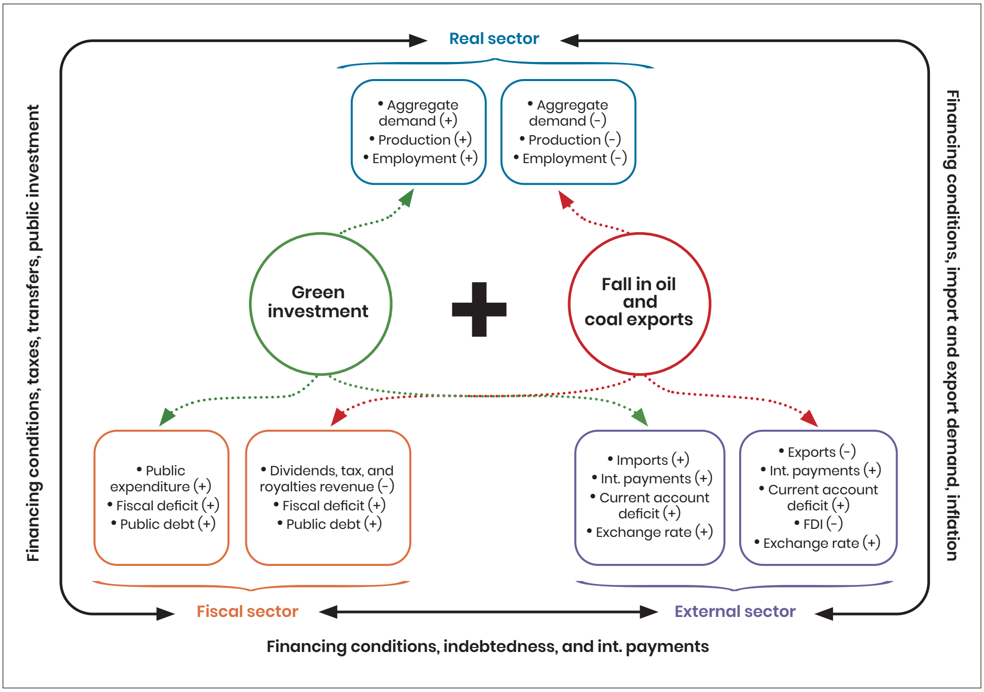
As demonstrated in Chapter 3, the repercussions of the low-carbon transition extend beyond the trade balance, up to Colombia's current account, reflecting a historical deficit comparable to that observed after the terms-of-trade shock in 2015. Although the deficit has been financed by stable sources such as foreign direct investment (FDI), the global transition may reduce this inflow, given that a significant portion of FDI has targeted the oil, coal, and mining sectors. This shift also affects the real economy, with the oil, gas, and coal sectors contributing about 5.3% of gross value added between 2015 and 2022. The fall in production and investment in these sectors, influenced by declining demand and prices for fossil fuels, has cascading effects on other industries, affecting both direct and indirect employment. In particular, certain regions such as La Guajira, Cesar, Casanare, Meta, Arauca, and Santander will experience more significant impacts due to their high dependence on these industries.

The impending decline in fossil fuel exports, coupled with Ecopetrol's efforts to diversify, raises concerns about a potential fiscal deficit and debt trajectory. This may impose further limitations on the policy space necessary for carrying out investments in biodiversity protection, adaptation, and mitigation, especially given the already tight fiscal conditions resulting from the COVID-19 pandemic and existing monetary and fiscal constraints.

1.3. A vulnerability synthesis

The preceding contextualisation of green investment needs in Colombia and the prospects for decarbonisation at the global level provide a glimpse of multiple macroeconomic and financial implications for the next three decades in Colombia. Figure 5 summarises some of these for the real, fiscal, and external spheres of the economy and considers some potential feedback between them. It is important to point out that these effects may become vulnerabilities and transition risks in the absence of appropriate policy responses and if the current trends of a high current account deficit, low export diversification, premature deindustrialisation, high participation of extractive sectors in FDI, and fiscal dependence on fossil fuel revenues continue.

Figure 5. ***Vulnerability conceptualisation of the Colombian low-carbon transition***



Source: Authors

On the domestic front, investments in biodiversity protection, mitigation, and adaptation actions would positively affect economic growth and employment. However, they would bring fiscal pressures and increase demand for imported green goods (capital and intermediate), raising the overall level of imports and putting pressure on the trade balance. In the context of a global low-carbon transition, reducing demand and prices of fossil fuels would imply lower output, employment, and decreasing revenues for exporting firms and the government in the coming decades. Thus, in the latter scenario, which further narrows the external and fiscal panorama, closing the green investment gap will face greater constraints and will be a more challenging task.

A more comprehensive and robust analysis of these channels of transmission and potential transition risks requires understanding how each of these three macroeconomic spheres interact, the role of funding sources in facilitating green investment, and what types of policies can smooth the transition. To this end, the following sections present the methodology and results of a modelling exercise to address these issues and provide better policy insights.

2. Methodology

Bearing in mind the challenges and opportunities that the transitions may entail for the Colombian economy, this chapter relies on the empirical SFC model presented in Chapter 2 to build scenarios and simulations in this regard for the period 2023–2050. In particular, this section addresses two questions.

First, what are the macroeconomic, fiscal, and external sector impacts of the investments in mitigation and adaptation to meet Colombia's NDC by 2030, achieve carbon neutrality by 2050, and become more resilient to climate change. It explores how these impacts change when different financing strategies are considered regarding interest rates, green taxes, grants, and green financing instruments. Secondly, it explores what additional transition risks may emerge when these investments are coupled with a permanent drop in oil and coal exports. In the latter case, the role of additional export diversification efforts to mitigate its effects is studied.

The empirical SFC model of the Colombian economy is a suitable tool to contribute to a better understanding of these questions. In this sense, the model allows for the construction of medium- and long-term scenarios to analyse different policy options and trajectories of variables related to the transition (e.g., green investment, fossil fuel exports) in order to envisage different transmission channels and implications. In turn, even though the model is not a forecasting tool, its empirical calibration matching the main macro-financial dynamics and stylised facts of the Colombian economy yields results and envisages empirically meaningful trends.

Apart from the above, the main advantage of this approach is the simultaneous encompassing of the real and financial spheres of the economy and the interactions between them. This makes it possible to capture not only first-round but also second-round effects that propagate a given shock through different channels and over time, making them sharper or smoother. Similarly, it captures a variety of feedback loops and balance sheet effects originating from changes in interest rates, the exchange rate, credit rationing, and risk premia relevant for any analysis of macro-financial vulnerabilities.

In the context of the research questions, two examples can illustrate these benefits. First, unlike many conventional debt sustainability analyses that follow an accounting or partial equilibrium approach, the model endogenously traces the feedback between the debt path with GDP growth, sectoral deficits, interest rates, and risk premia, which allows for more realistic dynamics. Second, when considering a fall in commodity exports, the focus is not only on the immediate impact on the real side of the economy but also on the exchange rate, financing costs, capital flows, and external indebtedness, which also influence and are influenced by real channels.

For all these reasons, the exercise presented here allows us to go beyond some studies that have analysed some of the macro-financial impacts of some of Colombia's transitions. Piraquive *et al.* (2023) analyse the impacts of the fall in fossil fuel exports, emphasising the real regional impacts using static input-output and computable general equilibrium techniques, while Willis Towers Watson (2023) also analyses other channels of fiscal, external, and financial transition risks independently using different microeconomic and financial risks methodologies. Studies such as Bernal *et al.* (2023) and World Bank (2023), which not only consider a fall in fossil fuel exports but also climate change-related investments, have used accounting and partial equilibrium approaches that omit key feedback and second-round effects from the financial to the real sphere and vice versa affecting the trajectories of different real, fiscal, and external variables.

Precisely to appreciate these advantages, the following subsection describes the scenarios and presents the simulation results addressing the questions initially posed.

3. Scenario description

The baseline scenario has been described at length in Chapter 2. This section will hence describe green investment scenarios with and without global transition scenarios.

This subsection describes two different simulation exercises considering the investment in climate change mitigation and adaptation to comply with Colombia's NDC. The green investment path amounts to 1.5% of GDP between 2023 and 2030 and 1.1% of GDP from 2031 to 2050. These magnitudes are based on the latest World Bank Country Climate and Development Report for Colombia (World Bank, 2023) for both the starting and ending points. Moreover, as many of the green investments to comply with the Paris Agreement have a public good character, even though there may be some private investment crowding in, it is assumed that they are fully undertaken by the government. Thus, the simulations present should be interpreted as an upper-bound scenario with no private sector involvement and full implementation of the commitments.

Table 3 presents a brief description of the scenarios used to construct our two simulation exercises, which will be compared with the baseline (i.e., no NDC investment and no drop in real fossil fuel exports). It is important to note that the investment paths as a percentage of annual GDP published by the World Bank (2023) and other studies, except in the case where they are expressed as a percentage of GDP of an observed base year, are difficult to replicate exactly in our simulations because GDP is endogenous in the model. Thus, although as percentages of GDP both paths may be similar, the series in Colombian pesos will be different and not necessarily comparable.

Table 2. ***Summary of the simulation exercises***

EXERCISE	CHARACTERISTICS	SCENARIOS
NDC investment without global transition	• Investment path of 1.5% of GDP until 2030 and 1.1% of GDP from 2031 to 2050	• Conventional financing • Mixed financing
NDC investment with global transition	• Investment path of 1.5% of GDP until 2030 and 1.1% of GDP from 2031 to 2050 • 2.5% annual decline in real fossil fuel exports from 2023 onwards • 10% increase in the propensity to export non-traditional goods over a 15-year horizon	• Mixed financing with fossil fuel exports decline • Mixed financing with fossil fuel exports decline and non-traditional exports increase

Source: Authors.

The first simulation takes as a starting point the already-outlined NDC investment pathway with two different financing strategies. Firstly, the *conventional financing scenario* assumes that the green investment is fully financed by conventional debt instruments (i.e., loans and bonds in domestic and foreign currency) at market rates. This scenario implies that the government assumes full responsibility for financing the NDC and that it does so at the cost at which it traditionally borrows to cover its financing needs. Consequently, this scenario is expected to generate significant fiscal pressures despite the multiple co-benefits of investing in mitigation and adaptation.

Secondly, the *mixed financing scenario* shares the financial burden arising from the green investment path among the government, the private sector, and the rest of the world. It is assumed that 10% of the investment value is financed by donations from the rest of the world. This value is around half of the share of climate financing flows observed between 2011 and 2021, which, according to the Departamento Nacional de Planeación and Fedesarrollo (2021), was 18.5%. Nonetheless, even if the share used in the model is lower, it is still a fairly optimistic assumption since the investment path is at a higher level than the one recorded over the last decade. In this sense, this assumption should be interpreted as one best-case scenario with strong support from the international community and successful efforts by foreign affairs institutions to attract donors.

Furthermore, it is assumed that 30% of the investment path is financed by green taxes paid by households and firms equally. This assumption tries to reach paid by a midpoint in the simulation between the medium-term carbon tax collection projections presented by the Ministerio de Hacienda y Crédito Público (2023) of 0.03% of GDP and a carbon tax collection scenario of 0.7% of GDP shown by the World Bank (2023). The remaining 60% of the investment is financed through green bonds and loans, which have a 10% lower interest rate (i.e., greenium) than conventional debt instruments and are issued in equal proportions in domestic and foreign currency. The latter assumption of a 10% greenium is also optimistic compared to the 2% greenium observed in the 10-year green bond issue of 31 October 2021 (Consejo Superior de Política Fiscal, 2022). Overall, the *mixed financing scenario* is an illustration under favourable assumptions and does not represent an optimal strategy. Therefore, alternative combinations in the financing sources may be considered and tested.

The second simulation exercise takes NDC investment with a mixed financing strategy as a starting point, as it is considered a feasible scenario that alleviates fiscal and external pressures. However, in line with the prospects for global decarbonisation, it deals with additional transition risks that arise from a fall in real fossil fuel exports which were not considered in the previous exercise. Hence, the first scenario encompasses a public green investment path with mixed financing and a drop in real oil and coal exports. More precisely, it is assumed that real fossil fuel exports fall by 2.5% annually from 2023 onwards based on the global transition scenarios proposed in Chapter 3.

Conversely, Colombia has set out to develop a public policy strategy for the reindustrialisation and diversification of the export basket in the coming years (Ministerio de Comercio, Industria y Turismo, 2023). If the objectives of this policy materialise, apart from the achievements in terms of economic growth and employment, the country would become less vulnerable to the decline in fossil fuel exports. Thus, the second scenario considers NDC investment with the mixed financing strategy and the drop in real fossil fuel exports already described, combined with a 10% increase in the propensity to export non-traditional goods over a fifteen-year horizon. This assumption represents additional diversification efforts to the projected increase in non-traditional exports shown by the Ministerio de Hacienda y Crédito Público (2023) and captured in the baseline scenario of Chapter 2.

4. Results

The results for the two simulation exercises presented in Table 3 are presented below.

4.1. NDC investment and financing strategies

Figure 6 presents the results of the first simulation for the NDC investment scenarios with conventional and mixed financing, which are compared against the baseline.

Both scenarios show higher economic growth (Panel b) due to the public investment push, especially during the first ten years of the simulation. This translates into a fall in the unemployment rate (Panel c) compared to the baseline scenario, which decreases more at the end of the period in the conventional financing scenario due to the boost that currency depreciation (Panel d) has on exports[31] (Panel f). The higher dynamism of aggregate demand, the pass-through of the exchange rate on imported intermediate and consumer goods prices, and the cost-push from carbon taxes cause the inflation rate (Panel e) in the mixed financing scenario to be slightly higher than in the conventional financing and baseline scenarios, respectively.

Import demand (Panel g) increases relative to the baseline in both scenarios due to the higher demand for green capital goods and the effect of this investment on economic growth, leading to a higher trade deficit relative to the baseline (Panel h) that also contributes to the currency depreciation (Panel d). While in both scenarios the current account deficit (Panel j) is larger relative to the baseline, it is smaller in the mixed financing scenario compared to the conventional financing scenario due to a larger supply of foreign exchange and better financial conditions. This is because the income account[32] of the current account (Panel i) improves in the mixed financing scenario due to grants received from the rest of the world and less interest paid to foreign creditors, the latter being a result of lower public indebtedness and interest rates below conventional market rates.

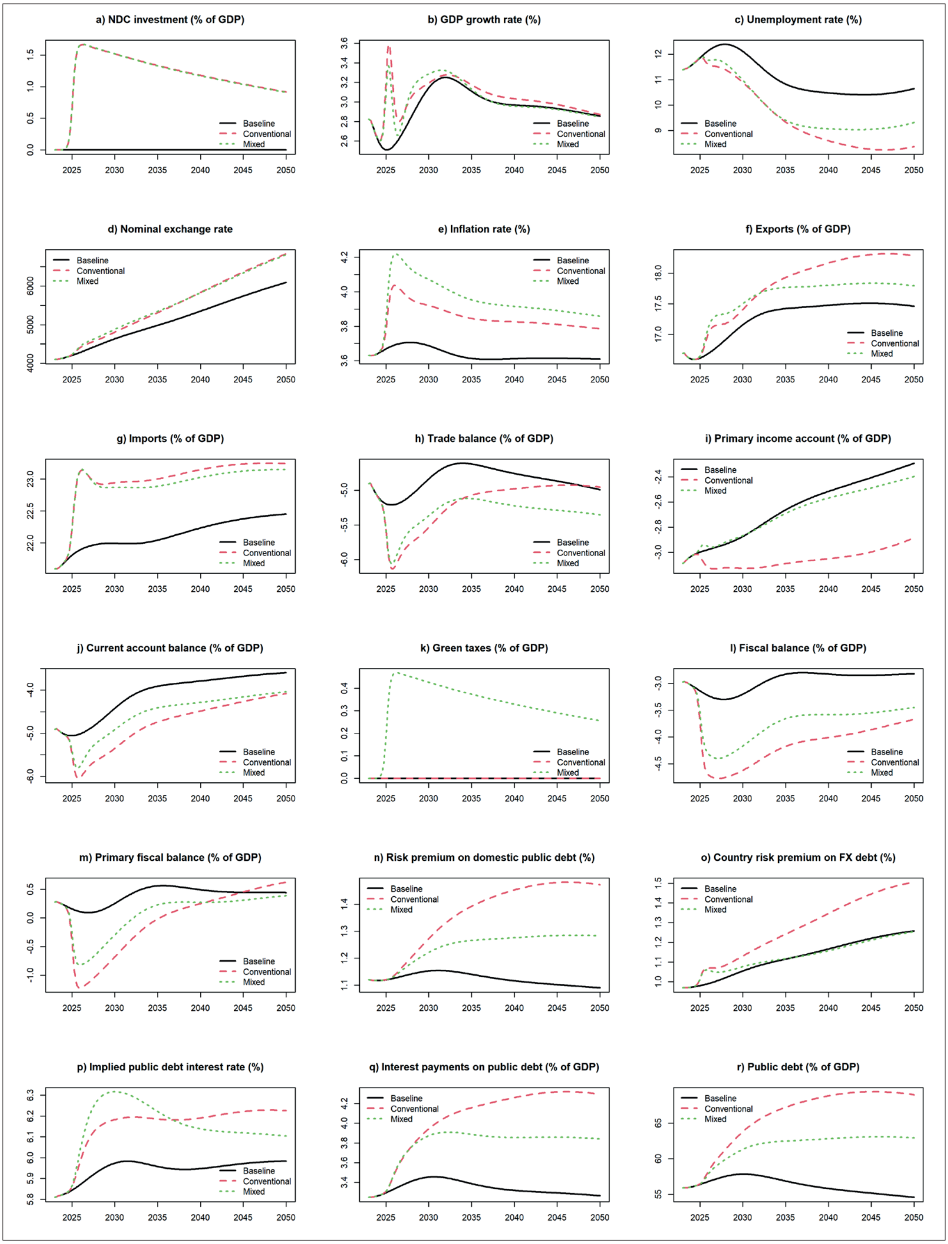
31. As expressed in Chapter 3, this result is given by the assumption that relative price only determines export propensities. In practice, other considerations such as production capacity or non-price competition play an important role and should hence mitigate the optimistic result that depreciation always leads to export growth.
32. Excluding remittances and other transfers.

On the fiscal side, public investment generates pressures on the total (Panel l) and the primary fiscal deficit (Panel m), even if higher GDP growth and inflation dampen them slightly. However, under a mixed financing scenario where carbon taxes are increased (Panel k) and grants from abroad are received, the general government's financing needs are lower in contrast to a scenario with conventional financing. Consequently, since in the mixed scenario a smaller share of investment is financed via debt issuance with lower interest rates than conventional market rates, the general government's interest payments (Panel q) and public debt as a percentage of GDP (Panel r) are also lower in the mixed scenario than in the conventional scenario, although higher in both cases compared to the baseline in which there is no NDC investment.

The lower external and fiscal imbalances achieved in the mixed financing scenario compared to the conventional financing scenario feed back into each other through different financial channels present in the model. First, the lower current account deficit and a lower path of public debt contribute in the long run to lower risk premia on domestic (Panel n) and foreign currency debt (Panel o). In turn, lower risk premia and the interest rate markdown on green debt instruments reduce the implied interest rate on public debt in the long run, resulting in lower fiscal and current account pressures via decreased interest payments (Panel p) to creditors. Finally, the higher supply of foreign exchange and a lower external deficit reduce the currency depreciation and contribute to a lower risk premium and lower balance sheet effects on public and private external debt.

Overall, the simulation shows that a transition undertaken entirely by the government through debt issuance may face constraints by inducing non-negligible fiscal pressures. While investments in climate change mitigation and adaptation have multipliers and high social and environmental returns, a financing strategy that alleviates the debt burden for the government is indispensable to enable a viable and sustainable transition over time. Access to long-term and low-cost financing, but also donations from international corporations and increased environmental tax revenues can contribute positively to this direction, but they do not eliminate the fiscal impact, especially if these resources cannot be guaranteed permanently. For this reason, even under optimistic financing assumptions, undertaking the transition would require some willingness from the public sector to assume a higher deficit in return for the benefits arising from green public investment.

Figure 6. ***Simulation of NDC investment and financing strategies***



Note: The black line shows the baseline, the red dashed line shows NDC investment with conventional financing, and the green dotted line shows NDC investment with mixed financing.
Source: Authors' computations.

4.2. NDC investment amid a global low-carbon transition

Figure 7 presents the results of the second simulation for the NDC investment scenarios with mixed financing, considering a drop in real fossil fuel exports and a partial diversification into non-traditional exports, which are compared against the baseline.

While investment in climate change mitigation and adaptation continues to have a positive impact on economic growth (Panel b) and employment (Panel c), this effect is attenuated especially in the short term when considering a fall in oil and coal exports. In the medium and long term, the export diversification policy leads to higher economic growth and lower unemployment compared to a scenario in which there is no diversification. It is worth noting that it is important to analyse with caution the rebound in exports (Panel f) in the long run for both scenarios, as this also seems to be driven by a price effect associated with the currency depreciation. However, given the production structure of the Colombian economy and the low price elasticity of demand that characterises its exports, the dynamics indicated by the model may be very optimistic.

The fall in foreign exchange inflows from lower fossil fuel exports and foreign direct investment in the sector generates a significant currency depreciation (Panel e) compared to the baseline and the scenario without a global low-carbon transition. This makes imports (Panel g) of consumer and intermediate goods more expensive, increasing the inflation rate (Panel d) due to the pass-through of the exchange rate on domestic prices. This not only has a negative impact on the purchasing power of the population, especially when expressed in foreign currency, but also contributes to the economic slowdown by causing an increase in the monetary policy interest rate. It is worth noting again that by implementing an export diversification policy that mitigates the fall in oil and coal exports, both the currency depreciation and the inflation rate are reduced.

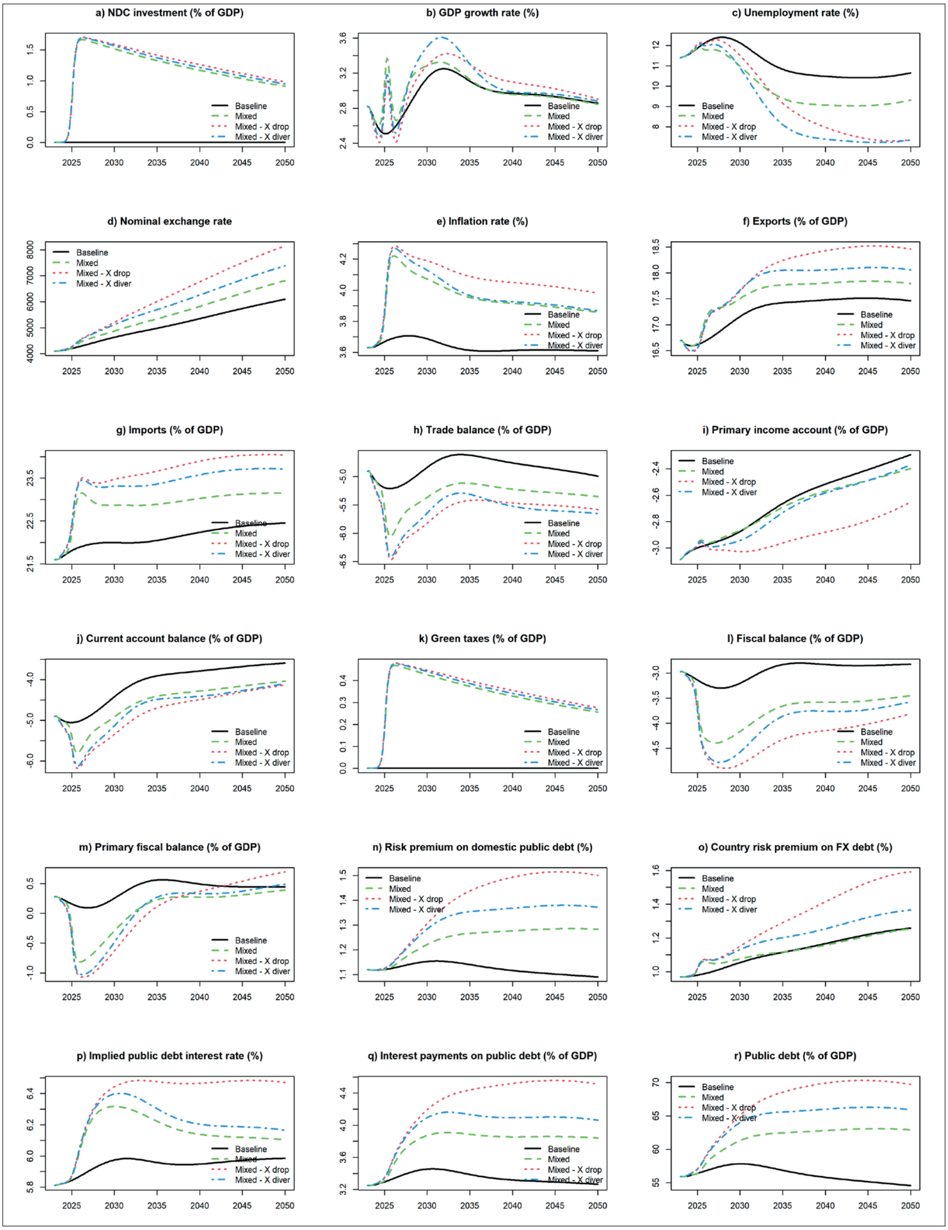
The pressures on the trade deficit (Panel h) generated by the NDC investment increasing imports, via non-locally produced green capital goods and higher economic growth, are amplified when the fall in oil and coal exports is considered and there is no policy to diversify exports. This, together with a higher deficit in the primary income account of the current account (Panel i) due to higher indebtedness, also translates into a higher total current account deficit (Panel j) compared to the baseline and no fossil fuel export drop scenarios. Here it is important to highlight that, while diversification can cushion some of the shock associated with a worldwide decarbonisation, it does not fully offset it. Hence, it shows the need for a more ambitious policy of structural change.

In the fiscal sphere, there is an additional source of fiscal pressures other than NDC investment, even when part of it is financed by grants, green taxes, and interest rate discounts on green debt instruments. Indeed, the fall in fossil fuel exports reduces fiscal revenues due to lower economic growth in the short term and permanently as a result of the fall in corporate income tax, royalties, and Ecopetrol's dividends paid by companies in the mining sector. As a counterpart to the latter and the existence of second-round effects of a financial character, the total (Panel o) and primary (Panel p) fiscal deficits are higher. Therefore, the public debt path (Panel r) of the scenario without diversification is well above the baseline and no fossil fuel export drop scenarios.

As in the previous simulation, the interactions between the real, fiscal, and external spheres of the economy mediated by different financial loops provide a better understanding of the differences between the scenarios with and without diversification. When exports are not diversified, the medium-term economic growth rate is lower, the supply of foreign exchange is reduced, and the levels of public and external indebtedness are higher, hence the currency depreciation and risk premia deterioration (Panel m and Panel n) are higher. This leads to larger fiscal and external imbalances via higher interest payments to creditors, due to balance sheet effects that increase the domestic value of foreign currency debt and the upward pass-through to public debt rates (Panel l). By contrast, when exports are diversified, second-round effects on the risk premium, depreciation, and government bond interest rates are dampened, leading to lower and more stable deficits.

To summarise, in a more realistic scenario for the coming decades in which oil and coal exports start to fall significantly, the permanent loss of fiscal revenues and the most important source of foreign exchange would put the Colombian economy in a rather tight situation. As a result of a more adverse macroeconomic and financial outlook, new constraints for the transition may emerge since the policy space for investing in climate change mitigation and adaptation is expected to be further reduced. Although the commitment to re-industrialise the economy and diversify exports towards more technologically complex and higher value-added goods may bear fruit in mitigating financial, fiscal, and external risks, the exposure to a global low-carbon transition is so high that it requires a policy of structural change that may take too long to materialise if it is not prioritised.

Figure 7. *Simulation of NDC investment with a drop in fossil fuel exports*



Note: The black line shows the baseline, the green dotted line shows NDC investment with mixed financing, the red dashed line shows NDC investment with mixed financing and a drop in fossil fuel exports, and the blue dashed line shows NDC investment with mixed financing, a drop in fossil fuel exports, and export diversification.

Source: Own computations.

5. Concluding remarks

In view of Colombia's commitments to biodiversity protection, climate mitigation and adaptation, and the prospects of a global low-carbon transition that reduces fossil fuels' world demand and prices, this chapter carried out some simulation exercises using the GEMMES Colombia model to better understand its medium-to-long-term implications. In general terms, based on the scenarios proposed, it was possible to consider that given the current macro-financial context, the productive and public finance structures, the pattern of international insertion, and the status of a peripheral economy with external constraints, the Colombian economy exhibits many vulnerabilities to the low-carbon transition. To the extent that these vulnerabilities have broad implications in various spheres of the economy, they may constrain the transition itself in spite of its multiple benefits.

The first thing that should be clear is that a sustainable transition requires thinking in terms of structural change. Given the influence of fossil fuel exports on fiscal revenues and foreign exchange inflows, a global decarbonisation would put the Colombian economy in a tricky situation from an external, fiscal and financial perspectives. On the fiscal front, more permanent sources of revenue should be sought to compensate for the lower collection of royalties, income tax, and Ecopetrol's dividends paid by the mining sector, even if this is challenging given Colombia's production structure and high levels of informality. Fiscal revenue loss should not lead to fiscal consolidation if Colombia seeks to fulfil its investment needs.

Re-industrialising the economy, diversifying exports, and even reducing import dependencies must be the way to compensate for the fall in foreign exchange inflows, attract long-term capital flows, and generate employment. This is highly relevant in order to ensure compliance with the Paris Agreement, since the investments undertaken to meet the NDC are highly import-intensive, as many green capital goods (e.g., solar panels, wind turbines, electric vehicles) are not produced domestically and exports of transition minerals are so far very low. Colombia does not export many highly complex goods, and its limited production and technology capabilities mean diversifying exports will not be easy. Hence, tackling this challenge requires prioritizing and coordinating efforts across different economic policies.

The public investment needs could be hard to meet, considering an already-narrow policy space that could shrink with loss of revenues from declining exports. Thus, albeit investments in mitigation and adaptation have a public good character, their cost and scale require the involvement of the private sector and a mixed financing strategy that share the financial burden among different actors. However, it is worth noting that no financing source is free of tensions and limitations in the Colombian context. For example, even if there is room to increase revenue from carbon taxes, they have macroeconomic and distributional impacts that should not be ignored. Moreover, the country's upper-middle-income status, which limits access to green financing on more favourable terms, and the low interest rate differential (i.e., greenium) between green and conventional debt instruments issued, make a case for broader access to low-cost climate finance.

However, it is important to clarify that even under optimistic scenarios of export diversification and green investment financing, transition risks cannot be reduced to zero. The country will undoubtedly be affected over the course of the coming decades at the external, fiscal, and financial levels, even with sound policy responses and a more favourable macro-financial context. Therefore, to meet biodiversity protection, climate adaptation and mitigation commitments, and to avoid the medium- and long-term costs of inaction, more policy space and much more favourable financing conditions are needed to facilitate green public investment. This requires a permanent and open dialogue with multilateral organisations, development banks, credit rating agencies, fiscal rule makers, and Congress in search of a new green fiscal framework capable of scaling up grants and long-term and low-cost financing and opening up policy space on a permanent basis.

To conclude, although the modelling exercise provides important policy insights for thinking about the transition as a process where vulnerabilities and opportunities are intertwined, it is not without room for improvement. Regarding limitations, the current model calibration overestimates the response of exports to a currency depreciation, labour productivity growth is assumed to be constant and insensitive to investment. Climate damages are not included to gain a better understanding of physical risks, and the unisectoral structure of the model omits heterogeneous impacts of the transition at the sectoral and regional levels. Therefore, future applications of the GEMMES model will attempt to address some of these limitations.

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Macroeconomic and external financing vulnerabilities

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Chapter 5

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Chapter 5

Macroeconomic and external financing vulnerabilities

Introduction

Climate change and its adverse effects have emerged as a major global risk for the coming years. Indeed, the danger facing the global economy is so great that governments have begun to assess how central banks can contribute to making the energy transition stable and sustainable (Bolton *et al.*, 2020). Despite efforts to date, the risk continues to grow due to the ongoing increase in greenhouse gas (GHG) emissions. Under the Paris Agreement (adopted at COP21), 196 countries have committed to reducing GHG emissions, with Colombia committing to reducing its emissions by 20% by 2030. In 2021, at COP26 in Glasgow, parties' emissions reduction targets were updated, and discussions were held on the importance of financing developing countries' transitions towards low-carbon economies, to help achieve the proposed mitigation and adaptation goals. Colombia presented a new Nationally Determined Contribution (NDC), aiming at a 51% reduction in GHG emissions by 2030. These ambitions are currently outlined in the E2050 Strategy, the Energy Transition Law, and the Climate Action Law, which serve as long-term guiding frameworks.

However, between the Paris Agreement and COP26, the COVID-19 pandemic drove the world economy into one of the worst recessions in history. As countries in different regions imposed lockdowns, especially during the first half of 2020, to mitigate the collapse of their health systems, the global economy contracted by 4.3% (International Monetary Fund, 2021). One of the main consequences of these lockdowns was that many people fell into poverty, or saw their incomes reduced and had no temporary or permanent means of compensating for that loss of income. Most countries therefore adopted expansionary fiscal measures, using mechanisms such as money transfers, as a short- and medium-term response to temper the socioeconomic crisis.

In most developing countries, the increase in public spending, the reduction in revenues due to the recession, and the failure of the government to generate new sources of income have resulted in an increase in national debt. In the short and medium term, this means that macroeconomic vulnerabilities have increased, due to greater restrictions on existing sources of financing or greater competition for it between countries. This, together with the current uncertainty due to the COVID-19 pandemic (because of the different speeds at which the population has been vaccinated), inflationary pressures, the energy crisis, and the deterioration of supply chains, generates a situation that is increasingly worrying at a global level.

In Colombia, achieving the targets for GHG emissions reduction and successfully transitioning towards a low-carbon economy hinges critically on securing the necessary financial resources to fulfil the commitments established. This chapter explores the implications of increased financial constraints for Colombia, stemming from external factors, on long-term economic growth. It emphasises the significant challenges these constraints pose, particularly in the context of meeting the government's ambitious GHG emissions reduction targets. To illustrate this, two different scenarios are presented that show how the Colombian economy currently faces increased macroeconomic vulnerabilities in the international financial market. The first scenario examines the impact of Colombia's loss of its investment grade status, a consequence of increased debt levels incurred during the pandemic and a sharp reduction in tax revenues. This downgrade highlights the country's financing challenges. The second scenario examines the rising market uncertainty, analysing the potential consequences of a financial crisis. It includes a case study on Evergrande, China's largest real estate firm, which, burdened with a USD 300 billion debt, has begun defaulting on interest and capital payments. While this crisis differs from the Lehman Brothers incident in its predictability, it may still have comparable effects, such as damaging the reputation of China's real estate market and triggering global repercussions.

The chapter is organised as follows: the next section provides a brief explanation of the background of the proposed scenarios. This is followed by a detailed account of the simulation methodologies and their transmission mechanisms. Subsequently, the results of these are presented, before we conclude with a brief discussion on policy implications based on these results.

1. Background of the scenarios

The two scenarios explored are relevant for developing economies, and especially for Colombia. This relevance is attributed to two key aspects of Colombia's national economy: first, its reliance on international financing as a crucial element for its operational effectiveness; and second, the necessity for Colombia to engage in global value chains through exports of agricultural goods and manufactured as well as raw materials from extractive industries.

1.1. Investment in Colombia: Credit rating agencies' decisions

The spread of COVID-19 around the world and the actions taken to mitigate its impacts made 2020 an unconventional year. To avoid the collapse of health systems, most countries initially implemented different levels of lockdown, resulting in one of the largest ever contractions in global GDP. Governments began to provide support (in kind and financial) to businesses and households to prevent a further decline in economic activity. In Colombia, the cost to the state of these efforts was equivalent to 2.7% of GDP. This increase in spending, combined with the drastic decrease in tax revenue due to the reduction in economic activity, drove the fiscal deficit to 7.6% of GDP in 2020.

In this context, international debt markets began to show signs of a loss of confidence in Colombia's ability to meet its commitments and financial obligations. This increase in uncertainty led Standard and Poor's to lower the rating of the debt issued by the Colombian government to speculative investment grade in May 2021, and although the other two rating agencies (Fitch and Moody's) did not immediately follow suit, the cost of servicing the country's debt was increased by Fitch in July 2021.

Moreover, concerns around the country's public finances were not a new phenomenon. Credit rating agencies had been expressing apprehensions regarding the financing of Colombian debt in 2017. Standard and Poor's, for example, had been on a trajectory of downgrading its rating in the first quarter of 2017, a trend that continued until May 2021. At this point, it declared Colombia's credit rating unreliable and reduced its grade to BB+. Fitch's response was similar, lowering its rating from BBB to BBB– in the first quarter of 2020, influenced by the fiscal instability brought about by the pandemic. This lower grade persisted until July 2021, when Fitch also downgraded Colombia's rating to BB+. Although Moody's has sustained an investment grade rating, and in October 2021 even improved its outlook on the country from negative to stable, Colombia still lost its investment grade status when Fitch followed Standard and Poor's in relegating its rating to junk.

1.2. A potential financial crisis: The case of Evergrande

Investors often find themselves troubled by the prospect of “black swans”—unforeseen events that can cause significant disruption to the economy, such as terrorist attacks or the bursting of a financial bubble. Equally concerning, though less recognised, are “grey rhinos.” These events are not only likely to occur but also tend to be overlooked despite their potential to inflict serious harm on the economy. Notable examples of grey rhinos include Hurricane Katrina or the collapse of the Soviet Union.

A recent case in point is the unfolding debt crisis at the real estate company Evergrande. By early 2021, the company had accumulated a staggering USD 300 billion in debt, raising questions about whether this could lead to a crisis akin to Lehman Brothers’ collapse in China. However, the situation with Evergrande differs in a crucial way: it represents a grey rhino event since the issues were apparent and evolved gradually while the Lehman Brothers crash was a black swan, a surprise.

Evergrande’s debt represents 6.5% of all Chinese real estate sector debt. In September 2021, Evergrande began to fail to meet repayment dates, but it was able to pay in time to avoid a declaration of default. However, in December 2021, it failed to make a fundamental payment, of USD 82.5 million, which resulted in Fitch lowering its rating to “restricted default,” a decision that also affected two of its subsidiaries, one of which acted as guarantor of the bonds that it had to pay. As a consequence, Evergrande entered into a debt restructuring process with the Chinese authorities, which may involve the sale of some of the personal assets of its founder.

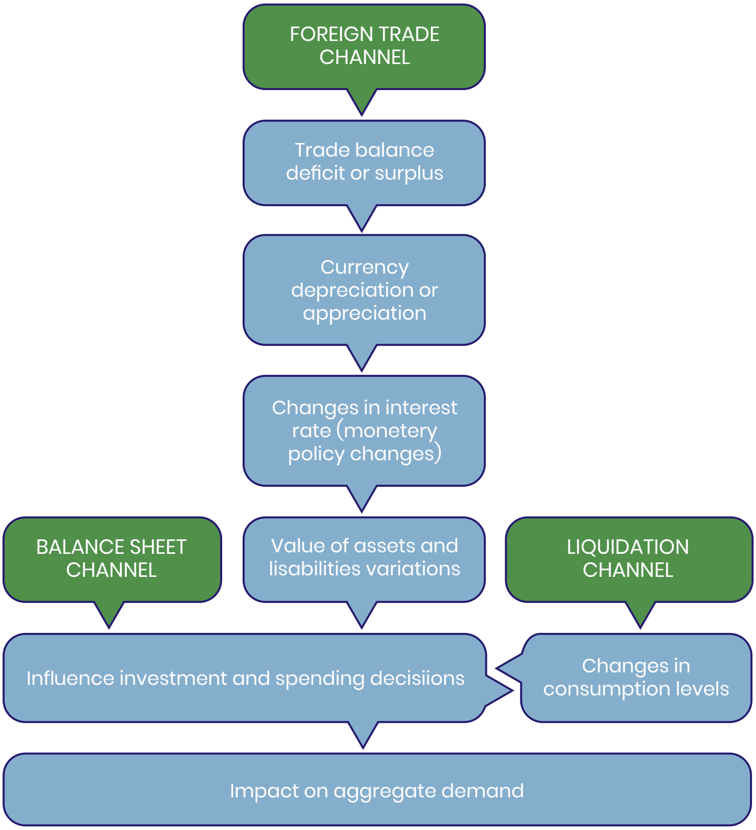
The collapse and liquidation of Evergrande has the potential to have a systemic impact like that of Lehman Brothers. The Chinese government has therefore made injections of RMB 120 billion (USD 18.6 billion) using repurchase agreements (repos) to maintain the liquidity of the banking system. The bankruptcy of this company would not have major implications for the US and European financial markets, although its current position has already caused falls in the stock markets. The greatest risk is that a domino effect will be generated in the Chinese mortgage sector, causing a slowdown in China’s economic growth and subsequently impacting the world economy. The potential consequences of an Evergrande bankruptcy, given its importance in the Chinese economy, have put the rest of the world on high alert: not only are they high impact but they are likely to be difficult to contain. As the contagion tends to be global, it seems unlikely that Latin America, including Colombia, would emerge unscathed.

The Evergrande case study is also useful for understanding the reality of several other companies that could also be classified as grey rhinos. These companies, together with the economic deterioration generated by the pandemic and geopolitical tensions, point to the financial fragilities of the global economy and raise the spectre of a more generalised financial crisis if they are not taken into account.

2. Simulations and transmission channels

For each of the above-mentioned scenarios, we present how the different simulations were built to be included in the model described in Chapter 2. For example, in the case of a lowering of the credit rating, there is no directly related parameter in the model, so changes in the Emerging Market Bond Index (EMBI) are taken as a proxy of the shock.

Figure 1. ***Transmission channels of economic shocks in Colombia***



Source: Authors. Based on GEMMES Colombia model.

In the case of the Evergrande default shock scenario, a soft link was made between the GEMMES model and a global vector autoregressive (GVAR) model (Pesaran *et al.*, 2004). This is because the GEMMES model has been built to simulate the effects of different shocks on the Colombian economy, and the GVAR model complements this analysis by considering the interactions of shocks at the global level (Ballesteros Ruiz and Rojas Aguilera, 2015).

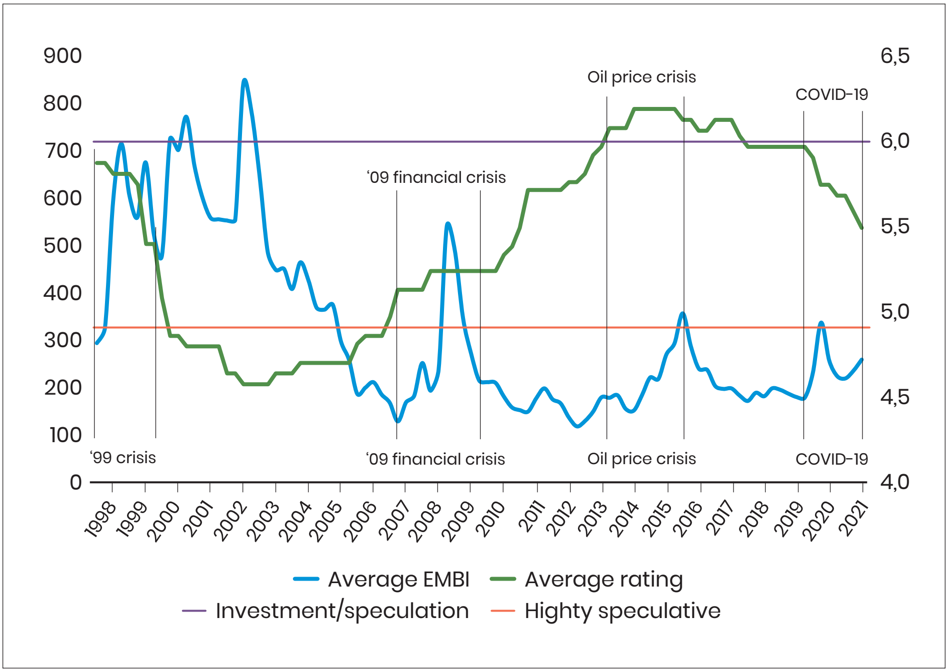
Additionally, for each of the shocks analysed, the channels through which the economy is impacted are shown, following Godin and Yilmaz (2020).

These three transmission channels give us a better understanding of how Colombia could be affected by global dynamics. They also show why, if the energy transition is to be carried out in a financially and fiscally sustainable manner, it is necessary to take into account all possible variables when discussing the transition.

2.1. A lowering of the credit rating

For the simulation within the model, the behaviour of the EMBI for Colombia was used as a proxy for a lowering of the credit rating. As shown in Figure 2, following the financial crisis in Colombia at the end of the 1990s, the country was classified as a highly speculative investment destination (below BB+), which caused the EMBI to rise from 325.4 basis points in the second quarter of 1998 to an average spread of 637.4 basis points in the third quarter of the same year. By the second quarter of 2003, the index began to decline slowly. It took Colombia approximately 11 years to recover its investment grade, as the EMBI remained quite high during this period, averaging 417.89 basis points, although this was partly due to a peak caused by the mortgage crisis in the United States: the index rose from 191.9 in the second quarter of 2008 to 539.6 basis points on average in the first quarter of 2009. Since 2014, when Colombia recovered its investment grade, the EMBI has stood at 160.4 basis points on average.

Figure 2. ***EMBI evolution and the credit rating***



Source: World Government Bonds and DatosMacro.

Before Standard and Poor's announced the downgrade of the country's credit rating, the finance ministry, in its statement of reasons for its tax reform project,[33] considered two scenarios that could emerge if no tax reforms were implemented. In the first scenario, the credit rating would be lowered by two notches, from BBB- to BB, which would translate into an increase of 82 basis points in the EMBI. In the second, the country would also default on debt interest payments, and its rating would thus be lowered three notches further, dropping to B, with the EMBI increasing by close to 241 basis points. However, according to Corficolombiana, a Colombian merchant bank, if tax reform were implemented, the rates of long-term treasury securities (TES) could show an increase of between 25 and 56 basis points, and there would be no lowering of the credit rating. In an alternative scenario, in which there is no tax reform, the country's rating

33. This tax reform proposal, introduced in early 2021 by Alberto Carrasquilla (Colombian finance minister between 2018 and 2021), preceded the loss of the Colombian investment grade. The failure to pass this reform contributed to the downgrade.

would be downgraded to BB+, with a negative outlook, and could be downgraded further in the future, leading to an additional devaluation of assets issued by Colombia in the debt market. Although a tax reform was approved in 2021, the markets did not consider that the increase in revenues was great enough for the credit risk to improve, so there is still a risk that the country's credit rating will be downgraded further. As Figure 2 shows, there is a high degree of correlation between the EMBI and the country's risk rating, so it was decided to use an increase in the EMBI as a proxy for the uncertainty generated by the lowering of the credit rating.

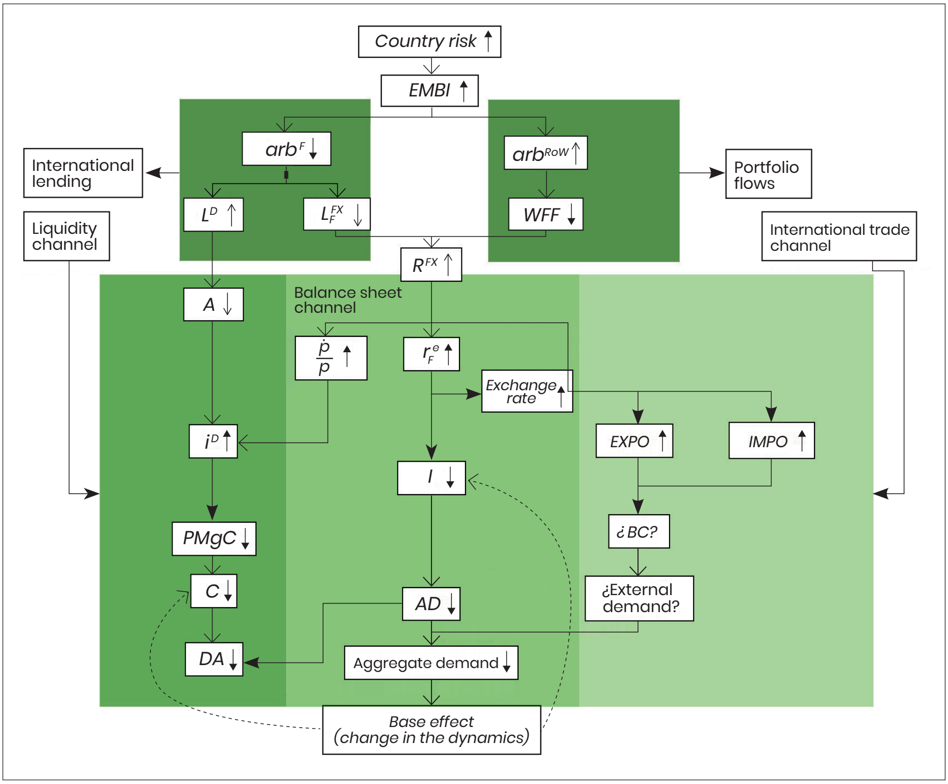
Thus, various scenarios are evaluated in which the EMBI increases by between 80 and 200 basis points. The 200 basis points scenario is the one that eventually transpired, since as soon as Fitch decided to withdraw the country's investment grade credit rating in 2021, the EMBI began a rise that took it from 556 to 750–760, having already previously risen due to the COVID-19 pandemic.

In terms of the transmission channels used by the model, in this case the balance sheet, an increase in the EMBI (as a proxy for the downgrade in the country's rating) prompts agents to begin to cover themselves by purchasing foreign currency. This leads to a significant depreciation of the currency and expectations of higher inflation. In this scenario, pressures are generated in the liquidity channel, leading to an increase in the domestic interest rate to control an increase in inflation and to keep foreign exchange in the domestic economy. These monetary policies also lead to a decrease in investment due to better profitability abroad, as well as lower household consumption due to less liquidity in the economy, which implies a decrease in aggregate demand.

Finally, in the foreign trade channel, following the devaluation of the currency, various impacts on the trade balance are possible, since both the value of exports (income) and the nominal value of imports (expenditures) increase, depending on the response of exports and imports to changes in the nominal exchange rate. Conversely, it is clear that in the capital account the deficit is likely to increase via capital outflows.

Here it is important to mention that the fiscal deficit may increase either due to less external financing or because obtaining it is much more expensive, given the increase in external interest rates. This deficit, although it can be financed in part by international reserves, is also a liability for the government's balance sheet since the holder of the reserves is the central bank.

Figure 3. ***Transmission channels of the lowering of the credit rating***



Source: Adapted from Godin and Yilmaz (2020).

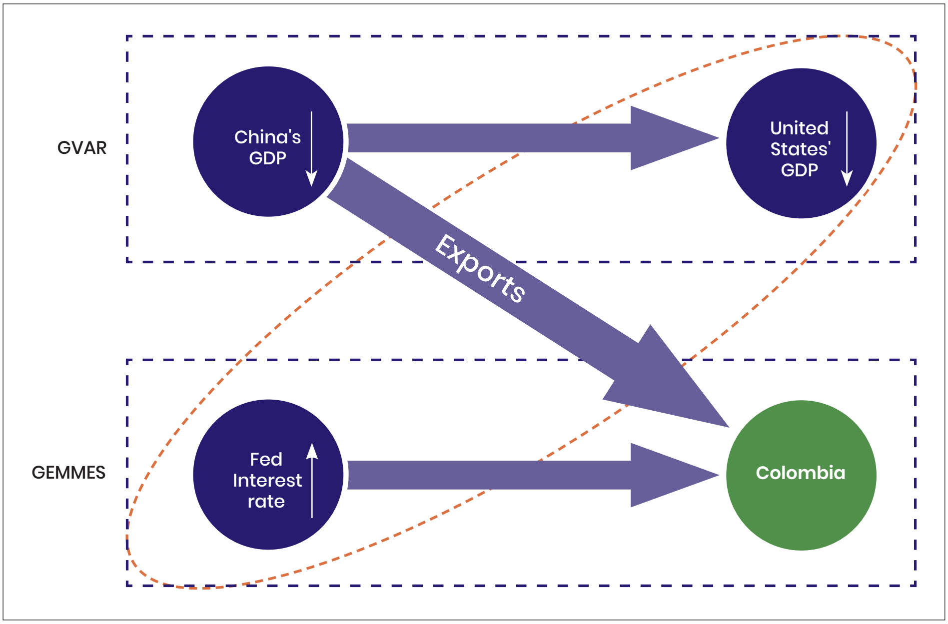
2.2. An Evergrande default

To construct the simulation, it is necessary to consider that Evergrande's eventual bankruptcy may cause a recession in the world economy and an increase in the foreign interest rate, thus affecting the financing of the Colombian government and the country's economy. Since there are no estimates for these effects, a GVAR model was used to obtain them, and then a soft link was made between the GEMMES and the GVAR models (Figure 4).

The GVAR model is designed to analyse a series of macroeconomic variables specific to each of the economies. This includes GDP, short- and long-term interest rates, exchange rates, inflation, and stock markets, thereby capturing the interdependencies of the global economy (see Pesaran *et al.*, 2004; Dees *et al.*, 2007). Although all these variables should be treated endogenously, this is not feasible when vector autoregressive (VAR) models are used, since there would be too many variables and data to make the estimates; this is known as the curse of dimensionality. One of the key assumptions of GVAR modelling is that country-specific foreign variables and global variables are weakly exogenous (di Mauro and Pesaran, 2013).

Taking this into account, the GVAR model gives us the necessary inputs to investigate and evaluate the impacts of international phenomena such as grey rhinos, in this case the Evergrande shock. We can then make a soft link between the GVAR model and the GEMMES model, which is stock-flow consistent. The latter allows the integration of all the flows and stocks of an economy, where three conditions are met: i) there are no black holes, meaning that "everything comes from somewhere and everything goes somewhere" (Godley *and* Lavoie, 2007, 6). This is guaranteed using the balance sheet and the transaction-flow matrix, which are integrated into a final matrix; ii) the financial and real sectors are integrated. Assuming the non-neutrality of money, the connection between real and financial variables is explicitly modelled; and iii) the behaviour equations have non-neoclassical foundations.

Figure 4. ***Soft link between the GEMMES and GVAR models***

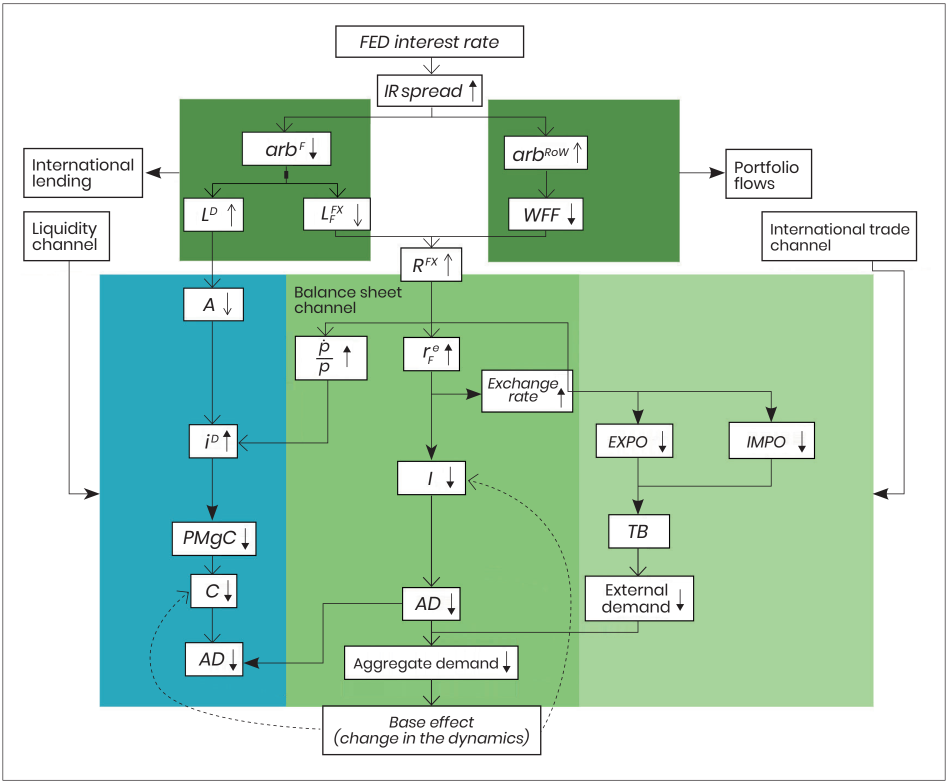


Source: Designed by the authors.

As Figure 4 shows, in the GVAR model, there is first a shock in the Chinese economy due to the Evergrande debt default. This implies a decrease in production in the world economy and an increase in interest rates, which makes external borrowing more expensive. Then, the following three shocks are introduced in the GEMMES model: i) recession in the world economy; ii) financing restrictions, via interest rates; and iii) a decrease in Colombian exports. A fall in world demand affects exports in a very similar way to the reduction of royalties (see Chapter 3), since this latter shock results from a decrease in exports. However, the magnitude of the shock on exports is much greater in this scenario.

Figure 5 shows the interaction between the real and financial sectors when the US Federal Reserve (Fed) interest rate increases through the three channels described above. The balance sheet of the economy is presented, where the financing restriction (due to an increase in interest rates, a response to monetary policy) generates an outflow of capital from the national economy due to expectations of higher returns in the rest of the world. This generates a strong depreciation, given the outflow of capital in foreign currency. Then, a rise in the nominal exchange rate can generate ambiguous results in the trade balance, in the sense that the value of both exports and imports can increase. Hence, the response of exports and imports to changes in world demand can produce a bigger or smaller deficit. Finally, the interaction with the financial sector occurs through the liquidity channel, which is connected with the real sector of the economy through inflation and the domestic interest rate, which, as they are increasing at the same time, affect the level of household consumption, reducing aggregate demand.

Figure 5. ***Transmission channels of an Evergrande default***



Source: Adapted from Godin and Yilmaz (2020).

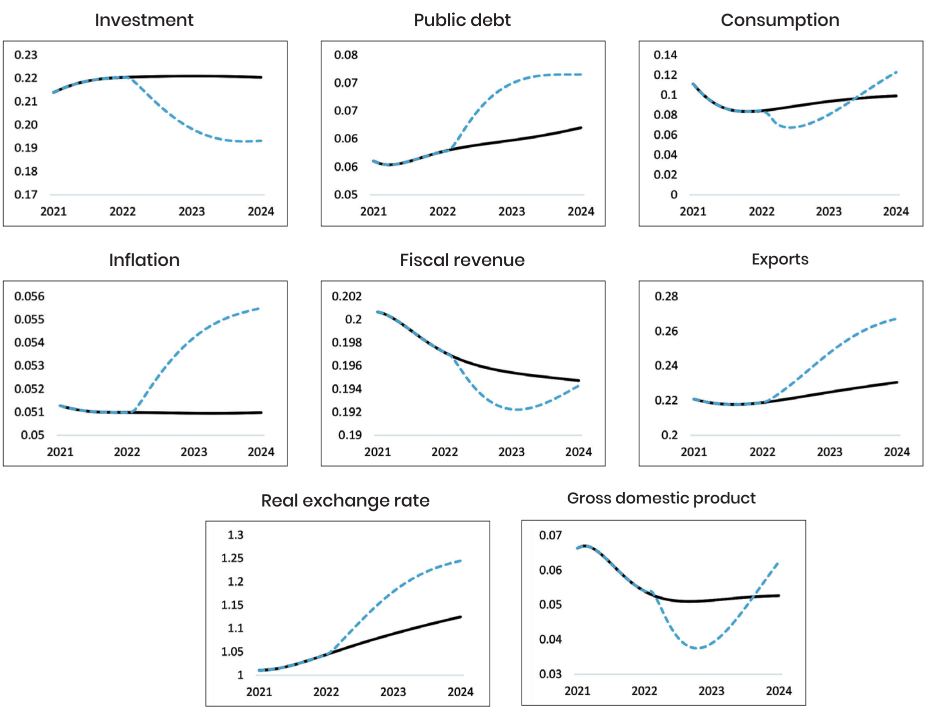
3. Simulation results

The results of the simulations show how, to a greater or lesser degree, aggregate demand is affected—through consumption, a lack of liquidity, or investment—when the interest rate, national or foreign, is increased. In addition, it is evident how the restriction in the international financial market, that is, higher international interest rates, causes the fiscal deficit to grow, increasing the need to find new sources of financing. It should be noted that in the external market the effects of the balance of payments are ambiguous, since, despite a decrease in world demand for exports, the currency ends up appreciating and thus compensates for this variable.

3.1. A lowering of the credit rating

Figure 6 shows the results of the dynamics of the model, if the EMBI increases by 120 basis points. Simulations were also run with increases of 80, 150, and 200 basis points; these qualitatively follow the results presented in the figure. As can be seen, GDP decreases by 100 basis points, i.e., if potential growth were 3% and the EMBI increased by 120 basis points, GDP growth would be 2%. Although this seems like a temporary shock, this level of growth is observed because comparison is made with a lower base; the same occurs with consumption and fiscal revenue. It is worth remembering that it took 11 years for the country to recover its investment grade. Additionally, the permanent effects of the shock are clearly reflected in investment, which falls 0.5 percentage points, and inflation, which increases from 3.0% (the average target in recent years) to 3.05%. The deterioration in the country's external accounts is shown by a long-term fall in international reserves, of 1.5%, a result of the need to finance the increase in the fiscal deficit.

Figure 6. ***Dynamics involved in a credit rating downgrade***



Source: Authors. Results from the GEMMES model.

Table 1 presents the different simulation scenarios that were built. As mentioned above, the results in all cases are consistent in showing the deterioration of production, because of the uncertainty in the financial markets. In the most pessimistic scenario, GDP growth may be 1.7 percentage points lower than expected, as a result of lower aggregate demand.

Table 1. ***Impacts and results of a credit rating downgrade***

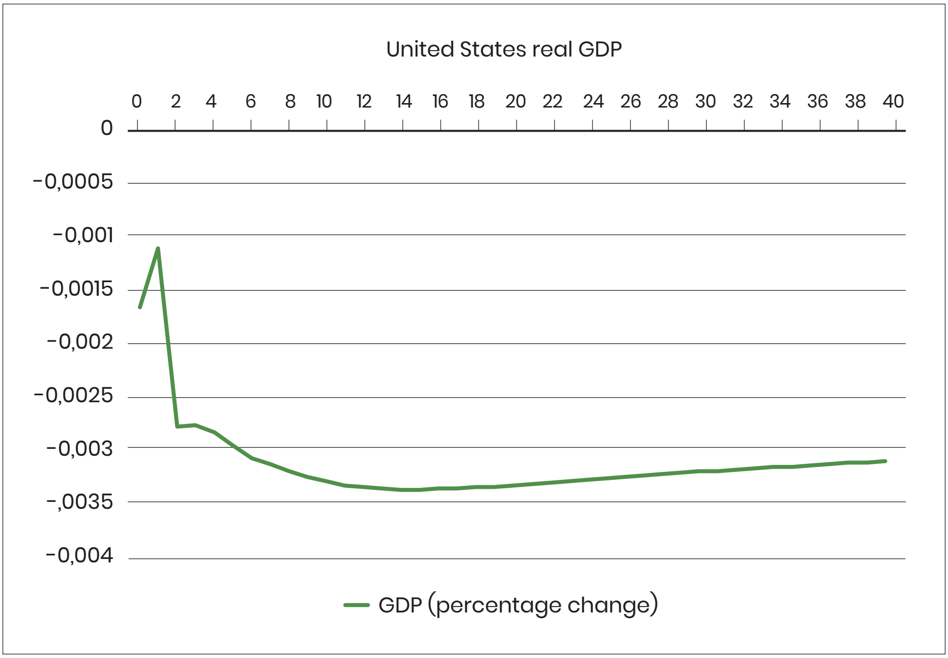
SCENARIO (>spread EMBI)	80 pb	120 pb	150 pb	200 pb
GDP	-70 pb	-100 pb	-125 pb	-170 pb
Consumption	-35 pb	-50 pb	-62.5 pb	-83.5 pb
Investment	-10 pb	-20 pb	-25 pb	-40 pb
Public debt	+15 pb	+20 pb	+25 pb	+35 pb
Fiscal revenue	-15 pb	-20 pb	-25 pb	-35 pb
Exports	-105 pb	-150 pb	-187.5 pb	-255 pb
Exchange rate	+280 pesos	+ 400 pesos	+ 500 pesos	+680 pesos
Inflation	+3.5 pb	+5 pb	+6.25 pb	+8.5 pb

Source: Authors' own calculations.

3.2. An Evergrande default

Here we present the analysis of the impulse response functions derived from the GVAR model, focusing especially on the evolution of the United States economy after the shock occurs. Analysis will focus on the effect of the shock in the short and medium term, although as Figure 7 shows, a period of 40 quarters is covered.

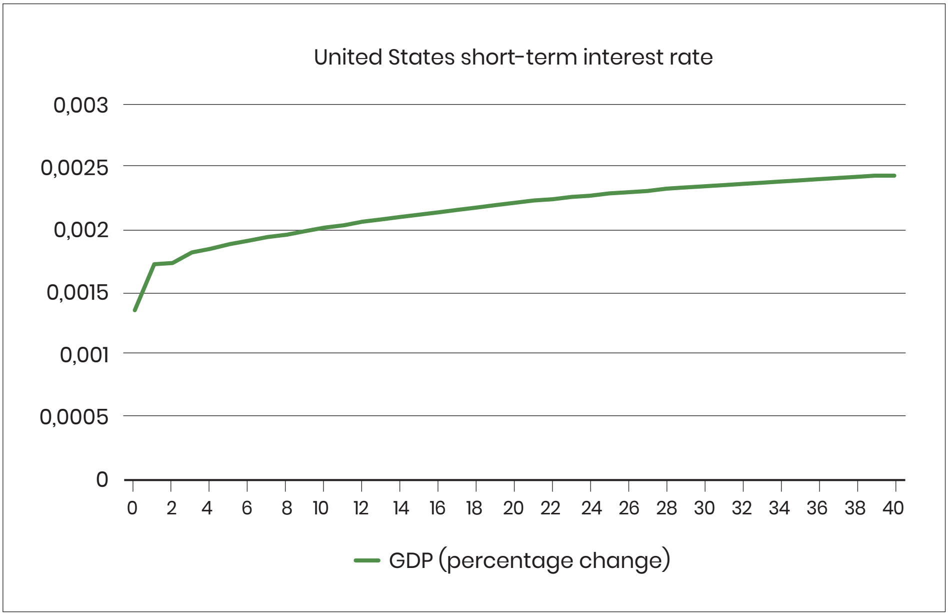
Figure 7. ***Evergrande default effects on the GDP of the United States***



Source: Elaboration by the Dirección de Estudios Económicos, Departamento Nacional de Planeación.

It should be taken into account that the possible default of Evergrande is taking place in a context of inflation in a large number of economies, which is leading central banks to increase their interest rates, among them the Fed. Therefore, a permanent positive shock of one standard deviation is introduced in the GVAR model, which makes the short-term interest rate in the United States increase by 17 basis points in the same quarter the shock is introduced, and subsequently continue increasing until it reaches 22 basis points.

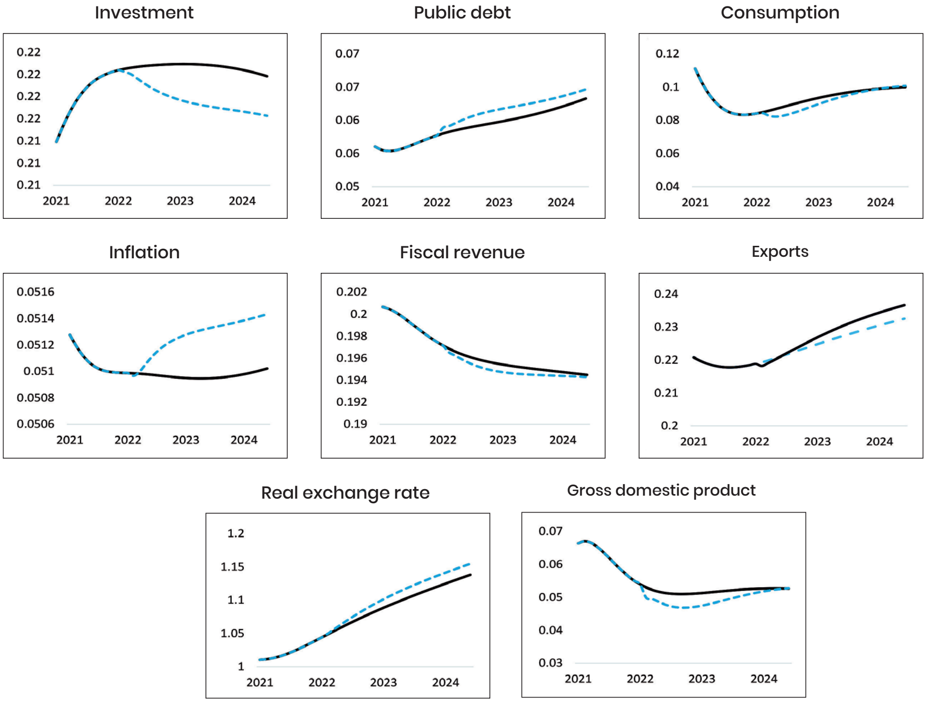
Figure 8. ***Effects on the short-term United States interest rate of an Evergrande default***



Source: Elaboration by the Dirección de Estudios Económicos, Departamento Nacional de Planeación.

As can be seen in Figure 7, there is a decrease in GDP in the long term. This is the result of a drop in aggregate demand, caused by a reduction in investment, which in turn is produced by the increase in international interest rates that places restrictions on investment financing. This drop in GDP leads to reduced fiscal revenues from tax collection, creating greater financing needs and increasing internal debt. Given the restrictions in international markets, this produces increases in interest rates internally, which implies a reduction in consumption, exacerbating the fall in aggregate demand as seen in Figure 9.

Figure 9. ***Dynamics of an Evergrande default***



Source: Results from the GEMMES model.

Table 2 presents the different simulation scenarios that were built. As mentioned above, the results in all cases are consistent with the disturbance that an increase in the Fed's interest rate—as a response to an Evergrande bankruptcy and its subsequent effects—would generate in the national economy. However, depending on the effects of the bankruptcy, for example, if other real estate companies such as Kaisa, Fantasia Holdings Group, and Shougang were badly affected by ricochet, the increase in interest rates may be higher than those calculated here.

Table 2. ***Results of an Evergrande default***

IINCREASE IN INTEREST RATE	35 bp	50 bp	75 bp
Investment	-30 bp	-46 bp	-50 bp
Public debt	+12 bp	+16.5 bp	+20 bp
Consumption	-14 bp	-16.5 bp	-18,5 bp
Real exchange rate	2.1%	3.0%	3.3%
Inflation	+0.23 bp	+0.28 bp	+0.33 bp
Fiscal revenue	-0.77 bp	-1.20 bp	-1.30 bp
Exports	-12 bp	-16.5 bp	-20 bp
Gross domestic product	-26.0 bp	-33.5 bp	-43.2 bp

Source: Authors' own calculations.

4. Discussion and conclusion

To recover from the COVID-19 crisis in a way that is sustainable and contributes to long-term emissions reduction, it is essential to restructure the economy by moving away from natural resource extraction and towards low-carbon industries. This will contribute to economic growth and allow the production structure to evolve towards an economy that is less dependent on raw materials (coal and oil) as the engine of development and has a new focus on manufacturing production, thus reversing the deindustrialisation observed over the last decade.

The increase in the Colombian fiscal deficit, a phenomenon seen throughout Latin America after the COVID-19 crisis, makes it necessary to seek new sources of financing, i.e., increasing taxes or acquiring debt. A tax increase in an economic context weakened by COVID-19 is particularly challenging. Equally, the acquisition of new resources in the external market is becoming more difficult as a result of global uncertainty about how the pandemic will develop and the increase in external interest rates.

As has been shown here, the risk scenarios in external financing produce significant macroeconomic vulnerabilities in the Colombian economy. There is a high probability that the economy's recovery will be slowed by greater restrictions on financing new investments and on spending on social programmes needed to mitigate the social consequences of the pandemic.

To obtain new sources of financing and achieve greater economic growth, while fulfilling commitments on reducing GHG emissions, it is necessary to build mechanisms that lead the economy towards a transition to low-carbon technologies. A carbon tax, for example, would raise fiscal revenues in the short term and favour the transition towards a more sustainable production structure. Another option would be for the Colombian state to issue green public bonds backed by investment in green infrastructure and thus attract new sources of international financing. Ensuring fiscal stability is not only healthy for the country; it is also essential to convey a message of security and confidence to international financial markets. This would reduce the country's perceived risk and thus attract higher levels of foreign capital to the economy.

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Structural change and green growth in Colombia

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Chapter 6

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Chapter 6

Structural change and green growth in Colombia

Introduction

The transition to low-carbon and climate-resilient economies is leading to structural changes in the world economy, with some industries (sunset) declining and others (sunrise) flourishing. Deliberate policies, evolutions of preferences, and technological and industrial changes are driving these economic transformations (Semieniuk *et al.*, 2021). The various economic and social consequences of these changes for countries (employment effect, change in fiscal stance, trade balance dynamics, etc.) depend on their industrial structure, as highlighted by Magacho et al. (2023). In this context, this chapter seeks to shed light on the Colombian economic production and trade structure and to analyse the drivers behind its historical evolution in order to better understand the country's current economic vulnerabilities and the potential opportunities, risks, and tensions posed by the climate transition.

The first section delves into a historical analysis of Colombia's economic production structure. It identifies and explores the fundamental elements that have shaped its evolution over the last two decades, drawing on input-output matrices from various years to provide a comprehensive perspective.

In the second part, we analyse the current state of Colombia's production structure in the transition to a low-carbon economy and then assess the potential constraints and opportunities arising from such a transition from a sectoral perspective. This structural change implies a profound transformation in the way energy is conceived and used, with significant impacts on technology, the economy, and society. To this end, we propose to explore the key fiscal, external, and socioeconomic vulnerabilities linked to declining industries in the context of regional disparities. Two major vulnerabilities are found in the Colombian economy: i) the external sector, due to the high dependence on income from coal and oil exports; and ii) the labour market, due to the high rate of informality, one of the highest in Latin America. Additionally, we highlight sectors with the potential to drive the shift towards green industries, thereby supporting economic diversification.

This chapter distinguishes itself from preceding ones by offering an analysis of the Colombian economy through a sectoral lens. The importance of the analysis of the productive composition lies in relating the weights of the different sectors, their transformations, and their relationships with the growth rate of the economy as a whole.

1. Tracing transformations: An analysis of Colombia's production and trade structure in recent decades

1.1. A premature deindustrialisation process

Beginning in the 1960s, Colombia's industry faced challenges, with a notable decline from the 1980s onwards, influenced by drug trafficking, armed conflict, and the failure to integrate the sector fully into the economy (Clavijo *et al.*, 2012). This period saw Colombia transition from a diverse economy, with a balance across the primary, industrial, and services sectors, to one increasingly dominated by services, lacking in industrial growth or solidification, notably since the 1980s (García, 2002). This structural change is noticeable in DANE (2022) data: the industrial sector's share in GDP fell from 19% in 1990 to approximately 12% by 2022. By contrast, the mining sector's contribution rose from 6% to 9.2% over the same period, adjusting to 6.2% in 2023. Meanwhile, the services sector saw an increase from 58% to around 65%. In terms of employment generation, the industrial sector contributed about 25% of total employment three decades ago, and 23% one decade ago, but today it contributes only 13% (Márquez Garzón, 2023). This trend—the fall in industrial participation in GDP—which may be described as "deindustrialisation" (Rodrik, 2015; Tregenna, 2009), occurred in Colombia alongside "tertiarisation" (Moncayo and Garza, 2005), marking a rise in services sector participation. This decline in the share of industry in GDP can be qualified as premature, since it was not due to the traditional sources of deindustrialisation, such as an increase in services demand led by an increase in income (Palma, 2014).

In other words, in Colombia, the initial phase of "simple manufacturing industrialisation" was indeed followed by an expansion of the services sector, which then compressed the contributions of the agricultural and industrial sectors within GDP. However, the peculiarity is that the economy primarily grew through commodity exports,[34] and industrial sector contributions to the economy declined more significantly. Clavijo *et al.*

34. A concept known as the "mining-export drive" or "*locomotora minero-exportadora*" in Spanish.

(2012) suggest that this was due to the influx of foreign currency from commodity exports, which led to an appreciation of the peso, adversely impacting the value of industrial and agro-industrial exports, especially those that are labour-intensive. These phenomena could be interpreted as symptoms of the so-called "Dutch disease" (Corden and Neary, 1982).

Beyond the mining-energy boom, which was accompanied by a relative increase in the cost of labour and a marked and persistent real appreciation of the exchange rate, Clavijo *et al.* (2012) also associate this deindustrialisation process in Colombia with structural difficulties in the provision of the most basic services (energy, telecommunications, transportation routes) (Márquez Garzón, 2023). Botta *et al.* (2016) indicate signs of financialised Dutch disease in the case of Colombia, where financial dynamics, coming mainly from foreign direct investment, tend to exacerbate appreciation/depreciation dynamics. Other authors support other theses surrounding the causes of this process, such as productivity differentials or outsourcing and bad policies implemented in Colombia.

The problem of a premature deindustrialisation is that rather than moving from industrial sectors to high-productivity services (sophisticated services), the economy is transitioning towards low-productivity services (traditional services sectors), which pay low wages and demand less qualified workers (Rodrik, 2015).

One argument contrary to the premature deindustrialisation view is that there has been an outsourcing of the services required by industrial production, which leads to an accounting reduction of industry in GDP, but this is not necessarily a negative process. This view argues that this process is a consequence of the sudden increase in the price of commodities[35] (Clavijo *et al.*, 2012). Carranza and Moreno (2013) and Moreno (2016) find that the vertical disintegration of the industrial production chain has caused a decrease in the share of industrial value added in total value added. This argument relies on the idea that it would be inadequate to compare industrial contribution to GDP over time given the emergence of a process of outsourcing and offshoring,[36] implying a *de facto* transfer of production from industrial sectors to services ones in the national accounts.

35. Clavijo *et al.* (2012) state that deindustrialisation is a consequence of the increase in exports of commodities (oil and coal), which push aside industrial and agro-industrial exports and generate an appreciation of the real exchange rate. They find evidence of their hypothesis in the negative correlation of the participation of industrial value added in GDP relative to the participation of mining in total exports.
36. Outsourcing and offshoring imply that many of the activities, such as transport, telecommunications, security, mail services, and so on, that were originally included within companies are externalised to service companies.

Therefore, a part of the outsourcing measurement can be attributed to a reallocation effect (Berlingieri, 2013). Additionally, industrial participation in GDP naturally decreases with the degree of development, which has been characteristic of the economic growth of developing countries. Holmes and Thornton (2001) suggest that companies consider the possibility of outsourcing some of their production processes, as technological advancements have made doing so more efficient and cost-effective. Nevertheless, despite its importance, this mechanism is not enough to explain the decline of manufacturing production and exports in Colombia.

1.2. Assessing structural changes and interdependencies in Colombia's economy: Sectoral dynamics (2005–2014)

This section proposes to analyse the Colombian economy's sectoral evolution from 2005 to 2014 (see Appendix 5 for details regarding data sources and processing methods). Sectoral indicators draw upon input-output analysis to identify the existence or otherwise of structural changes within different industries and in the economy in general. Revealing whether these structural shifts in the Colombian economy have occurred can help us to understand the factors that have shaped its past and present state.

This knowledge is important for creating more effective and suitable policies (diversification strategies or reduction of dependence on specific commodities like oil and coffee). The identification of structural changes can also better guide the identification of new investment opportunities in the country, which is trying to attract more foreign investment, particularly in areas like technology, tourism, and agriculture, seeking to go beyond traditional exports. Furthermore, as Colombia continues to integrate into the global economy and competition intensifies, understanding its structural shifts from a historical perspective is essential for making the most of international trade agreements, attracting foreign investment, participating effectively in global supply chains, and spurring innovation in sectors like technology, manufacturing, and services.

The assessment of these structural changes will be conducted through a series of specific indicators such as backward and forward linkages. Both capture direct and indirect industrial connections. Higher numbers suggest stronger relationships or dependences. While forward linkages refer to the distribution of an output from one industry to other industries as an input (i.e., how much a sector is a supplier for other sectors), backward linkages refer to the inputs required by one industry from other industries (i.e., how much a sector is a demander from other sectors). The latter therefore measure how much a sector pulls the economy, meaning how much an increase in production in one sector leads to an increase in production in other sectors. This methodology was introduced by Dietzenbacher in 1992 (refer to Appendix 1 for details on the methodology). To enrich our analysis of (de)industrialisation dynamics, we incorporate a complexity index (CI). This index, built upon the average propagation length concept developed by Dietzenbacher *et al.* (2005) (refer to appendices 2 and 3 for details on the methodology), allows us to track the evolution of complexity within the economy.

Tables 1 and 2 provide a nuanced view of the economic interdependencies within the Colombian economy between 2005 and 2014. While the data suggest stability in the overall structure of linkages and sectoral classifications, the slight shifts that do occur reveal much about the country's economic trajectory and the impact of global events.

From 2005 to 2010 in Colombia, we observe a marginal strengthening of backward linkages (Table 1) across most sectors—and especially for the "meat and fish" and "dairy products" and "coffee products" sectors—suggesting an intensification of intersectoral economic activities. This period coincides with the aftermath of the 2008 financial crisis, when Colombian producers turned inwards, bolstering domestic markets and value chains in the face of export contractions. Such a trend underscores the resilience of the domestic economy and its capacity to adapt to external shocks by reinforcing local production networks, which leaned on these robust sectors to maintain economic stability. Concurrently, Table 2 reveals a parallel trend in forward linkages, particularly in sectors like "energy," "wood products," and "other private services." These sectors have demonstrated their critical role as suppliers, suggesting that they not only drive their own activities but also fuel a wide array of other economic sectors.

Table 1. ***Rasmussen backward linkage indices and sectoral classification 2005, 2010, and 2014***

	RASMUSSEN BACKWARD LINKAGE			RANKING			SECTORAL CLASSIFICATION *		
SECTOR	2005	2010	2014	2005	2010	2014	2005	2010	2014
Meat and fish	2.44	2.45	2.41	1	1	1	SBL	SBL	SBL
Dairy products	2.28	2.26	2.21	2	2	2	SBL	SBL	SBL
Coffee products	2.16	2.11	2.14	3	3	3	SBL	SBL	SBL
Social services	1.96	2	1.99	11	5	4	SBL	SBL	SBL
Oil (animal and vegetable)	2.07	2.08	1.99	4	4	5	KS	KS	KS
Cocoa	2.01	1.95	1.94	6	8	6	SBL	SBL	SBL
Sugar	2.02	1.98	1.93	5	6	7	SBL	SBL	SBL
Paper and cardboard	1.94	1.94	1.92	13	9	8	KS	KS	KS
Basic metallurgical products	1.92	1.93	1.91	16	10	9	KS	KS	KS
Processed foods	1.97	1.92	1.9	9	12	10	SBL	SBL	SBL
Other private services	1.38	1.37	1.36	52	50	50	SFL	SFL	SFL
Sewerage	1.43	1.37	1.36	49	49	51	LL	LL	LL
Private education	1.41	1.37	1.35	50	51	52	LL	LL	LL
Agriculture (non-coffee)	1.38	1.36	1.31	51	53	53	LL	LL	LL
Non-metallic minerals	1.3	1.31	1.3	54	54	54	SFL	SFL	SFL
Forestry	1.3	1.3	1.29	55	55	55	SFL	SFL	SFL
Oil and gas	1.27	1.27	1.28	56	56	56	SFL	LL	LL
Public education	1.24	1.24	1.28	57	57	57	LL	LL	LL
Real estate	1.16	1.15	1.15	59	58	58	LL	LL	LL
Coffee	1.18	1.15	1.13	58	59	59	SFL	SFL	SFL

** KS: Key sector; SBL: Strong backward linkage; SFL: Strong forward linkage; LL; Lower linkage.*
Source: Own calculations based on DANE.

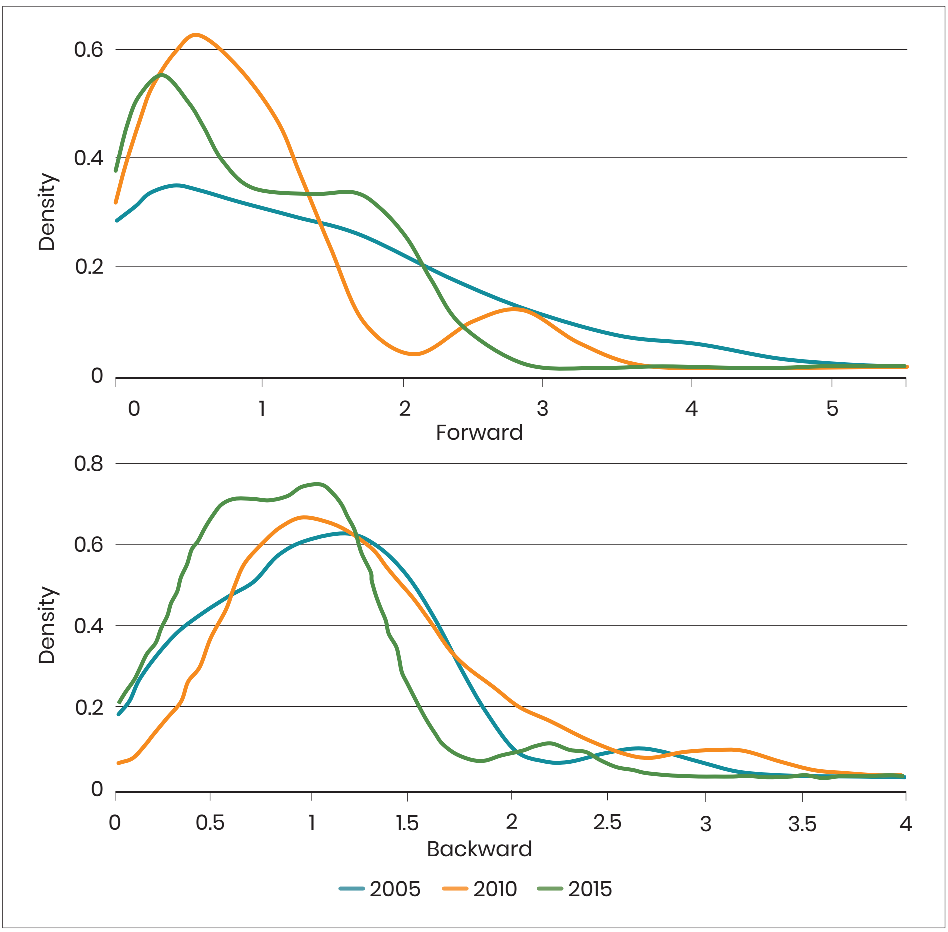
Table 1. ***Rasmussen forward linkage indices and sectoral classification 2005, 2010, and 2014***

	RASMUSSEN BACKWARD LINKAGE			RANKING			SECTORAL CLASSIFICATION *		
SECTOR	2005	2010	2014	2005	2010	2014	2005	2010	2014
0ther private services	2.51	2.57	2.5	1	1	1	SFL	SFL	SFL
Metallic minerals	1.87	2.42	2.71	19	2	2	SFL	SFL	SFL
Energy	2.24	2.42	2.48	5	3	3	KS	KS	KS
Non-metallic minerals	2.24	2.33	2.33	6	5	4	SFL	SFL	SFL
Oil refinery products	1.8	2.08	2.42	25	12	5	SFL	SFL	SFL
Wood products	2.27	2.37	2.3	4	4	6	KS	KS	KS
Non-metallic mineral products	2.1	2.16	2.27	12	9	7	KS	KS	KS
Complementary transport services	2.31	2.24	2.2	3	7	8	SFL	KS	KS
Paper and cardboard	2.34	2.25	2.13	2	6	9	KS	KS	KS
Publishing and printing	2.15	2.17	2.04	11	8	10	KS	KS	KS
Cocoa	1.26	1.25	1.24	48	49	50	SBL	SBL	SBL
Coffee products	1.2	1.22	1.16	51	50	51	SBL	SBL	SBL
Culture and leisure	1.17	1.17	1.12	53	52	52	SBL	SBL	SBL
Tobacco products	1.08	1.1	1.15	56	56	53	SBL	SBL	LL
Civil works	1.17	1.13	1.11	52	53	54	SBL	SBL	SBL
Coal	1.12	1.11	1.1	55	54	55	LL	LL	LL
Construction and repairs	1.13	1.1	1.08	54	55	56	SBL	SBL	SBL
Private education	1.05	1.05	1.06	58	58	57	LL	LL	LL
Public administration	1.05	1.07	1.05	57	57	58	LL	LL	LL
Public education	1.03	1.03	1.02	59	59	59	LL	LL	LL

** KS: Key sector; SBL: Strong backward linkage; SFL: Strong forward linkage; LL; Lower linkage.*
Source: Own calculations based on DANE.

However, the data from 2010 to 2014 depict a shift likely influenced by the "Dutch disease," where the rise in commodity prices favoured non-tradable sectors such as construction and civil works. These sectors, which are less involved in international trade, exhibit stable or increasing forward linkage indices that indicate a redirection of economic resources and effort at the expense of tradable sectors like agriculture and industry, which show a decline in backward linkage indices. This diversion of resources from export-oriented industries has led to the weakening of traditional supply chains, as evidenced by the decline in backward linkage indices for many sectors during this period. The increased importation of final goods to meet domestic demand, substituting for diminished domestic production, further decreases these linkages.

Figure 1. ***Kernel Dietzenbacher linkages***

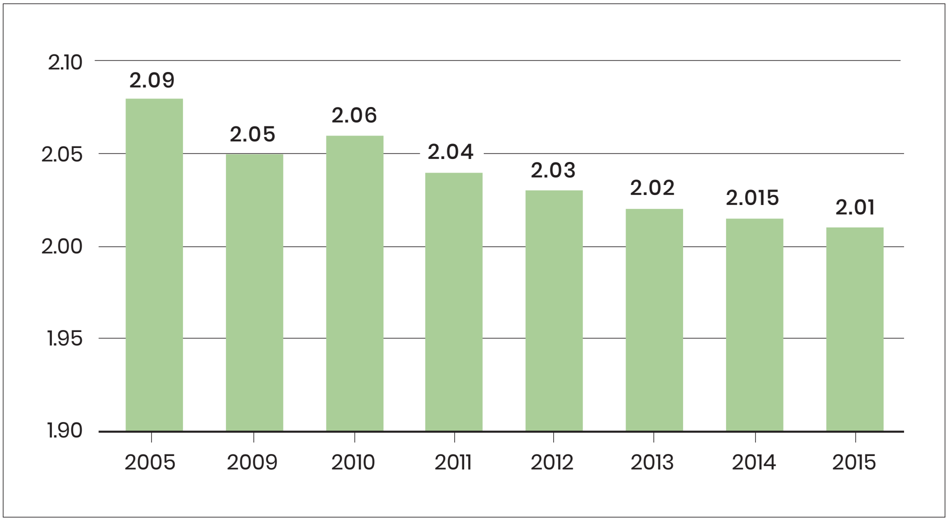


Source: Own calculations.

Over the last decade, Colombia's economic structure has evolved, with notable changes in sectoral interconnectivity, which peaked in 2005 and displayed a marginal decline by 2014, as shown by Figure 1, which shows the density of backward and forward linkages. This reduction in linkage density is very notable for forward linkages, indicating that sectors are having a lower and lower supply effect, with the exception of a few sectors. It is less strong in the case of the demand effect of industries (backward linkages), which sees a displacement to the left of the mode of the density curve.

The moderate decline in sectoral interconnectivity over the observed decade aligns with the trajectory of the complexity index (CI) depicted in Figure 2 (see Appendix 3 for details regarding the construction of the index). The CI experiences a decrease of 3.1% from 2.08 in 2005 to 2.01 in 2015, reflecting a simplification in Colombia's production structure. This trend could be attributed to an increased reliance on imported inputs. Dissecting the trend, we see that the CI diminishes by approximately 0.96% from 2005 to 2010, dropping to 2.06. From 2010 to 2014, the pace of decline in the CI is more moderate, decreasing by 1.94% to 2.02, suggesting a gradual yet steady shift towards a less complex economic structure, and therefore one less resilient to shocks.

Figure 2. ***Complexity index trends in the Colombian economy***



Source: Own calculations based on DANE.

This section presented an empirical analysis highlighting a significant structural transformation within the Colombian economy between 2005 and 2014. This transformation was not uniform across all sectors. As for general trends, the primary sector, consisting of agriculture and mining, remained relatively stable, with the notable exception of the oil sector (see Table 2), for which the forward linkage decreased. This trend was possibly due to the high prices between 2005 and 2014, which favoured the export of crude products over domestic refinement and use. Compared to the primary and services sectors, the industrial sector underwent a distinct transformation between 2005 and 2014, unique in its nature and pace, and significantly influenced by technological change (more on this in the following sections). The lack of industrial consolidation indicates this sector's divergent path within the broader narrative of Colombia's economic development, singled out by a transition from a three-sector system (primary, industry, and services) to one dominated by the services sector (García, 2002).

The variation in trends between different sectors, particularly the distinct dynamics observed in the industrial sector, can be largely attributed to the influence of international trade dynamics and technological changes, which significantly impacted production and supply chains (the complexity index of the economy decreased). This contrasts with other sectors like agriculture, construction, and civil works, which experienced more stable patterns and were less affected by these global influences. Understanding these differentiated trends over the past decade is crucial, as they reflect the varying degrees of sensitivity and adaptability of each sector to external economic pressures and opportunities.

1.3. Drivers of Colombia's economic growth: Demand dynamics and sectoral transformation (2005–2014)

The preceding empirical analysis highlighted the existence of a significant structural transformation, although one that was not uniform across sectors, within the Colombian economy between 2005 and 2014. This section now aims at identifying its determinants based on structural decomposition analysis (SDA) and therefore aims at identifying production growth drivers and constraints. More precisely, the SDA approach allows us to see whether changes in production depend on changes in international trade, production processes, or aggregate demand. This analysis considers that changes in gross production by sector can be broken down into changes in final demand and changes in the Leontief coefficients (see Appendix 4 for more methodological details).

First, the drivers of structural transformations in the Colombian economy between 2005 and 2014 can be identified (see Table 3) by assessing the impact of technological changes (**$\Delta\%A$**), substitution of imported inputs for domestic inputs (**$-\Delta\%Am$**), and changes in production due to variations in final demand (**$\Delta\%y$**). The change in technology, denoted by **$\Delta\%A$**, shows a decrease in the Leontief technological coefficients by 0.9 percentage points (pp) over the entire period. This suggests a marginal technological advancement or a slow pace of improvement in production processes. In terms of import substitution, indicated by **$-\Delta\%Am$**, there is a slight negative impact on economic growth, with a reduction of 1.9 pp over the period. This implies that the increase in the import of inputs has slightly outpaced the growth of domestic inputs in the production process, potentially indicating a shift towards globalisation or a dependence on foreign materials and components. Therefore, changes in input coefficients—resulting from the combined effect of technological changes and the substitution of imported for domestic inputs—had limited effects on Colombian production growth. The most significant factor that influenced production growth is the change in final demand (**$\Delta\%y$**), which contributed an increase of 37.7 pp to production over the observed period. This robust growth in final demand was a major driver of economic expansion, suggesting that consumption, investment, and government spending played pivotal roles in propelling the Colombian economy.

Table 3. ***Structural decomposition analysis, 2005–2014***

	2005–2010	2010–2014	2005–2014
Technological impacts ($\Delta\%A$)	-1.1 pp	0.0 pp	-0.9 pp
Import substitution ($-\Delta\%Am$)	0.3 pp	-2.2 pp	-1.9 pp
Final demand impacts ($\Delta\%y$)	21.8 pp	20.2 pp	37.7 pp
Total impacts ($\Delta\%x$)	**21.0 pp**	**18.0 pp**	**34.9 pp**

Source: Own calculations based on DANE.

Then, based on a granular examination of sector-specific contributions, the services sector was predominant in driving a gross production upsurge of 313.956 trillion pesos at 2014 prices (see Table 4), contributing to 50.5% of the increase, followed by the construction and civil works sector, which accounted for 13.8%. Manufacturing sectors, including the agribusiness, natural-resources-intensive, unskilled-labour-intensive, and high-technology-intensive sectors, cumulatively enhanced gross production by 17.7%, with the high-technology-intensive and agribusiness sectors leading this growth, demonstrating significant contributions of 9.9% and 4.1%, respectively. The agribusiness sector was distinguished by productivity-driven growth, in contrast to other sectors, where growth was mainly a function of increasing sectoral demand. While the agribusiness sector, together with the utilities and services sectors, registered positive technological advancements (Leontief coefficients), they were, however, somewhat neutralised by the substitution effect of intermediate goods.

Table 4. ***Structural decomposition by sector, 2005–2014 (billions of 2014 pesos and percentages)***

	Δ%A		- Δ%Am		Δ%Y		Δ%X	
Agriculture	19.9%	-1,605	6.0%	-1,042	3.2%	10,878	2.6%	8,231
Mining	6.9%	-555	9.9%	-1,709	7.4%	24,962	7.2%	22,698
Agribusiness	-13.8%	1,115	14.3%	-2,469	4.2%	14,261	4.1%	12,906
Natural-resources-intensive	42.7%	-3,450	4.8%	-826	4.1%	13,756	3.0%	9,481
Unskilled-labour-intensive	27.1%	-2,187	5.8%	-1,003	1.6%	5,341	0.7%	2,151
High-technology-intensive	48.4%	-3,914	37.5%	-6,478	12.2%	41,491	9.9%	31,099
Utilities	-1.1%	92	1.4%	-233	2.5%	8,508	2.7%	8,366
Construction and civil works	7.1%	-576	0.2%	-28	12.9%	43,884	13.8%	43,281
Transport	11.7%	-947	-2.0%	339	5.3%	17,897	5.5%	17,289
Services	-48.8%	3,945	22.2%	-3,828	46.7%	158,337	50.5%	158,455
Total	**100%**	**-8,083**	**100%**	**-17,277**	**100%**	**339,317**	**100%**	**313,956**

Source: Own calculations based on DANE.

Table 5. ***Contribution to the change in gross production, 2005–2014***

	Δ%A	-Δ%Am	Δ%y
Agriculture	-19.5%	-12.7%	132.2%
Mining	-2.4%	-7.5%	110.0%
Agribusiness	8.6%	-19.1%	110.5%
Natural-resources-intensive	-36.4%	-8.7%	145.1%
Unskilled-labour-intensive	-101.7%	-46.6%	248.3%
High-technology-intensive	-12.6%	-20.8%	133.4%
Utilities	1.1%	-2.8%	101.7%
Construction and civil works	-1.3%	-0.1%	101.4%
Transport	-5.5%	2.0%	103.5%
Services	2.5%	-2.4%	99.9%
Total	**-2.6%**	**-5.5%**	**108.1%**

Source: Own calculations based on DANE.

Following the evaluation of minor technological progress and its limited impact on growth, the analysis turns to the economic effects of import substitution. This shift in focus unveils a significant trend within the Colombian economy towards an increased reliance on imported inputs over domestic ones, a movement that notably constrained gross production growth across all sectors, as detailed in tables 5 and 6. This substitution had a varied impact: it detrimentally affected unskilled-labour-intensive manufacturing, with a 60.3% decrease in output following the 2008 recession (contraction in external demand), yet it benefited high-tech industries initially, with a 22.9% positive effect (see Table 6). As a result, the production chains of the unskilled-labour-intensive sectors were significantly affected. However, from 2010 to 2014, this trend intensified, reducing overall output by 6.9%, with high-tech manufacturing sectors experiencing a substantial decline in production of 43.7%, while the unskilled-labour-intensive sectors grew by 13.7%.

Table 6. ***Impact of the substitution between imported and domestic inputs on output***

	2005–2010	2010–2014	2005–2014
Agriculture	-25.6%	13.0%	-12.7%
Mining	-2.0%	-5.5%	-7.5%
Agribusiness	-15.7%	-3.5%	-19.1%
Natural-resources-intensive	3.3%	-12.0%	-8.7%
Unskilled-labour-intensive	-60.3%	13.7%	-46.6%
High-technology-intensive	22.9%	-43.7%	-20.8%
Utilities	4.8%	-7.6%	-2.8%
Construction and civil works	0.0%	-0.1%	-0.1%
Transport	6.7%	-4.7%	2.0%
Services	-0.4%	-2.0%	-2.4%
Total	**1.4%**	**-6.9%**	**-5.5%**

Source: Own calculations based on DANE.

The sector-specific insights shed light on the critical roles of the services and construction sectors, among others, in fuelling economic growth. Highlighting the diversity of growth drivers, these findings lay the groundwork for a discussion on the impacts of these shifts on Colombia's economic landscape. Its evolution through 2005 to 2014 was marked by sector-specific responses to both domestic policies and international market dynamics. The observed changes in inputs and sectoral dynamics offer insights that can be interpreted through complementary explanations, reflecting the nuanced interplay between internal policy decisions and external economic forces: the first related to free trade agreements and the second to the international context over that time span. Regarding the former, in 2012, free trade agreements began with Canada, the United States, and Europe, which opened up the possibility of selling new products to these markets. The sale of products in these markets requires that the inputs be of a higher quality or meet certain standards, which cannot be obtained on the domestic market; therefore, there is a substitution of imported inputs for domestic inputs. As pointed out by Hernández (2015), Colombia's exports are primarily low value-added products such as oil and coal, and industrial exports are declining due to the reduction of trade with Venezuela and the economic recession that decreased the purchase of Colombian products abroad.

The SDA therefore shows that gross production growth was driven by demand, but that it was limited by technological change and import substitution. It also found that an industrial restructuring process took place, as the scope of intersectoral demand expanded in the high-tech and agribusiness sectors but shrank in the low capital-intensive industries (unskilled-labour-intensive and natural-resources-intensive). On this last point, we must mention how those changes could be due to technological innovations, an increase in the benefits obtained from economies of scale, changes in product mix, variation in relative prices, or changes in trade patterns.

2. Sectoral perspectives on Colombia's climate transition: Assessing economic vulnerabilities and emerging opportunities

Taking a prospective stance now, it is probable that Colombia, like every other country in the world, will have to transition towards a low-carbon economy. As it does so, it could face various obstacles, considering its present economic behaviour and trade practices. Such challenges stem from the nation's established production frameworks and its role in international trade, both of which rely significantly on industries that have high carbon footprints. This section will examine how industries can navigate this transition, aiming to identify avenues for resilience and uncover Colombia's current macroeconomic vulnerabilities and the potential opportunities, risks, and/or tensions emerging from this transition.

2.1. Analysing Colombia's economic exposure to the low-carbon transition based on MRIO

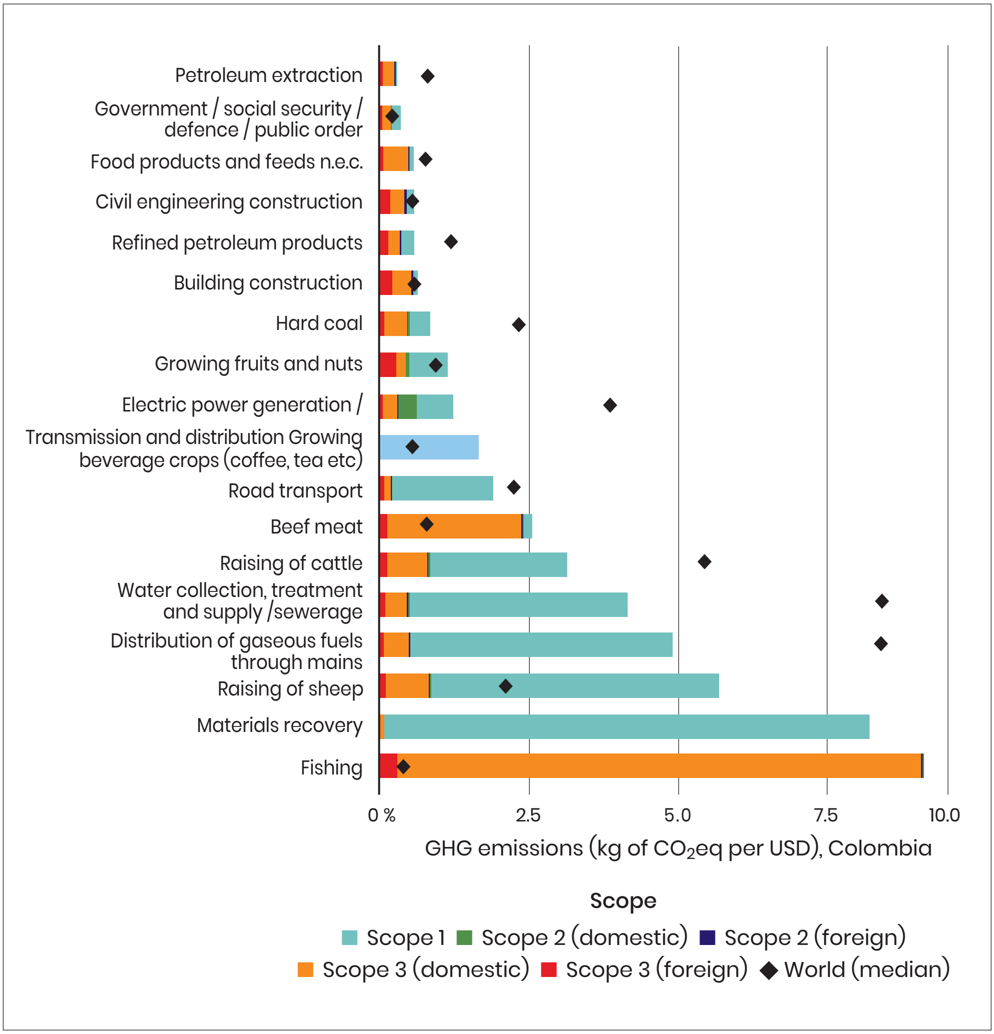
Magacho *et al.* (2023) developed a macroeconomic framework, called ESTEEM,[37] to analyse countries' dependences on identified sunset industries using an environmentally extended multi-regional input-output (MRIO) dataset. In this framework, the authors calculate, based on industrial interlinkages, countries' direct and indirect dependence on carbon-intensive industries in three dimensions: external, fiscal, and socioeconomic. These dependences are computed as the share of foreign currency, fiscal revenue, wages, and employment that depends

37 Exposure to Structural Transition in an Ecological-Economic Model.

directly or indirectly on industries that will either shrink due to a reduction in world demand, such as fossil fuels, or will need to be replaced by other technologies to reduce GHG emissions, such as iron, steel, and cement. The approach is replicated here for the case of Colombia using a new environmentally extended MRIO, called Gloria; see Lenzen *et al.* (2022).

Figure 3 presents data on emission intensity per sector, particularly for Colombia's most emitting industries. It shows that the country is doing better than the world median (diamond points in the figure) in the majority of high-emitting industries. The few exceptions are in agriculture and food production (fruits and nuts, beverage crops, beef meat, raising of sheep, and fishing) and materials recovery. This has to do with the nature of the country's electricity production, which is based mostly on hydropower (70%). The division of emissions into scopes 1, 2, and 3—direct, indirect from energy, and other indirect, respectively—shows the relatively low importance of energy in other industries' emissions. Scope 2 emissions, which usually play an important role in other countries, are almost irrelevant for Colombia, and the electric power generation sector has an emission intensity about 70% below the world median. While, on a global scale, 79% of GHGs come from the energy sector and 22% from the agriculture, forestry, and other land uses (AFOLU) sector, in Colombia the ratio is reversed: 31% come from the energy sector (transport, energy industries, manufacturing and construction industries, fugitive emissions, fuel production) and 59% from the AFOLU sector, which is consistent with the data from IDEAM *et al.* (2021).

Figure 3. ***Breakdown of sectoral emission intensity by scope, most emitting industries***



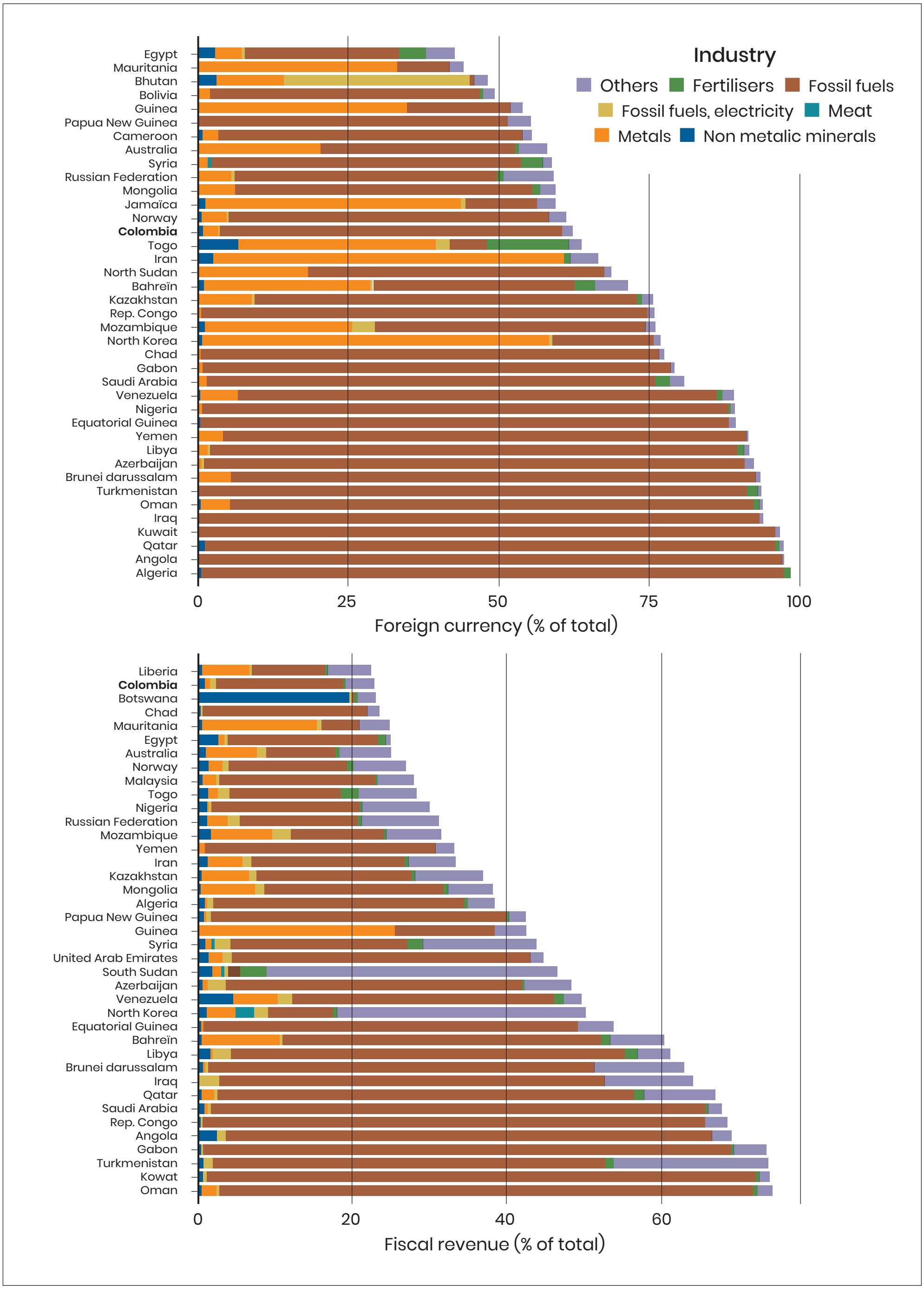
Source: Authors, based on Gloria MRIO (version 057 for 2021).

Despite presenting relatively low emission intensity in most sectors, this does not mean that Colombia is not exposed to the low-carbon transition. To be sure, the country's lower dependence on fossil fuels to generate electricity reduces this exposure, because it can produce energy-intensive goods and services while emitting less than many other countries. However, the dependence on fossil fuels and other emitting industries, particularly for exports but also for transport or heating, may constrain the country's capacity to embark on a fast and sustainable transition to a greener economy. This is particularly true considering the increasing domestic demand for petroleum-based fuels and the fact that primary energy consumption remains dependent on fossil fuels (36% oil, 23% gas, and 7% coal), in contrast with electricity, which is highly reliant on hydropower.

2.1.1. External and fiscal constraints

Fossil fuels, in particular coal and oil, play a major role in determining countries' exposure to the low-carbon transition, as shown in Figure 4, which presents the direct and indirect dependence of the most exposed quarter of countries on sunset industries in terms of net foreign currency and fiscal revenue. Even though metals such as iron, steel, and aluminium are relevant for some countries in terms of both foreign currency and fiscal revenue, the majority of highly exposed countries are dependent on oil and coal exports (as shown in Chapter 3 of this book) for their fiscal revenue. This is the case for Colombia, where about 60% of foreign currency revenue and 20% of fiscal revenue come directly from oil and coal. This dependence puts Colombia among the most exposed quarter of economies in both the external and fiscal dimensions.

Figure 4. ***Share of sunset industries in foreign currency and fiscal revenue (% of total)***



Note: Includes only the most exposed quarter of countries
Source: Authors, based on Gloria MRIO.

The dependence on coal and oil indicates that the country will have to diversify its economy to reduce the importance of carbon-intensive industries in order to avoid facing tensions in the fiscal, trade, and socioeconomic dimensions. This will require a structural shift away from these industries, taking into consideration an already fairly low-carbon electricity mix.

2.1.2. Socioeconomic vulnerability

In terms of socioeconomic exposure, we observe in Figure 5 that Colombia does not lie within the most exposed quarter of countries but is nonetheless close to them, indicating a certain degree of exposure, particularly in terms of wages. Because the coal and oil industries in Colombia are extremely capital-intensive, employment generation is not highly dependent on sunset industries in the country (only about 10% of jobs are directly or indirectly dependent on sunset industries). However, because these industries pay higher than average wages, Colombia is close to the most exposed countries when it comes to wages, with almost 20% of the wage bill depending on these industries.

Moreover, as one can see from the colour of the points, Colombia does not have a particularly high level of social protection, since the informality rate in Colombia is close to 60%. This means that while there is some level of social safety net—which could help mitigate the impact of declining industries on workers—it is far from comprehensive. Therefore, a significant portion of the workforce could be vulnerable to a low-carbon transition due to insufficient social protection mechanisms. Colombia would need to continue diversifying its economy and strengthening its social protection systems to reduce vulnerability to declining industries and ensure economic stability for its workforce.

Figure 5. ***Share of sunset industries in wages and employment (% of total)***

Note:The dashed lines mark out the most exposed quarter of countries;
SPC stands for social protection coverage; GVC means Global Value Chain.
Source: Authors, based on Gloria MRIO.

2.2. Building diversification strategies amid departmental production structure discrepancies

The impacts at the national level of a policy such as the gradual reduction of production in the coal and oil sectors tend to be relatively "minor," but with much greater effects proportionally at the regional level, which is why, in addition to determining its consequences at the national level, the impacts at the regional level must be considered. Thus, after analysing key fiscal, external, and socioeconomic vulnerabilities at a national scale, this section analyses the differentiated effect on departmental production of a halving of oil and coal production in order to understand how departmental production structure discrepancies might create higher vulnerabilities in specific locations. Sectors with potential for mitigating the undesired effects of a decarbonisation of the economy will be identified, highlighting potential areas for governmental intervention to offset reliance on the extractive sector.

During most of the 1980s and especially in the 1990s, both the oil and coal sectors played a major role in the growth of the Colombian economy (see Chapter 1). The departments where oil reserves were discovered and coal mining began contributed positively to GDP growth, but this has been decreasing over time (see Table 7) in response to changes and diversification in the economic structure, both at the sectoral and regional levels (Hernández *et al.*, 2022).

Table 7. ***Importance of departments intensive in extractive sectors, 1990–2019***

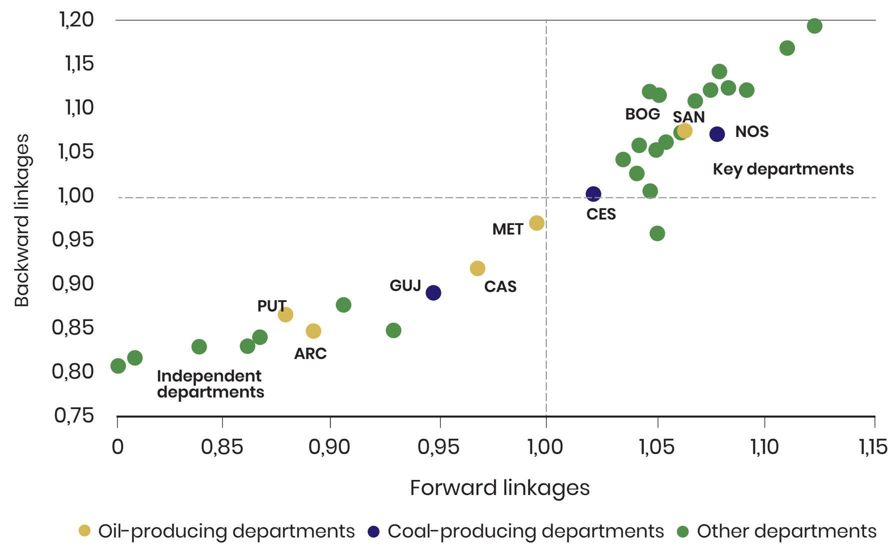
	1991–2000		2001–2010		2011–2019	
Departments	Departments' ranking[1]	Contribution to growth[2]	Departments' ranking[1]	Contribution to growth[2]	Departments' ranking[1]	Contribution to growth[2]
Coal-producing departments						
Cesar	6	+	7	+	6	+
La Guajira	9	+	17	-	28	-
Norte de Santander	23	-	22	-	27	-
Oil-producing departments						
Casanare	1	+	31	-	7	+
Santander	2	+	4	+	21	-
Putumayo	4	+	28	-	15	-
Meta	5	+	2	+	2	+
Arauca	31	-	6	+	33	-

1 *A higher number means a higher share of GDP* 2 *Average over the decade*
Source: DANE and own calculation.

Transitioning from this historical context to the present, the disparity in economic contribution becomes starkly evident when examining the latest data from DANE (2023).

The substantial 48.5% contribution to national GDP by Bogotá, Antioquia, and Valle del Cauca contrasts sharply with the smaller combined contribution of less than 20% from the eight departments focused on coal and oil (5.7% and 11.3% respectively). This discrepancy echoes Figure 6, which shows the limited economic interconnection of the extractive sectors in comparison to the dynamic interlinkages and growth that characterise Bogotá's economic profile, highlighting significant regional GDP per capita disparities in Colombia. Indeed, when observing the interrelation of the coal- and oil-producing departments with the rest of the departments, it is found that the production structure of most of the departments that engage intensively in the extractive sectors is below the average of the economy (located in the lower left quadrant), except Santander and Norte de Santander (located in the upper right quadrant).

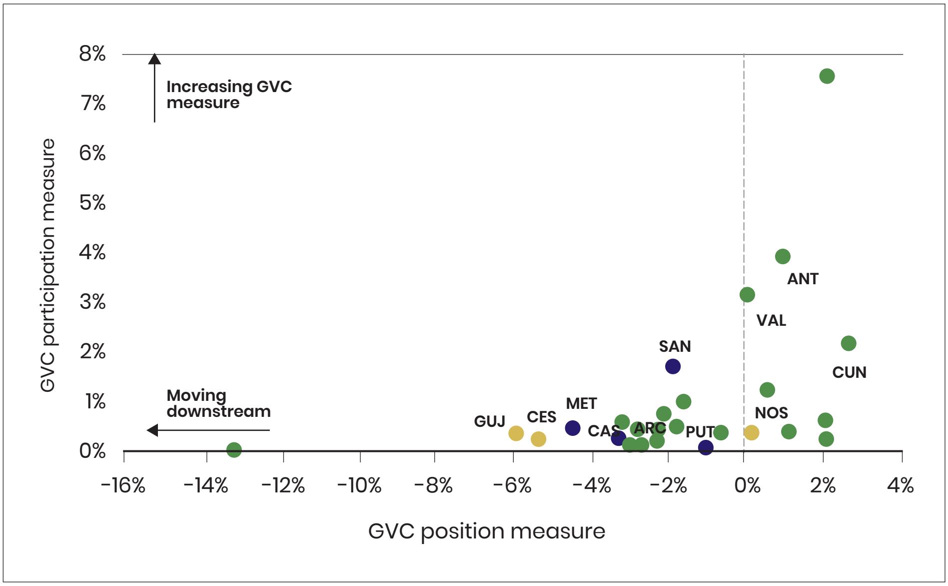
Figure 6. ***Departmental classification according to linkages, 2015***



Coal-producing departments: Cesar (CES), La Guajira (GUJ), and Norte de Santander (NOS). Oil-producing departments: Arauca (ARC), Casanare (CAS), Meta (MET), Santander (SAN), and Putumayo (PUT).
Source: Hernández et al. *(2022).*

A closer look at their relationships with other departments, as depicted in Figure 7, indicates that the oil- and coal-producing departments typically maintain negative interdepartmental trade balances, importing more from other departments than they export to them. Additionally, their participation in interdepartmental trade—the sum of exports and imports—remains minimal, with an average share of only 1.2%. This underscores the limited economic integration of these departments with the broader national economy, highlighting a critical area for policy focus to enhance their trade balance and integration.

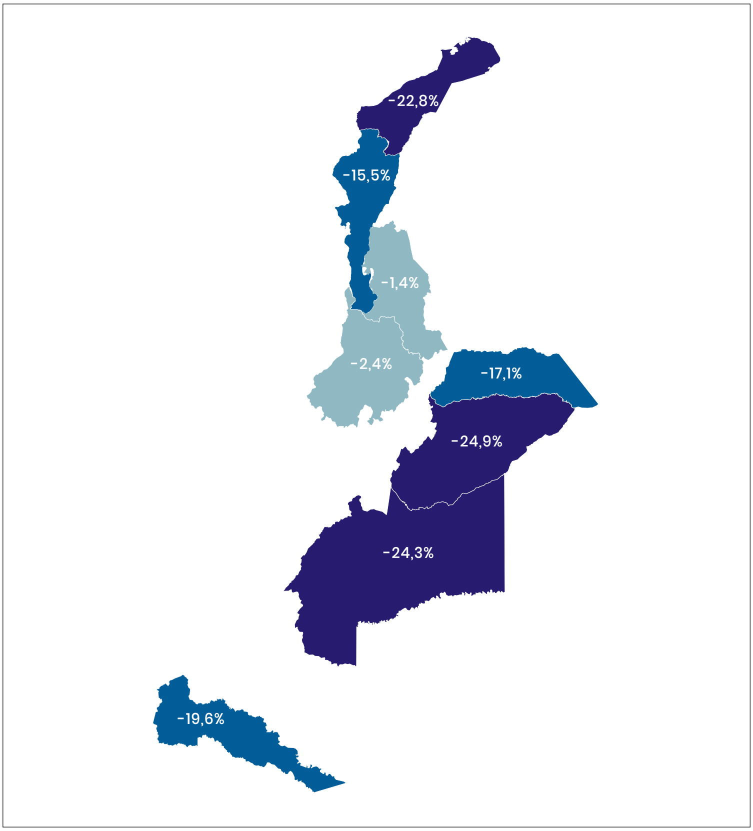
Figure 7. ***Interdepartmental trade, 2015***



Coal-producing departments: Cesar (CES), La Guajira (GUJ), and Norte de Santander (NOS).
Oil-producing departments: Arauca (ARC), Casanare (CAS), Meta (MET), Santander (SAN), and Putumayo (PUT).
Source: Hernández et al. *(2022).*

Figure 8, which represents the differentiated effect on departmental production of a halving of oil and coal production, shows that some departments (Casanare, -24.9%, Meta, -24.3%, and La Guajira, -22.8%) are more affected than others (Santander, -2.4%, and Norte de Santander, -1.4%). In departments where the oil and coal sectors constitute a significant portion of the production structure but that exhibit weak intersectoral and interdepartmental linkages, the repercussions of production shocks are more severe. This is contrasted with departments with more diversified production structures and reduced dependence on oil and coal production, which demonstrate greater resilience to such shocks.

Figure 8. ***Effects on departmental production of a halving of oil and coal production***



Coal-producing departments: Cesar, La Guajira, and Norte de Santander.
Oil-producing departments: Arauca, Casanare, Meta, Santander, and Putumayo.
Based on the departments that have information for the GEIH
(Gran Encuesta Integrada de Hogares; Great Integrated Household Survey).
Calculations based on a multi-regional input-output matrix.
Source: Garay et al. *(2023).*

The data also highlight that regions specialising in oil and coal extraction face significant reductions in aggregate production, with declines of -12.1% and -11.8%, respectively. This stands in contrast to a mere -0.6% reduction observed across other departments (Table 8). Two primary factors contribute to this disparity: first, the departments most impacted by these reductions lack substantial productive linkages with other regions, as noted by Hernández *et al.* (2022); second, the oil and coal sectors are predominantly oriented towards exportation, with minimal utilisation as intermediate inputs in domestic production processes.

These insights underscore the critical need for economic diversification and the strengthening of both intra- and interdepartmental connections to counter sector-specific downturns effectively. Enhancing sectors such as agriculture, agribusiness, and tourism could mitigate the adverse effects of economic decarbonisation.

Table 8. ***Regional effects of a halving of oil and coal production on departmental production***

		PRODUCTION INCREASE				
DEPARTMENTS	PRODUCTION REDUCTION	Agriculture (1)	Agribusiness (2)	Tourism (3)	(1) + (2)	(1) + (2) + (3)
Oil-producing	-12.1%	1.5%	3.2%	4.7%	2.0%	6.7%
Coal-producing	-11.8%	1.6%	3.4%	5.0%	4.1%	9.1%
Others	-0.6%	0.0%	0.1%	0.1%	0.1%	0.2%
Total	**-2.6%**	**0.2%**	**0.6%**	**0.8%**	**0.5%**	**1.3%**

Coal-producing departments: Cesar, La Guajira, and Norte de Santander.
Oil-producing departments: Arauca, Casanare, Meta, Santander, and Putumayo.
Calculations based on a multi-regional input-output matrix.
Source: Garay et al. *(2023).*

In Table 8, the projected economic impact of a 50% boost in the agriculture, agribusiness, and tourism sectors is again analysed using a multi-regional input-output matrix, focusing on departments reliant on extractive industries. As stated before, the oil-producing departments of Casanare, Santander, Putumayo, Meta, and Arauca face a significant challenge as they seek to mitigate a 12.1% drop in production due to the decline in the extractive sectors. In the light of this observation, the anticipated growth in the agriculture, agribusiness, and tourism sectors offers some relief, reducing the impact to a 6.7% reduction. The situation does not appear more promising for coal-producing departments like Cesar, La Guajira, and Norte de Santander. The boost in alternative sectors could not substantially offset an initial 11.8% fall in production, tapering it down to about 9.1%. Meanwhile, the “others” category shows a marginal production decline of 0.2%, indicating a more robust inherent economic resilience.

Diversification through an agricultural production boost holds particular significance for the Caribbean region. Notable crops in this region include cotton, particularly in the valleys of the Sinú River and Cesar, plantain and bananas in the Urabá region of Antioquia, African palm in the mid-stream part of the Magdalena River, and rice along the Atlantic Coast. Moreover, semi-intensive livestock farming is prevalent in the departments of Magdalena, Cesar, Sucre, and the central and northern parts of Córdoba. This agricultural wealth presents an opportunity for some oil- and coal-producing departments (especially Cesar, La Guajira, and Putumayo) to diversify their economies, although low coverage of irrigation and drainage systems in these areas could remain a challenge (Lozano-Espitia and Restrepo-Salazar, 2016).

While the agribusiness sector appears as a particularly effective economic stabiliser, capable of adding significant value to agricultural products, tourism can also be key in the diversification process. Growth in the tourism sector has the greatest single effect on mitigating the impact of falls in production in oil- and coal-producing departments. Nevertheless, the aggregate positive effect of boosting all three sectors—agriculture, agribusiness, and tourism—produces a more significant mitigating effect than any single sector alone.

Hence, Colombia's economic strategy should address the vulnerabilities inherent in its extractive sectors while proactively enhancing the potential of the agriculture, agribusiness, and tourism sectors. As highlighted by Mejía *et al.* (2021), focusing on these sectors not only exploits Colombia's distinctive environmental assets in order to give it a global competitive advantage, but it also strategically diversifies the economy away from an overdependence on fluctuating extractive industries like oil and coal. This dual approach is crucial for Colombia to navigate the challenges of global commodity market volatility and ensure long-term economic stability and growth.

3 Future perspectives and policy recommendations: Towards a sustainable industrial strategy

3.1. Conclusions

This chapter explores the structural dynamics of the Colombian economy, juxtaposing its historical underpinnings with the contemporary thrust towards a sustainable low-carbon future from the sectoral and departmental perspectives. To this end, it employs structural decomposition analysis (SDA) and an input-output analysis to estimate indicators such as sectoral linkages and economic complexity, among others.

Findings from the empirical investigation reveal that there was a structural change in the Colombian economy, but that it differed greatly between sectors. While sectors such as agriculture, construction, and transport experienced minimal changes, the industrial sector exhibited a distinct and dynamic transformation. This variation is largely due to international economic influences, emphasising the crucial role of substituting imported with domestic inputs in the SDA. It assumes that the impact of technological change is underestimated without this substitution, particularly for the industrial sector. Consequently, this led to the weakening of production chains, as evidenced by the decline in the economy's complexity index.

Moreover, the SDA shows that gross production growth was driven by demand, but that it was limited by technological change and import substitution. It also found that an industrial restructuring process took place, as the scope of intersectoral demand expanded in the high-technology and agribusiness sectors but shrank in low capital-intensive industries (unskilled-labour-intensive and natural-resources-intensive). On this last point, we must mention how those changes could be due to technological innovations, an increase in the benefits obtained from economies of scale, changes in product mix, variation in relative prices, or changes in trade patterns.

Furthermore, the SDA indicates that demand factors primarily propelled gross production growth, which was nevertheless constrained by technological advancements and the dynamics of import substitution. Additionally, evidence suggests an industrial restructuring process, characterised by an expansion of intersectoral demand within the high-technology and agribusiness sectors, contrasted by a contraction in sectors with lower capital intensity (notably those reliant on unskilled labour and intensive in natural resources). This observation underscores the need to consider a range of potential factors, including technological innovations, increased efficiencies derived from economies of scale, shifts in product mix, fluctuations in relative prices, or alterations in trade patterns.

Focusing on Colombia's current direct and indirect dependences on industries vulnerable to global demand shifts and GHG emissions reduction imperatives, the analysis also shows that the country is exposed to fiscal, external, and socioeconomic transition risks. Despite its relatively low emission intensity across most sectors, thanks to its hydro-powered electricity generation, the country needs to mitigate this exposure.

This exposure varies depending on the production structures of different Colombian departments. Strategies for Colombia to diversify its economy are explored, focusing in particular on reducing dependence on the oil and coal sectors. Historical reliance on these sectors has significantly contributed to GDP growth, but with the current push for decarbonisation, it is crucial to identify alternative sectors that can mitigate the adverse effects of reducing fossil fuel production. Analysis shows the need to strengthen interdepartmental trade and productive linkages. Strategies include bolstering sectors like agriculture, agribusiness, and tourism, which have the potential to offset the economic impacts of transitioning away from carbon-intensive industries. The data suggest that departments that are more reliant on oil and coal are at risk of larger economic downturns, emphasising the importance of diversifying towards sectors that can provide stable growth and resilience against sector-specific shocks. Investing in agriculture and tourism, for example, not only leverages Colombia's natural and cultural assets but also supports broader economic stability. This approach aligns with the goal of navigating commodity market volatility and securing long-term economic prosperity.

3.2. Recommendations

In addressing Colombia's shift towards a low-carbon economy, the push for green reindustrialisation emerges as a strategic priority. Given the structural changes and interdependencies observed from 2005 to 2014, past trends in sectoral evolution, including the marginal strengthening of backward linkages in key sectors, and the impacts of the "Dutch disease" (Corden and Neary, 1982), diversification away from an over-reliance on commodities is crucial, as also highlighted in Chapter 3 of this book.

This process aims to design a holistic policy framework that not only fosters regional integration but also merges with the nation's strategic diversification efforts. Investments in infrastructure, workforce development, and innovation incentives are therefore needed to foster Colombia's economic integration into global value chains. These investments also serve as a foundation for addressing the issue of diminishing connections in tradable sectors, such as agriculture. By strengthening the infrastructure and enhancing workforce skills and innovation, Colombia can improve the connectivity between its tradable sectors and those with significant forward linkages, like the energy sector. This approach ensures that advancement in one sector facilitates growth and stability across others, thereby creating a more interconnected and robust economic landscape.

Additionally, the processing of agricultural materials and the production of high-tech industrial goods and certain services appear as sectors with dynamic linkages and the potential to spearhead economic reactivation. Garay *et al.* (2012) especially underscore the promotion of agribusiness and the implementation of employment buffer policies through intensive public investment. These sectors, alongside the energy industry, are therefore identified as vital for long-term sustainable growth. Notably, the food, beverage, and other agricultural processing industries stand out as significant employment generators. However, their reliance on agriculture and livestock, major sources of GHG emissions, calls for innovative adaptation strategies in their production processes, as well as cross-sectoral policies to refine the productive processes of their inputs. Furthermore, if policy makers wish to balance the contributions made by the increase in final demand with stimulus for technological change to promote economic growth, incentives need to be provided for those changes to take place. In this context, initiatives such as policies for improving business logistics (Technical report of the Misión de Logística y Comercio Exterior,2017) or sustainable growth (Departamento Nacional de Planeación, 2019) are important for innovation and for creating a more business-friendly environment.

Region-specific strategies are also essential for recognising the heterogeneous economic profiles across Colombia's departments. Tailored policies are required to match the needs and opportunities within each locality. Enhancing interdepartmental trade and economic integration can also offset vulnerabilities and promote resilience against global market shifts in energy demand. Such diversification efforts should be complemented by investments in human capital to ensure the workforce is capable of thriving in the evolving global and domestic economic landscape and the enhancing of social protection mechanisms to support a stable and equitable transition to a greener economy.

4. Appendices

Appendix 1. Estimating linkages and identifying key sectors

The Leontief input-output model assumes that output is determined by final demand and that there is no constraint regarding the volume of production. Final demand is composed of consumption expenditure by households and government, investment, and exports. We thus have:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y} \tag{1}$$

where $\mathbf{x}$ represents the total gross production vector, $\mathbf{A}$ is the matrix of technical coefficients, where each element $(a_{i,j})$ is the amount of input j that sector i requires to produce a unit of its product, and $\mathbf{y}$ is the vector of final demand.

Analogously to the Leontief model, which focuses on upstream relations, the Ghosh input-output model seeks to analyse the forward linkages of the economy. Given a matrix of allocation coefficients, $\mathbf{B}$, which presents for each product the destination of the total output for intermediate consumption, one can estimate how sectoral production propagates throughout the economy. Total production is then obtained as the sum of inputs used for intermediary consumption and value added:

$$\mathbf{x'} = \mathbf{x'B} + \mathbf{v'} \qquad (2)$$

where $\mathbf{B}$ is the matrix of allocation coefficients, each element (b_{ij}) is defined as the interindustry flows from an industry i to an industry j per gross output of i, and $\mathbf{v}$ is the vector of value added.

From equations (1) and (2), it is possible to construct the basic matrices, making necessary transformations, for calculating linkages and the key sectors of the economy. These matrices are: $\mathbf{A}$, $\mathbf{M}$, $\mathbf{B}$, and $\mathbf{G}$, defined in Table 1.

Table 1. ***Matrices transformations, adapted from Miller and Blair (2009)***

Leontief model	Technical coefficients	$\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$
	Leontief inverse	$\mathbf{M} = (\mathbf{I} - \mathbf{A})^{-1}$
Ghosh model	Ghosh matrix	$\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{Z}$
	Ghosh inverse	$\mathbf{G} = (\mathbf{I} - \mathbf{B})^{-1}$

The linkages generally used are those proposed by Rasmussen (1957), which capture the direct and indirect linkages in an economy. The sum of the columns of the Leontief inverse ($\mathbf{e}^T\mathbf{M}$, where $\mathbf{e}$ is a line-vector of ones) measures the backward linkages, while the forward linkages can be defined as the sum of the rows of the Ghosh inverse ($\mathbf{Be}$). In economic terms, backward linkages measure how much a sector pulls the economy, i.e., how much an increase in production in sector j leads to an increase in production in the other sectors of the economy. Forward linkages on the other hand reflect how much a sector is a supplier for other sectors in the economy, i.e., how much an increase in production in the other sectors of the economy allows for an increase in production in sector j.

A normalisation of these linkages is carried out to find the key sectors of the economy. The normalisation of backward linkages is $\frac{ne^TM}{e^TMe'}$, where n is the number of sectors in the economy, which produces a row vector whose average value is unity, so that the sectors with "above average" backward linkages have indices greater than one and those with "below average" linkages have indices less than one. In the same way, we can normalise and analyse forward linkages, that is, $\frac{n\boldsymbol{Ge}}{\mathbf{e}^T\boldsymbol{Ge}}$. Dietzenbacher (1992) shows that the eigenvector procedure is superior to classical procedures such as those proposed by Chenery and Watanabe (1958) and Rasmussen (1957), since it can find more robust estimates of the linkages and is capable of detecting structural changes. Dietzenbacher showed that the backward (resp. forward) linkage is the result of the procedure that converges to the eigenvector to the left (resp. right) of the matrix $\mathbf{A}$ (resp. $\mathbf{B}$), which is denoted $\mathbf{u}$ (resp. $\mathbf{z}$). Their respective normalisations are $\frac{vu^T}{u^Te}$ and $\frac{vz^T}{z^Te}$.

Hirschman (1958) suggested that key sectors have high backward and forward linkages (above one when normalised). Table 2 classifies sectors by the value of their index (less than or greater than one).

Table 2. ***Classification of intersectoral linkages***

		TOTAL FORWARD LINKAGE	
		Low (< 1)	High (>1)
Total backward linkagel	Low (< 1)	Weak linkages (LL)	Strong forward linkages (SFL)
	High (>1)	Strong backward linkages (SBL)	Key sectors (KS)

Source: Authors. Adapted from Miller and Blair (2009).

Appendix 2. Spearman's rank correlation of linkages

Spearman's rank correlation - dietzenbacher linkages

Table 1. ***Backward linkages***

	2005	2010	2014
2005	1.0000		
2010	0.9030*	1.0000	
2014	0.8597*	0.9240*	1.0000

** 99.0% confidence interval.*

Table 2. ***Forward linkages***

	2005	2010	2014
2005	1.0000		
2010	0.8527*	1.0000	
2014	0.8528*	0.9193*	1.0000

** 99.0% confidence interval.*

Appendix 3. Measuring economic complexity via average propagation lengths

One could see the degree of sectoral interaction of intermediate production as a measure of the complexity of an economy. Dietzenbacher *et al.* (2005) propose another measure by constructing an indicator of the economic distance between sectors. Distance is intended as the number of steps required for a shock to propagate from sector i to sector j. This allows us to obtain a measure of the time and cost of the adjustment and, consequently, of the complexity of the system: the average propagation length (APL). Dietzenbacher *et al.* (2005) show that APL can be calculated, from the demand side,[38] as:

$$APL_{i,j} = \begin{cases} \dfrac{h_{i,j}}{m_{i,j}} & \text{for } i \neq j. \\ \dfrac{h_{i,j}}{m_{i,j}-1} & \text{for } i = j. \end{cases}$$

where $h_{i,j}$ is an element from $\mathbf{H} = \mathbf{M}(\mathbf{M}-\mathbf{I})$ and $m_{i,j}$ is an element from $\mathbf{M}$.

As pointed out (Romero *et al.*, 2009), the element $APL_{i,j}$ indicates the average propagation length of a demand-pull (directed backward) from sector j to sector i and, at the same time, a cost-push in sector i (directed forward) to affect the output value in sector j. This implies that when considering the distance from one sector of the economy to another, the averages are taken into account and two perspectives can be used, forward or backward.

38 The same result is achieved if the indicator is calculated from the supply side (Dietzenbacher *et al.*, 2005).

The forward average APL is defined as:

$$FA_i = \frac{1}{n}\sum_{j=1}^{n} APL_{i,j}$$

while the backward average APL is defined as:

$$BA_j = \frac{1}{n}\sum_{i=1}^{n} APL_{i,j}$$

Finally, Romero *et al.* (2009) define a complexity index (CI) to measure the complexity of the production system, given by the following expression:

$$CI = \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n} APL_{i,j}$$

$$= \frac{1}{n}\sum_{i=1}^{n} FA_i = \frac{1}{n}\sum_{j=1}^{n} BA_j$$

Appendix 4. Structural decomposition analysis (SDA)

Structural decomposition analysis (SDA), proposed in Magacho *et al.* (2018), is used to identify the determinants of the change in production growth. This approach allows us to see whether changes in production depend on changes in international trade, changes in production processes, or changes in aggregate demand.

Structural decomposition analysis (SDA) considers that changes in gross production by sector can be broken down into changes of final demand and changes in the Leontief coefficients. Following the SDA method proposed by Miller and Blair (2009), we consider the basic Leontief model for two years (0 and 1). The gross production ($\mathbf{x}$) in year t is:

$$\mathbf{x}^0 = \mathbf{M}^0\mathbf{y}^0 \quad (1)$$

$$\mathbf{x}^1 = \mathbf{M}^1\mathbf{y}^1 \quad (2)$$

The changes seen in gross production are given by:

$$\Delta\mathbf{x} = \mathbf{x}^1 - \mathbf{x}^0 = \mathbf{M}^1\mathbf{y}^1 - \mathbf{M}^0\mathbf{y}^0 \quad (3)$$

We can rearrange the above-mentioned equation in order to see the changes in $\mathbf{M}$ and $\mathbf{y}$ and their effects on $\Delta\mathbf{x}$, which can be done in two different ways:

$$\Delta\mathbf{x} = \mathbf{M}^1(\mathbf{y}^0 + \Delta\mathbf{y}) - (\mathbf{M}^1 + \Delta\mathbf{M})\,\mathbf{y}^0 = \Delta\mathbf{M}\mathbf{y}^0 + \mathbf{M}^1\Delta\mathbf{y} \quad (4)$$

$$\Delta\mathbf{x} = (\mathbf{M}^0 + \Delta\mathbf{M})\mathbf{y}^1 - \mathbf{M}^0(\mathbf{y}^1 - \Delta\mathbf{y}) = \Delta\mathbf{M}\mathbf{y}^1 + \mathbf{M}^0\Delta\mathbf{y} \quad (5)$$

Both expressions break down the change in production into a part attributable to technological change $\Delta\mathbf{M}$ and a part attributable to changes in final demand $\Delta\mathbf{y}$. Despite the fact that the two equations are mathematically equivalent, they are not equivalent in economic terms, since in the equation (4) $\Delta\mathbf{M}$ is weighted by $\mathbf{y^0}$ and $\Delta\mathbf{y}$ is weighted by $\mathbf{M^1}$. Something similar occurs in the equation (5), where $\Delta\mathbf{M}$ is weighted by $\mathbf{y^1}$ and $\Delta\mathbf{y}$ is weighted by $\mathbf{M^0}$. According to Dietzenbacher and Los (1998), we must add the last two equations, leading to:

$$\mathbf{2\Delta x = \Delta M y^0 + M^1 \Delta y + \Delta M y^1 + M^0 \Delta y}$$

or

$$\mathbf{\Delta x} = \frac{1}{2}\underbrace{\mathbf{\Delta M\ (y^0 + y^1)}}_{\text{technological change}} + \frac{1}{2}\underbrace{\mathbf{(M^0 + M^1)\Delta y}}_{\text{final demand}}$$

The change in production is therefore an average between technological change and changes in final demand.

As shown by Loiola and Aparecida (2016), the calculation is based on the changes in the Leontief matrix. Thus, the effect of technological change shows how the linkages between the sectors vary (weakening or strengthening of the link). The factors that explain this technological change include: innovations, import substitution, an increase in the benefits obtained from economies of scale, changes in the product mix (with the adoption of new inputs or complementary inputs in the production process), variation in relative prices (given that technical coefficients in the Leontief matrix arise from monetary valuation), and changes in trade patterns (exports and also import substitution). Although they can be calculated (Schuschny,2005), the model does not contain information to identify and analyse its causes.

In accordance with Magacho *et al.* (2018), the changes in the Leontief matrix can be partitioned into technological change and substitution between imported and domestic goods.[39] Given that $\mathbf{M^1 = (I - A_d^1)^{-1}}$, where $\mathbf{A}_d$ is the direct domestic coefficients matrix, we thus have:

$$\begin{aligned}
\mathbf{M^1(I - A_d^1)} &= \mathbf{(I - A_d^1)^{-1}(I - A_d^1)} \\
\mathbf{M^1(I - A_d^1)} &= \mathbf{I} \\
\mathbf{M^1 - M^1 A_d^1)} &= \mathbf{I} \\
\mathbf{M^1 - 1} &= \mathbf{M^1 A_d^1} \\
\mathbf{M^1 M^0 - M^0} &= \mathbf{M^1 A_d^1 M^0}
\end{aligned}$$

39 Hereinafter, subscript d indicates that the matrix or vector contains domestic goods, and subscript m that the matrix or vector contains imported goods.

In the same way, given that $\mathbf{M}^0 = (\mathbf{I} - \mathbf{A}_d^0)^{-1}$, we can reorder it as:

$$\begin{aligned} (\mathbf{I} - \mathbf{A}_d^0)\mathbf{M}^0 &= (\mathbf{I} - \mathbf{A}_d^0)(\mathbf{I} - \mathbf{A}_d^0)^{-1} \\ (\mathbf{I} - \mathbf{A}_d^0)\mathbf{M}^0 &= \mathbf{I} \\ \mathbf{M}^0 - \mathbf{A}_d^0\mathbf{M}^0 &= \mathbf{I} \\ \mathbf{M}^0 - \mathbf{I} &= \mathbf{A}_d^0\mathbf{M}^0 \\ \mathbf{M}^1\mathbf{M}^0 - \mathbf{M}^1 &= \mathbf{M}^1\mathbf{A}_d^0\mathbf{M}^0 \end{aligned}$$

We thus have:

$$\begin{aligned} \mathbf{M}^1\mathbf{M}^0 - \mathbf{M}^0 - (\mathbf{M}^1\mathbf{M}^0 - \mathbf{M}^1) &= \mathbf{M}^1\mathbf{A}_d^1\mathbf{M}^0 - \mathbf{M}^1\mathbf{A}_d^0\mathbf{M}^0 \\ \Delta\mathbf{M} &= \mathbf{M}^1\mathbf{A}_d^1\mathbf{M}^0 - \mathbf{M}^1\mathbf{A}_d^0\mathbf{M}^0 \end{aligned}$$

Since the direct and indirect domestic coefficients matrix is the difference between the total direct and indirect technical coefficients matrix and the direct and indirect imported coefficients matrix $(\mathbf{A}_d^t = \mathbf{A}^t - \mathbf{A}_m^t)$, we thus have:

$$\Delta\mathbf{M} = \mathbf{M}^1[(\mathbf{A}^1 - \mathbf{A}_m^1) - (\mathbf{A}^0\mathbf{A}_m^0)]\,\mathbf{M}^0$$

Rearranging the decomposition of the Leontief matrix, between technological change[40] and substitution of domestic for imported intermediate consumption, we thus have:

$$\begin{aligned} \Delta\mathbf{M} &= \mathbf{M}^1[(\mathbf{A}^1 - \mathbf{A}_m^1 - \mathbf{A}^0 + \mathbf{A}_m^0]\,\mathbf{M}^0 \\ \Delta\mathbf{M} &= \mathbf{M}^1\Delta\mathbf{A}\mathbf{M}^0 - \mathbf{M}^1\Delta\mathbf{A}_{\mathrm{m}}\mathbf{M}^0 \end{aligned}$$

Thus, total production growth can be broken down into: *i*) technological change, *ii*) substitution of domestic and imported intermediate consumption, and *iii*) growth of final demand.

$$\Delta\mathbf{x} = \frac{1}{2}(\mathbf{M}^1\underbrace{\Delta\mathbf{A}\mathbf{M}^0)(\mathbf{y}^0}_{\text{technological change}} + \mathbf{y}^1) + \frac{1}{2}(\mathbf{M}^1(\underbrace{-\Delta\mathbf{A}_{\mathrm{m}})\mathbf{M}^0)}_{\text{substitution of domestic inputs}}(\mathbf{y}^0 + \mathbf{y}^1) + \frac{1}{2}\underbrace{(\mathbf{M}^0 + \mathbf{M}^1)\Delta\mathbf{y}}_{\text{final demand}}$$

40 In the SDA, technological change means changes in the coefficients of the input-output matrix but not necessarily technological growth. In other words, the SDA sees technological change as changes in the process of production.

Appendix 5. Sources and processing of the data

The indicators mentioned above were built based on Colombian data from 2005–2014. This period was chosen based on criteria of data availability, quality, and comparability. In order to build input-output matrices, following Miller and Blair (2009) and Eurostat (2008), we used supply and use tables for those years built by DANE. These matrices include a classification of 60 sectors based on data provided by the national accounts with base year 2005.

Since we are comparing several years and the data are in current prices, they must be deflated. We use 2014 as the base year, and we use the method known as "double deflation,"(Miller and Blair, 2009), which is a two-stage process. In a first stage, we deflate intermediate consumption, final demand, and gross production, using a price index for each sector calculated as an implicit deflator of gross production with a base in the national accounts of DANE. The price index for the 60 sectors in the national accounts is computed as follows:

$$\begin{aligned} I_{i,2005/2005} &= 100, \\ I_{i,2006/2005} &= I_{i,2005/2005} * GPg_{i,t} \\ I_{i,t/t-1} &= I_{i,t-1/t-1} * GPg_{i,t} \end{aligned}$$

Where $GPg_{i,t}$ is the annual growth rate of the deflator of gross production in i over the period t,i = 1, 2, ..., 60, and t = 2005, ..., 2014. The change of basis to the year 2014 was carried out in the following manner:

$$I_{i,2014/2014} = \frac{I_{i,2005/2005}}{I_{i,2014/2005}} * 100$$

We established a price index, π, spanning 60 sectors. Subsequently, we adjusted the values for intermediate consumption, final demand, and gross production to account for inflation.

$$\pi^t = \begin{bmatrix} I_{1,t} \\ \vdots \\ I_{61,t} \end{bmatrix}$$

$$\begin{aligned} \mathbf{A}_t^{deflated} &= \hat{\pi}_t \mathbf{A}_t \\ \mathbf{y}_t^{deflated} &= \hat{\pi}_t \mathbf{y}_t \\ \mathbf{x}_t^{deflated} &= \hat{\pi}_t \mathbf{x}_t \end{aligned}$$

The second stage consists in calculating a price index to deflate value added.[41] We thus determine the deflator that ensures that the deflated value added $\boldsymbol{v}_t^{def}$ def is still consistent with deflated gross production $\mathbf{x}_t^{def}$ and the deflated interindustry matrix $\mathbf{A}_t^{deflated}$, that is[42]:

$$(\boldsymbol{v}_t^{deflated})^{\mathsf{T}} = (\mathbf{x}_t^{deflated})^{\mathsf{T}} - \epsilon^{\mathsf{T}}\mathbf{A}_t^{deflated}$$

41 An alternative to calculate this deflator of value added is $\hat{\pi}_t^{deflated} = \hat{\boldsymbol{v}}_t^{deflated}(\hat{\boldsymbol{v}}^t)^{-1}$.

42 According to Miller and Blair (2009), the double deflation method has many disadvantages for deflating input-output matrices, since all elements in the rows of the transaction matrix are deflated by the same index. They point out that prices among industries can shift considerably in many economies, thus the deflation for the same index could be incorrect. We nonetheless decided to use this method due to the lack of any other methodology and because it is widely used.

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Empirical appendix of the GEMMES Colombia model

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Empirical appendix of the GEMMES Colombia model

Introduction

This empirical appendix describes the process of developing the empirical transaction-flow matrix of the GEMMES Colombia model. To do so, the document is structured as follows. Section 1 depicts the accounting structure of the model that has to be matched with actual data. Section 2 describes the main data sources used throughout the exercise. Section 3 details the procedures, data harmonisation, and assumptions undertaken to build the empirical TFM, and section 4 presents some additional remarks. Lastly, section 5 concludes.

1. Accounting structure

For the ease of readability, the transaction-flow matrix (TFM hereinafter) and the balance sheet (BS hereinafter) of the GEMMES Colombia model are presented again below. Each row represents a real or financial flow in the case of the TFM and a financial or non-financial asset in the case of the BS. For both matrices, each column corresponds to one of the six main institutional sectors according to the System of National Accounts terminology: non-financial corporations (NFCs hereinafter), households, financial corporations (FCs hereinafter), the central bank, the general government, and the rest of the world (RoW hereinafter).

The TFM (see Table 1) shows the main real and financial transactions that take place between the institutional sectors in the economy. The transactions (i.e., the rows) of the TFM are divided into three main blocks, separated by solid lines. The first part of the TFM presents the non-financial transactions, for which a positive sign (+) represents receipts and a negative sign (-) represents outflows. As in the sequence of the System of National Accounts, the sequence of non-financial transactions is grouped into three accounts delimited by dotted lines: the goods and services account, the income generation and primary income distribution account, and the secondary income distribution account.

The sum of these non-financial transactions leads to the net lending/borrowing position of each institutional sector, represented only for the three agents for which there is an explicit distinction between the current and capital accounts (represented by the retained earnings line). For the three other agents (households, government, and rest of the world), the savings/borrowing needs are implicit. Subsequently, the second part of the TFM shows the accumulation of non-financial assets, i.e., capital and inventories, represented as memo items within square brackets. The third part of the TFM represents the flow of financial funds for each agent, in which a positive sign (+) indicates an accumulation of liabilities (i.e., a source of funding) and a negative sign (-) indicates an accumulation of assets (i.e., a use of funds).

The TFM highlights a tight accounting structure by showing that, on the one hand, each line sums up to zero, ensuring that each expenditure by an institutional agent is matched by an income for an institutional agent (possibly the same). Note that the only transactions where this rule is not respected refers to the memo items of non-financial assets accumulation. On the other hand, the sum of each column, including the current and capital ones, is also equal to zero, representing the budget constraints faced by all the institutional agents.

Finally, the BS (see Table 2) displays the stocks of financial and non-financial assets resulting from the investment and financing decisions shown in the capital and bottom part of the TFM. The first part of the BS presents the stocks of non-financial assets constituted by the stock of capital and inventories. The second part of the BS shows the financial stocks for which each asset (+) held by an institutional sector is a liability (-) for someone else; therefore, the sum of the financial assets for all the institutional sectors is equal to zero. Finally, the wealth or net worth equals the sum of net financial and non-financial assets for each agent.

Table 1. ***Transaction-flow matrix of the Colombian model***

Variable	Non financial corporations Current	Non financial corporations Capital	Households	Financial corporations Current	Financial corporations Capital	Central bank Current	Central bank Capital	Government	RoW	Σ
Consumption of NFCs' products	$+C$		$-C_H$					$-C_G$		0
Public services								$+PS_G - PS_G$		0
Consumption of FCs' services			$-(INS_H + COM_H)$	$INS_H + COM_H$						0
Interm. cons. of NFCs' products	$+IC$			$-IC_B$				$-IC_G$		0
Interm. cons. of FCs' services	$-(INS_F + COM_F)$			$INS_F + COM_F$						0
Gross fixed capital formation	$+I_K$	$-I_F^K$	$-I_H^K$		$-I_B^K$			$-I_G^K$		0
Change in inventories	$+I^V$	$-I^V$								0
Imports	$-IM$								$+IM$	0
Exports	$+EX$								$-EX$	0
Taxes on imports	$-T^{IM}$							$+T^{IM}$		0
Value-added tax	$-T^V$							$+T^V$		0
Other taxes on products	$-T^P$							$+T^P$		0
Wages	$-W_F$		$+W$	$-W_B$				$-W_G$		0
Employers' social contributions	$-SC_F$		$+SC$	$-SC_B$				$-SC_G$		0
Mixed-income distribution	$-MI_H$		$+MI_H$							0
GOS redistribution	$-GOS_F$		$+GOS_F^H$					$+GOS_F^G$		0
Net other taxes on production	$-T_F^Y$			$-T_B^Y$				$-T^Y$		0
Int. on deposits	$+IntD_F$		$+IntD_H$	$-IntD$				$+IntD_G$		0
Int. on domestic loans	$-IntL_F$		$-IntL_H$	$+IntL$						0
Int. on domestic FX loans	$-IntL_F^{FX,B}$			$+IntL_F^{FX,B}$						0
Int. on RoW FX loans	$-IntL_F^{FX,W}$			$-IntL_B^{FX,W}$					$+IntL^{FX,W}$	0
Int. on domestic public bonds				$+IntBg_B$				$-IntBg$	$+IntBg_W$	0
Int. on FX public bonds								$-IntBg^{FX}$	$+IntBg^{FX}$	0
Int. on FX public loans								$-IntLg^{FX}$	$+IntLg^{FX}$	0
Int. on advances				$-IntA$		$+IntA$				0
Int. on FX reserves				$+IntR_B^{FX}$		$+IntR_{CB}^{FX}$			$-IntR^{FX}$	0
Firms' dividends	$-Div_F$		$+Div_F^H$					$+Div_F^G$	$+Div_F^W$	0
Banks' dividends			$+Div_B^H$	$-Div_B$					$+Div_B^W$	0
Royalties	$-Roy$							$+Roy$		0
Taxes on income	$-T_F^I$		$-T_H^I$	$-T_B^I$				$-T^I$		0
Workers' social contributions			$-WSC$	$+WSC_B$				$+WSC_G$		0
Social transfers			$+ST$	$-ST_B$				$-ST_G$		0
Remittances			$+Rem \cdot e^N$						$-Rem \cdot e^N$	0
Central bank profits						$-F_{CB}$		$+F_{CB}$		0
Other transfers	$-O_F$		$+O_H$	$-O_B$				$-O_G$	$-O_W$	0
Retained earnings	$-RE_F$	$+RE_F$		$-RE_B$	$+RE_B$					0
[Capital]		$[\dot{K}_F]$	$[\dot{K}_H]$		$[\dot{K}_B]$			$[\dot{K}_G]$		$[\dot{K}]$
[Inventories]		$[\dot{V}]$								$[\dot{V}]$
Foreign direct investment		$+FDI_F$			$+FDI_B$				$-FDI$	0
Cash and deposits		$-\dot{D}_F$	$-\dot{D}_H$		$+\dot{D}$			$-\dot{D}_G$		0
Gov. deposits at the CB							$+\dot{D}_{CB}$	$-\dot{D}_{CB}$		0
FX deposits		$-\dot{D}_F^{FX} \cdot e^N$			$-\dot{D}_B^{FX} \cdot e^N$			$-\dot{D}_G^{FX} \cdot e^N$	$+\dot{D}^{FX} \cdot e^N$	0
Domestic currency loans		$+\dot{L}_F$	$+\dot{L}_H$		$-\dot{L}$					0
Domestic FX loans		$+\dot{L}_F^{FX,B} \cdot e^N$			$-\dot{L}_F^{FX,B} \cdot e^N$					0
RoW FX loans		$+\dot{L}_F^{FX,W} \cdot e^N$			$+\dot{L}_B^{FX,W} \cdot e^N$				$-\dot{L}^{FX,W} \cdot e^N$	0
Domestic public bonds					$-\dot{Bg}_B$			$+\dot{Bg}$	$-\dot{Bg}_W$	0
FX public bonds								$+\dot{Bg}^{FX} \cdot e^N$	$-\dot{Bg}^{FX} \cdot e^N$	0
FX public loans								$+\dot{Lg}^{FX} \cdot e^N$	$-\dot{Lg}^{FX} \cdot e^N$	0
Insurance, pensions, and SGS			$-\dot{IPS}_H$		$+\dot{IPS}_H$					0
Domestic currency reserves					$-\dot{Rd}$		$+\dot{Rd}$			0
FX reserves					$-\dot{R}_B^{FX} \cdot e^N$		$-\dot{R}_{CB}^{FX} \cdot e^N$		$+\dot{R}^{FX} \cdot e^N$	0
Advances					$+\dot{A}$		$-\dot{A}$			0
Σ	0	0	0	0	0	0	0	0	0	0

Table 2. ***Balance sheet of the Colombian model***

Variable	NFCs	Households	FCs	CB	Government	RoW	$+\Sigma$
Capital stock	$+K_F$	$+K_H$	$+K_B$		$+K_G$		K
Inventories	$+V_F$						V
[Non-financial assets]	$+NFA_F$	$+NFA_H$	$+NFA_B$	$+NFA_{CB}$	$+NFA_G$	$+NFA_W$	NFA
Foreign equity	$-EQ_F^W$		$-EQ_B^W$			$+EQ^F$	0
Cash and deposits	$+D_F$	$+D_H$	$-D$		$+D_G$		0
Gov. deposits at the CB				$-D_{CB}$	$+D_{CB}$		0
FX deposits	$+D_F^{FX} \cdot e^N$		$+D_B^{FX} \cdot e^N$		$+D_G^{FX} \cdot e^N$	$-D^{FX} \cdot e^N$	0
Domestic currency loans	$-L_F$	$-L_H$	$+L$				0
Domestic FX loans	$-L_F^{FX,B} \cdot e^N$		$+L_F^{FX,B} \cdot e^N$				0
RoW FX loans	$-L_F^{FX,W} \cdot e^N$		$-L_B^{FX,W} \cdot e^N$			$+L^{FX,W} \cdot e^N$	0
Domestic public bonds			$+Bg_B$		$-Bg$	$+Bg_W$	0
FX public bonds					$-Bg^{FX} \cdot e^N$	$+Bg^{FX} \cdot e^N$	0
FX public loans					$-Lg^{FX} \cdot e^N$	$+Lg^{FX} \cdot e^N$	0
Insurance, pensions, and SGS		$+IPS_H$	$-IPS_H$				0
Domestic currency reserves			$+Rd$	$-Rd$			0
FX reserves			$+R_B^{FX} \cdot e^N$	$+R_{CB}^{FX} \cdot e^N$		$-R^{FX} \cdot e^N$	0
Advances			$-A$	$+A$			0
[Financial assets]	$+FA_F$	$+FA_H$	$+FA_B$	$+FA_{CB}$	$+FA_G$	$+FA_W$	0

2. Data sources

Representing the theoretical TFM and BS of the model with actual data for the Colombian economy is a challenging and data-intensive task. Even if there is a high correspondence between the System of National Accounts (SNA hereinafter) and the accounting structure of the model, the SNA has sometimes an insufficient level of disaggregation, conceptual differences with the theoretical framework adopted, and discrepancies between the real and financial side of the economy. Therefore, to fill with data all the entries of the TFM and the BS while respecting the budget and adding up constraints of the institutional sectors, it is necessary to resort to additional data sources and harmonise them. Table 3 summarises then the different data sets and their respective sources for the period 2005–2019.

To start with, different datasets built under the SNA guidelines constitute the main input for filling with data most of the entries of the TFM and BS. First, the integrated economic accounts (IEA) published by the Departamento Administrativo Nacional de Estadística (DANE) (Colombian National Statistics Office) records the non-financial flows of the economy. Thus, the IEA provides information on the production, goods and services, income generation, primary income distribution, secondary income distribution, and capital accounts of the SNA. Second, the flow of funds (FoF) published by the Banco de la República (Banrep) (the Colombian central bank) shows the main financial flows for the different institutional sectors using an economic classification that groups instruments such as cash and deposits, equity and investment fund shares, loans, and debt securities. Lastly, using the same instruments as the FoF, the financial assets (FA) of the SNA shows the financial assets and liabilities constituting the balance sheet of the main institutional sectors.

Table 3. ***Main datasets used in the construction of the empirical TFM***

SOURCE	DATASET
Departamento Administrativo Nacional de Estadística (DANE)	Integrated economic accounts (IEA) of the SNA
	Gross domestic product (GDP)
	GDP price deflators
Banco de la República (Banrep)	Flow of funds (FoF) of the SNA
	Financial account (FA) of the SNA
	Balance of payments (BoP)
	International investment position (IIP)
	Central bank's balance sheet
	Central bank's financial income statements
	Foreign direct investment (FDI) by sector
Superintendencia Financiera de Colombia (Superfinanciera)	Household and NFC loans
	Aggregate deposits
	Interest payment on household and NFC loans
Ministerio de Hacienda y Crédito Público (MHCP)	Public debt of the general government
	Fiscal balance of the general government

Source : Authors

Although following a functional instead of an economic classification,[43] the balance of payments (BoP) published by the central bank is also an important source of information. On the one hand, the current account of the BoP records the real transactions between residents and non-residents such as exports, imports, property income, wages, and remittances. On the other hand, the financial account of the BoP records the financial flows between residents and non-residents such as direct investment, portfolio investment, and other investment. Similar to the BoP, the international investment position (IIP) also released by the central bank shows the stocks of financial assets and liabilities held by residents and non-residents.

43 The distinction between economic and functional classification will be discussed in section 5.

The Colombian financial regulator (Superfinanciera) compiles more detailed information on the stock of loans owed by households and NFCs to banks and the stock of private sector deposits in the economy, as well as the respective aggregate interest payments. Finally, the Ministerio de Hacienda y Crédito Público (MHCP) (Ministry of Finance and Public Credit) publishes complementary information regarding public debt, public debt holdings and composition, and income and expenditure fiscal balance at the general government level.

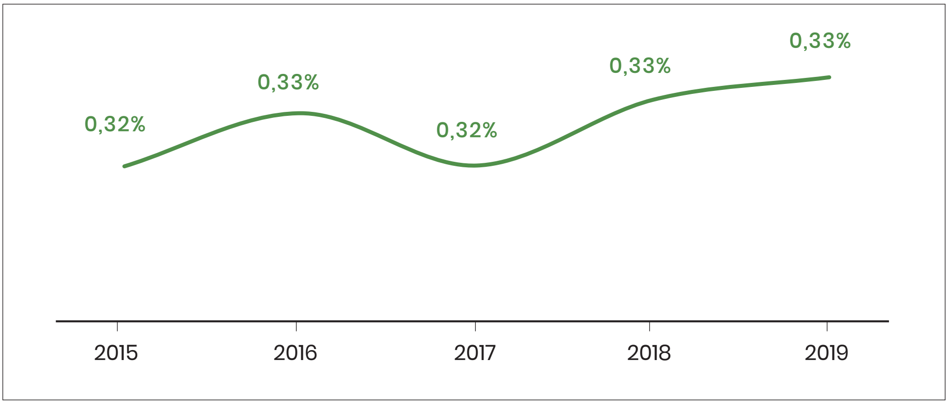
3. Developing the empirical TFM

With the accounting framework and the data sources already in mind, this section elaborates on the main challenges that need to be addressed to construct the empirical TFM. To do so, the reasons behind these difficulties are explained and some solutions to deal with them are proposed, considering the advantages and limitations of the assumptions and data harmonisation procedures suggested. This aims to guarantee the reproducibility and transparency of the results, accounting consistency, and proximity to the theoretical framework adopted.

3.1. Reallocation of non-profit institutions serving households

In contrast to the TFM shown in Table 1, the SNA presents an additional institutional sector corresponding to non-profit institutions serving households (NPISHs). The main role of NPISHs is to provide non-market services and to redistribute income through in-kind social transfers to households. Although NPISHs perform functions with high social relevance, their real and financial transactions are rather small in comparison to the whole economy. As can be seen in Figure 1, between 2015 and 2019, NPISHs' production accounted for about 0.3% of the total production of the economy. Therefore, since NPISHs are not an analytically relevant sector to be explicitly included in the model, they were merged with the household sector in the empirical TFM. This allows horizontal and vertical accounting consistency to be maintained, as no money flows, however small, were dropped out.

Figure 1. ***Share of NPISHs' production in total production (%)***

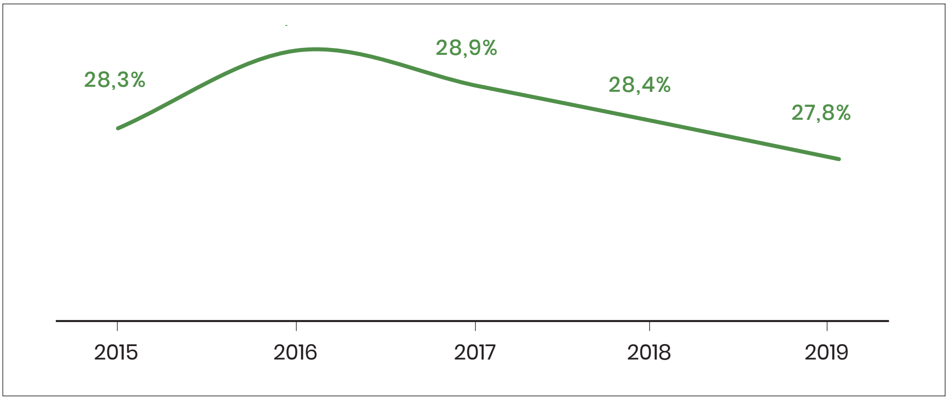


Source: DANE and authors' computations.

3.2. Household production

In the SNA, apart from consuming and saving, households are also involved in the production of market and non-market goods and services. This is particularly important in countries like Colombia with high informality rates, in which self-employment and production for self-consumption provide a livelihood to millions of inhabitants. In fact, Figure 2 shows that the share of household production in total production fluctuated around 28.6% between 2015 and 2019. This differs from the theoretical model where households are only consumers and firms carry out most of the production and, accordingly, create value added in the economy.

Figure 2. ***Share of household production in total production (%)***



Source: DANE and authors' computations.

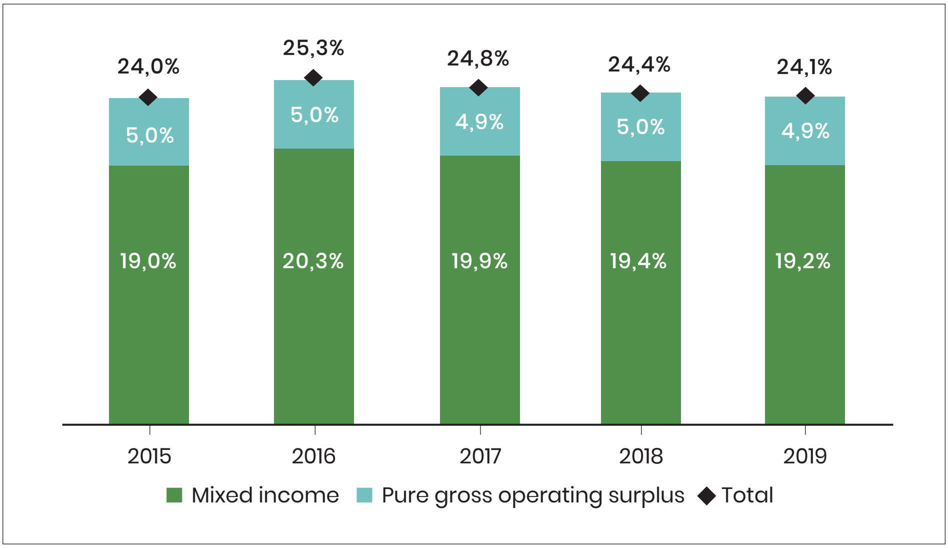
To reduce the gap between theory and empirics and to avoid the complexity of modelling each institutional sector as a productive sector, following the SNA nomenclature, the value of household production (P.1) was shifted to non-financial corporations (NFCs). To maintain accounting consistency, this also requires shifting to NFCs other production-related flows that represent an outflow for households such as intermediate consumption (P.2), taxes less subsidies on production (D.29 – D.39), wages and salaries (D.11), and employers' social contributions (D.12). Based on these flows, it is possible to calculate the value added (see equation 1) and the gross operating surplus (see equation 2), as done in the SNA.

$$\textit{Value added} = \textit{Production (P.1)} - \textit{Intermediate consumption (P.2)} \quad (1)$$

$$\begin{aligned}\textit{Gross operating surplus} \\ &= \textit{Value added-Wages and salaries (D.11)} \\ &- \textit{Employers' social contributions (D.12)} \qquad (2) \\ &- \textit{Taxes less subsidies on production (D.29-D.39)}\end{aligned}$$

In order not to alter the net lending/borrowing position of households and NFCs, it is necessary to redistribute back to households the surplus value added once the production costs expressed in equation 2 have been paid (i.e., the gross operating surplus). As shown at the top of the TFM and according to the disaggregation provided by DANE, this redistribution takes the form of mixed income and pure gross operating surplus. Figure 3 shows that the mixed income and the pure gross operating surplus generated by households averaged 24.5% of GDP between 2015 and 2019.

Figure 3. ***Gross operating surplus redistributed to households (%GDP)***



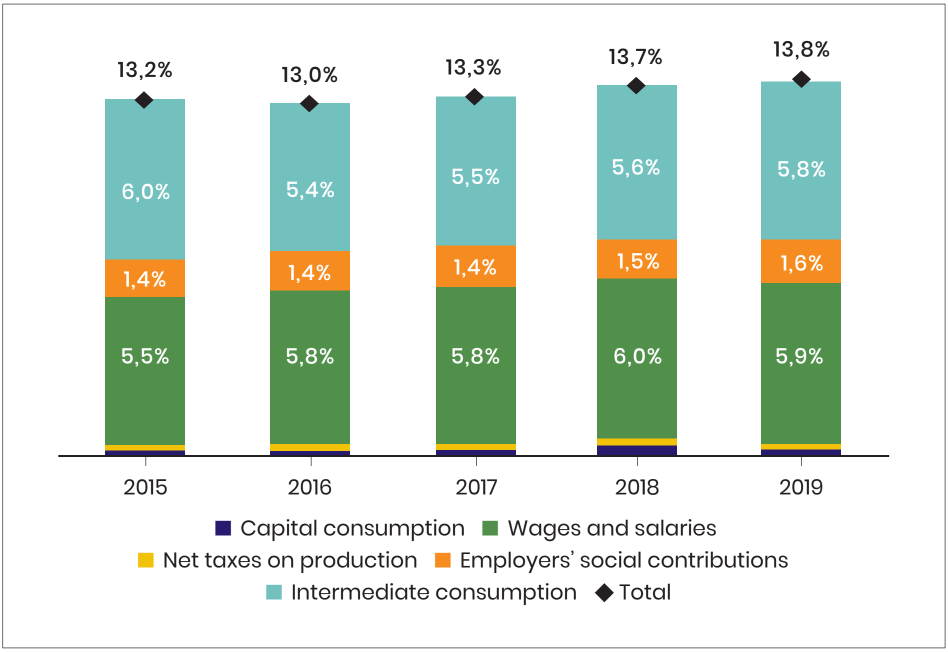
Source: DANE and authors' computations.

3.3. Government production

In the SNA, the government also conducts market and non-market production of goods and services. According to the SNA manual 2008 (United Nations *et al.*, 2009), market production corresponds to those goods and services that are provided at economically significant prices that allow for making profits and sustaining the economic activity over time (p. 106). On the other hand, non-market production refers to those goods and services usually provided by the public sector and NPISHs free of charge or at a price well below their market value, such as education and health (p. 107). This non-market output is demanded as final consumption by the government and NPISHs themselves to be redistributed in kind to households.

To the extent that there are no significant market prices, the SNA calculates the value of non-market production at the cost of production incurred by the government. As can be seen in equation 3, the value of government non-market production equals the sum of intermediate consumption (P.2), wages and salaries (D.11), employers' social contributions (D.12), taxes less subsidies on production (D.29 – D.39), and consumption of the fixed public capital stock (i.e., depreciation). Figure 4 disaggregates the value of government non-market production among its components, which averaged 13.4% of GDP between 2015 and 2019.

Figure 4. ***Government non-market production (%GDP)***



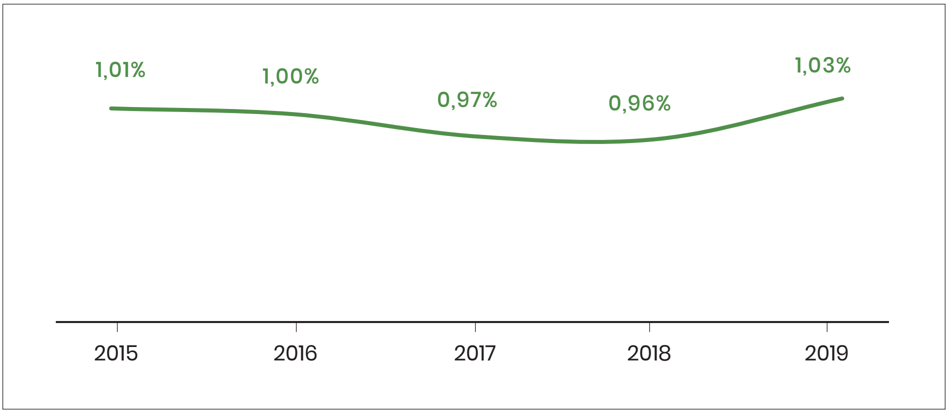
Source: DANE and authors' computations.

$$\begin{gathered}\text{Non} - \text{market production} = \text{Intermediate consumption (P.2)} + \\ \text{Wages and salaries (D.11)} + \text{Employers' social contributions (D.12)} + \\ \text{Taxes less subsidies on production (D.29-D.39)} + \\ \text{Consumption of fixed capital} \end{gathered} \tag{3}$$

Instead of shifting government non-market production to NFCs, it was kept in the government column for three reasons. First, it is an accounting imputation whose dynamics are more determined by the supply of public services than by private sector profitability motivations and aggregate demand fluctuations. Second, it can be easily calculated since all the variables on the right-hand side of the equality of equation 3 are in the model. Third, it does not alter the net lending/borrowing position of the government since all the non-market output is demanded as final consumption by the government itself. The latter explains why the public services row in the TFM is netted out.

On the other hand, government market production received a similar treatment to that given to household production in section 4.2, insofar as it was shifted to NFCs. As the SNA does not show the disaggregation of what percentage of intermediate consumption, wages, and social contributions paid by the government is used to produce market goods and services, these cannot be shifted as in the case of households. Thus, to keep the net lending/borrowing position unchanged, NFCs redistribute back to the government the gross operating surplus published by DANE. Figure 5 shows that the gross operating surplus of the government averaged 1.0% of GDP between 2015 and 2019.

Figure 5. ***Government's gross operating surplus (%GDP)***



Source: DANE and authors' computations.

3.4. Who pays whom

One of the limitations in trying to fill the TFM with actual data is that for some transactions the SNA does not present detailed information on the flows of income and expenditure between institutional sectors and, consequently, on who pays whom. In other words, sometimes it is not possible to determine how much each institutional sector pays and/or receives in monetary terms, in such a way that the sum of each TFM entry equals zero. Table 4 presents the SNA flows for which this problem arises, grouped by type of account.

Table 4. ***SNA real flows with insufficient level of disaggregation***

ACCOUNT	2005
Goods and services	Exports (P.6), Imports (P.7), Final consumption (P.3), Intermediate consumption (P.2), Gross fixed capital formation (P.51), and Taxes less subsidies on products (D.21 - D.31)
Primary income distribution	Interest (D.41) and Distributed income of corporations (D.42)
Secondary income distribution	Miscellaneous current transfers (D.75)

Source: SNA

In the goods and services account of the SNA, while the aggregate value of imports received by the rest of the world and of taxes less subsidies on products received by the government is known, it is not known how much of these imports and taxes are paid by each institutional sector. Similarly, while it is known how much each institutional sector spends as final consumption, intermediate consumption, gross capital formation, and exports, the SNA does not show how much of this demand is received or accrues to each institutional sector.

To address this difficulty, as discussed in the previous subsections, it is assumed that NFCs carry out most of the production in the economy except for government non-market production and the production of financial services. This allows NFCs to receive all the aggregate demand in the economy excluding the government's consumption of its own non-market output and the final and intermediate consumption of financial services. To the extent that aggregate demand is valued at market prices, rather than at producer prices, and that it includes goods and services produced domestically and abroad, NFCs have to pay for imports and net taxes on products (e.g., VAT and import taxes) as if they were costs of production. The latter keeps the net lending/borrowing position of NFCs unchanged since imports and indirect taxes are not sources of profits for domestic firms.

Due to the emphasis of SFC models on the financial sphere of the economy and its feedback loops on the real sphere, especially concerning the effect of debt service payments and interest rate changes, it is important to have in the TFM the interest payments associated with each of the assets included in the balance sheet of each institutional sector. However, the SNA does not provide such a level of disaggregation as interest payments are aggregated and not shown by asset type; thus, it is not possible to identify who pays whom.

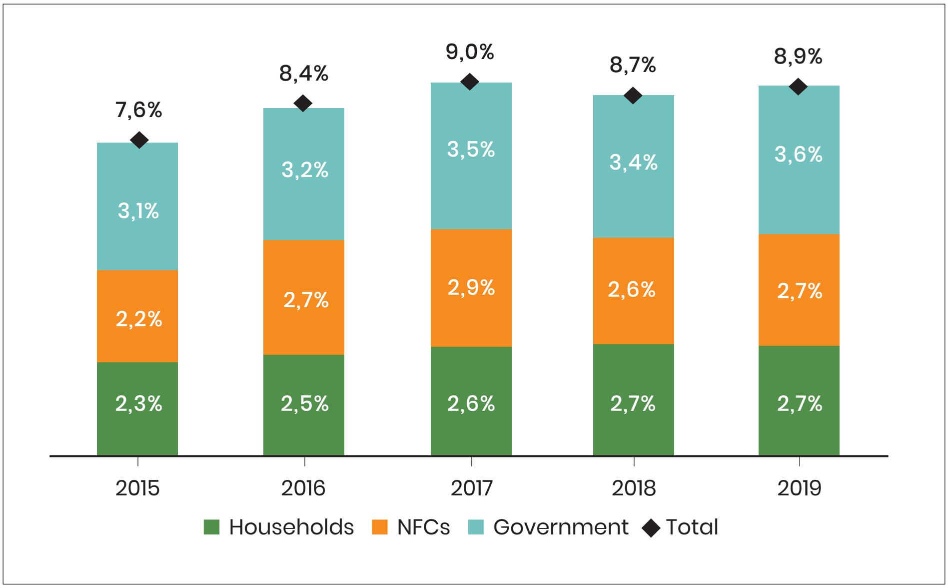
It is therefore necessary to resort to additional sources of information to fill the interest payment rows in the TFM, which are summarised in Table 5. The information comes from reports by the Superfinanciera, the balance of payments and financial income statements published by the Banco de la República, and the fiscal balance at the general government level published by the Ministerio de Hacienda y Crédito Público. By way of illustration, Figure 6 shows the interest payments made by households, non-financial corporations, and the general government, which averaged 8.5% of GDP between 2015 and 2019.

Table 5. ***Data sources for interest payment transactions***

CATEGORY	SOURCE
Interest on domestic currency deposits	Superfinanciera
Interest on households' and NFCs' domestic currency loans	Superfinanciera
Interest on NFCs' FX loans with local banks	Superfinanciera
Interest on NFCs' and FCs' loans with foreign banks	Banco de la República – BoP
Interest on domestic public debt	Ministerio de Hacienda y Crédito Público
Interest on FX public debt	Ministerio de Hacienda y Crédito Público
Interest on the central bank's liquidity advances	Banco de la República – income statements
Interest on FX reserves assets	Banco de la República – BoP

Source: Authors.

Figure 6. ***Interest payments paid by households, NFCs, and the government (%GDP)***



Source: DANE and authors' computations.

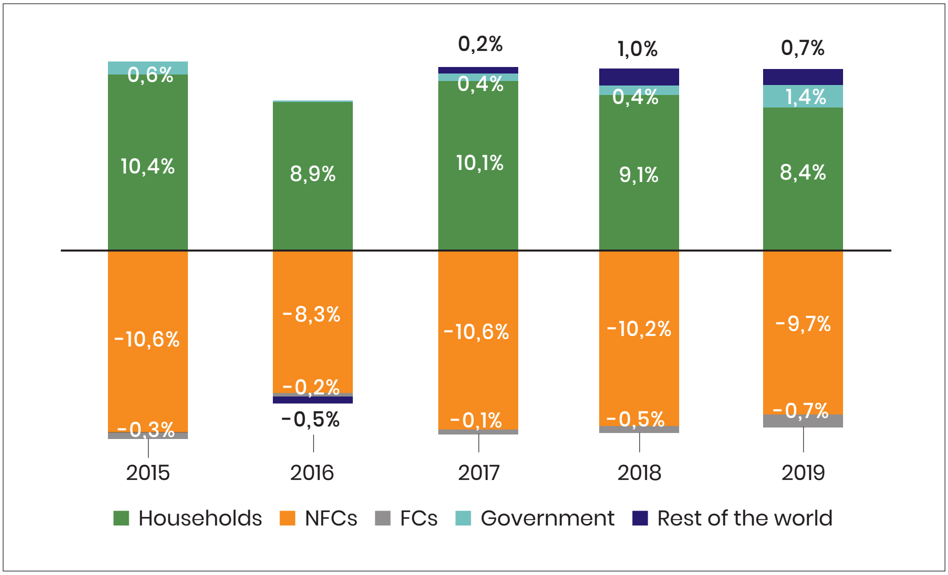
Regarding dividends,[44] the SNA shows how much each institutional sector receives and pays but does not disaggregate intersectoral payments. For this reason, it is necessary to make assumptions about the distribution of dividends that are consistent with the characteristics of the Colombian economy and allow the model to define who pays whom. To this end, a three-step procedure was carried out. First, the net dividends of each sector are defined as the difference between receipts and payments. By way of illustration, Figure 7 shows the net dividends for each institutional sector as a percentage of GDP, where it can be seen that NFCs and FCs pay dividends, while the other sectors (mainly households) receive them.

Based on the above, it is assumed that NFCs distribute their net dividends to the government, the rest of the world, and households. Government dividends are connected to the existence of fully and partially state-owned enterprises, especially Ecopetrol (oil company), which the SNA includes within the non-financial sector. Dividends paid to the rest of the world are mainly connected to foreign direct investment inflows targeting mainly

44 As in the balance of payments, dividends correspond to the sum of distributed income of corporations (D.42) and reinvested earnings on foreign direct investment (D.43).

non-financial activities, notably the mining and energy sector. Finally, dividends coming from FCs are paid to households, which ensures that this TFM entry adds up to zero horizontally.

Figure 7. ***Net dividends (%GDP)***



Source: DANE and authors' computations.

3.5. Financial intermediation services indirectly measured

When using alternative sources of information to derive interest payments on loans and deposits, it is important to consider the methodology by which the SNA calculates such interest flows. This is to avoid double counting and ending up significantly changing the net lending/borrowing positions of the institutional sectors involved.

In the SNA, interest payments on loans and deposits are determined based on a reference interest rate and not on the basis of banks' interest rates actually paid in the credit market. The idea behind this is that banks produce financial intermediation services when they mobilise resources from surplus units to other deficit units,[45] in exchange for which they are implicitly

45 This idea is related to the loanable funds theory, where banks require prior savings in the form of deposits to offer loans. However, banks can create money out of nothing since, whenever they make a loan, they create a deposit in the borrower's account, expanding both sides of their balance sheet. Afterwards, depending on the liquidity preference of the public and the reserve requirements, banks will look for central bank money reserves.

remunerated by depositors and borrowers. In this sense, the reference interest rate represents the pure cost of the resources that are mobilised in the banking system, without considering any type of charge or commission for these financial intermediation services rendered.

This is known as financial intermediation services indirectly measured (FISIM), which are produced by financial corporations and the rest of the world and are purchased by the rest of the institutional sectors as final consumption and intermediate consumption. According to equation 4, FISIM equal the spread between the reference rate $(\boldsymbol{i^R})$ and the implied interest rate on deposits $(\boldsymbol{i^D})$ multiplied by the stock of deposits $(\boldsymbol{D})$, plus the spread between the implied interest rate on loans $(\boldsymbol{i^L})$ and the reference rate $(\boldsymbol{i^R})$ multiplied by the stock of loans $(\boldsymbol{L})$. This formula shows that a significant part of the interest payments in the primary income distribution account of the SNA does not represent the interest flows actually paid in the credit market. As a result, the SNA underestimates the interest paid by debtors and overestimates the interest received by depositors.

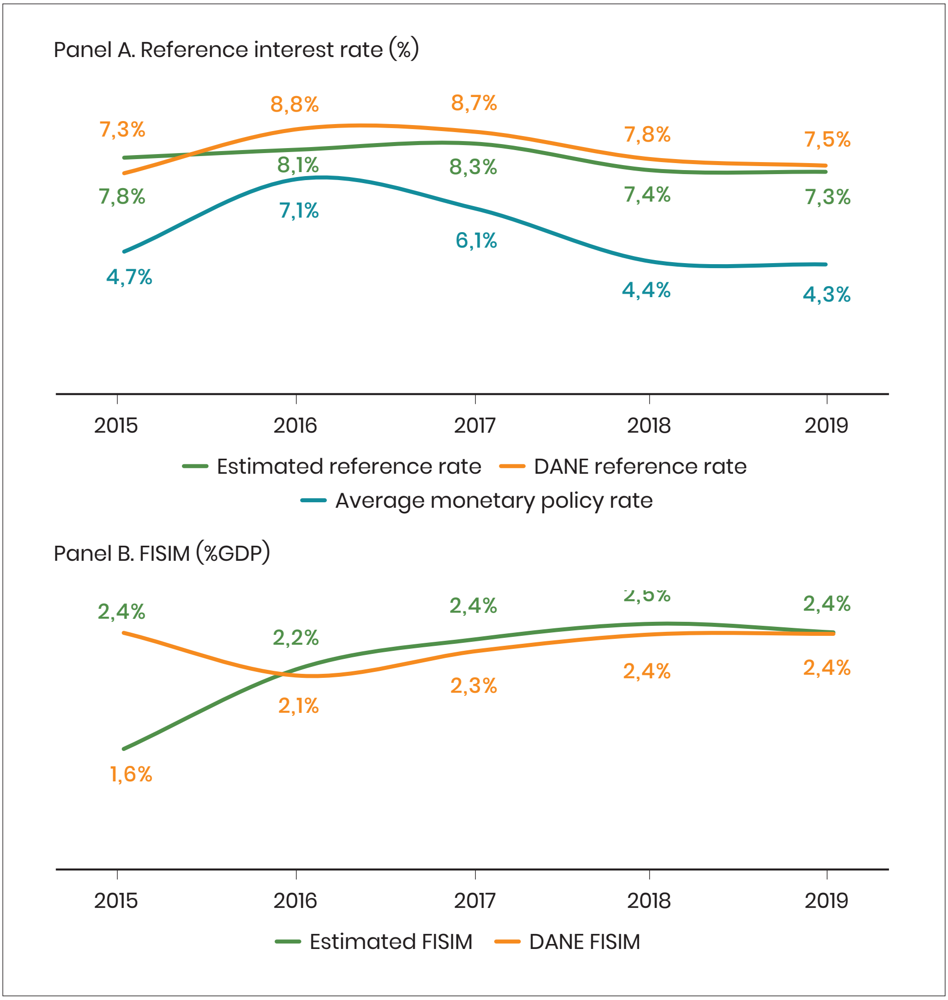
$$FISIM = \left(i^R - i^D\right) \cdot D + \left(i^L - i^R\right) \cdot L \qquad (4)$$

To calculate the FISIM, it is necessary to determine the reference interest rate used by the statistical office of each country. In the case of Colombia, DANE (2008) defines the reference interest rate in domestic currency as a midpoint rate (see equation 5), which is defined as the ratio between interest payments on loans and deposits and the total stock of loans and deposits. For the numerator, the aggregate interest payments on domestic currency deposits and loans were provided by the Superfinanciera. For the denominator, the stock of household and corporate loans in domestic currency was taken from the Superfinanciera, and the stock of domestic currency deposits was taken from the SNA. As for the calculations of FISIM in foreign currency, these were taken directly from the imports in the balance of payments for FX loans and deposits with foreign banks, while for FX loans with local banks they were calculated using the six-month Libor as a reference rate (DANE, 2008).

$$i^R = \frac{i^L.L + i^D.D}{L + D} \qquad (5)$$

Figure 8 shows an illustration of the procedures described above. Panel A presents the reference interest rate estimated following equation 5, which is very close to the reference rate actually used by DANE and follows the dynamics of the Banco de la República's monetary policy rate. Subsequently, Panel B presents the FISIM estimated from equation 5 and the FISIM published by DANE as a percentage of GDP, which are very similar except for the year 2015. Overall, the estimates are quite accurate, and the discrepancies that arise are related to the use of different data sources.

Figure 8. ***FISIM and reference interest rate estimated***



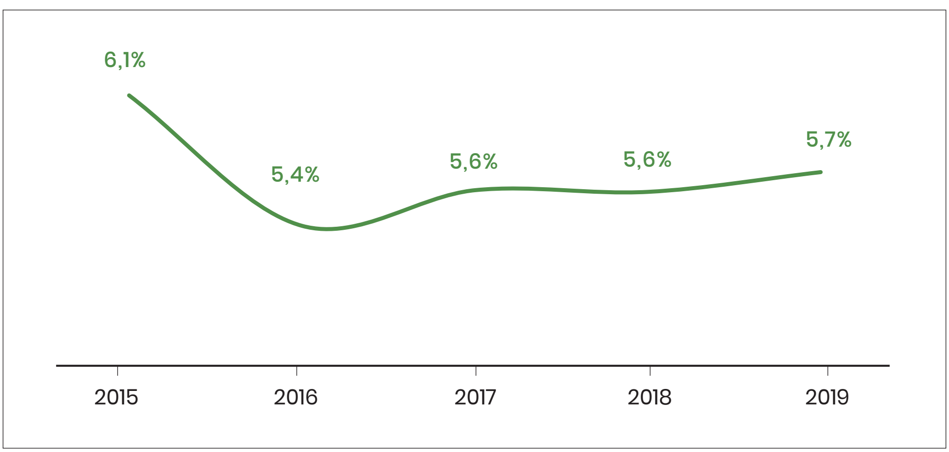
Source: DANE, Superfinanciera and authors' computations.

To the extent that the TFM includes the interest payments on loans and deposits calculated at market interest rates rather than at the SNA reference interest rate, FISIM should be deducted from the macroeconomic aggregates to avoid double counting. This deduction should respect the accounting identity given by equation 6, where supply equals demand for FISIM. On the one hand, supply is given by the production of FISIM by local banks and imports of FISIM. On the other hand, FISIM demand is given by the final and intermediate consumption of FISIM by the institutional sectors with loans and deposits on their balance sheet.

$$\begin{aligned} &Production_{FISIM} + Imports_{FISIM} \\ &\quad \equiv Final\ consumption_{FISIM} \\ &\quad + Intermediate\ consumption_{FISIM} \end{aligned} \tag{6}$$

With the above in mind, the production of financial corporations (FCs) can be split between FISIM production and production of non-FISIM financial services, the latter being commissions and insurance services mostly. Thus, FCs' production row shown in the TFM arises from the difference between FCs' production recorded in the SNA minus the estimated FISIM of local banks. As an illustration, Figure 9 shows the production of financial services other than FISIM, which averaged 5.7% of GDP between 2015 and 2019. Similarly, the value of FISIM imports is also subtracted from the total value of imports.

Figure 9. ***Estimated non-FISIM production of financial corporations (%GDP)***



Source: DANE, Superfinanciera and authors' computations.

To subtract domestic and imported FISIM from aggregate demand, it is important to determine to which institutional sector they belong, which is done following DANE (2008). First, FISIM from loans and deposits held by NFCs, FCs, and the government is considered intermediate consumption. Second, FISIM from households arising from consumer loans and deposits is defined as final consumption, while FISIM from mortgages is intermediate consumption. Third, imported FISIM is defined as intermediate consumption and is distributed among NFCs, FCs, and the government according to each institutional sector's share in the interest on FX loans paid to the rest of the world.

3.6. The flow of funds

As in the previous section, completing the entries of the financial side of the TFM is challenging because the SNA data are not disaggregated enough for some assets and/or do not show the debt relationships across sectors. For this reason, it is necessary to resort to additional sources of information when appropriate to complement the SNA, which are presented in Table 5 for each of the financial flows in the model. The main sources include the Superfinanciera, the Banco de la República, and the Ministerio de Hacienda y Crédito Público.

Table 6. ***Data sources for the flow of funds***

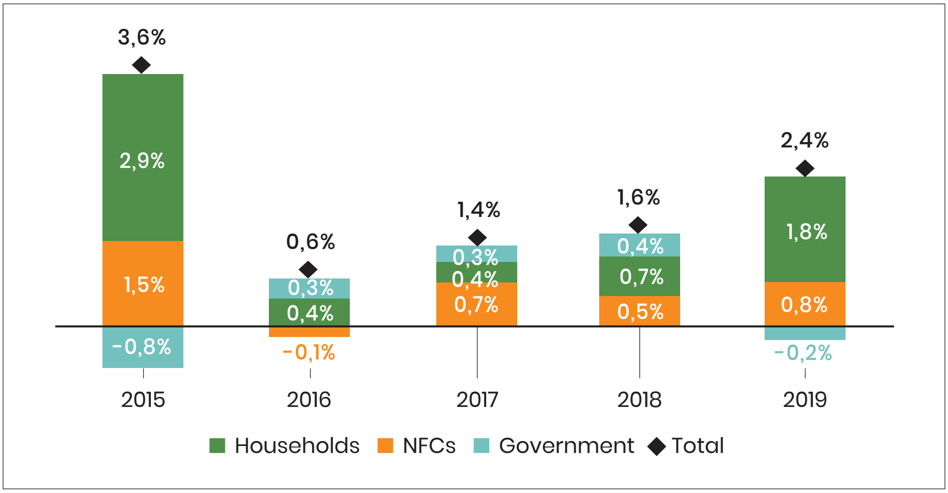
CATEGORY	SOURCE
Cash and deposits, FX deposits, and Insurance, pensions, and standardised guarantee schemes (SGS)	SNA – Flow of funds
Government deposits at the central bank, Domestic currency reserves, and Liquidity advances	Banco de la República – Balance sheet
Domestic loans and FX loans with local banks	Superfinanciera
Private FX loans with foreign banks	Banco de la República – BoP
Domestic government bonds, FX government bonds, and FX government loans	Ministerio de Hacienda y Crédito Público
Foreign direct investment and FX reserves	Banco de la República – BoP

Source: Authors

The SNA provides data on the accumulation of cash and deposits made by NFCs, households, and the government, which increase the liabilities of financial corporations (FCs). It is important to note that the cash and deposits held by FCs as an asset are not included since they also represent a liability on their balance sheet, so they are netted out and do not affect their financial position. By way of illustration, Figure 10 presents the accumulation of cash and deposits for these three sectors, which averaged 1.9% of GDP between 2016 and 2019. From the SNA we also take the foreign currency deposits accumulated by NFCs, FCs, and the government vis-à-vis the rest of the world. Similarly, household savings in insurance, pensions, and SGS, which are a liability for FCs, are also taken from the SNA.

From the central bank's balance sheet, it was possible to derive most of the financial flows related to the central bank. These include government deposits at the central bank associated with the treasury operations of the Ministerio de Hacienda y Crédito Público, the bank reserves that FCs are required to hold at the central bank for precautionary reasons, and finally, the liquidity advances that the central bank offers to commercial banks that have high-powered money needs. The latter aggregate open market operations (OMOs) net of contractionary OMOs and government bonds purchased in the secondary market.[46]

Figure 10. ***Accumulation of cash and deposits (%GDP)***

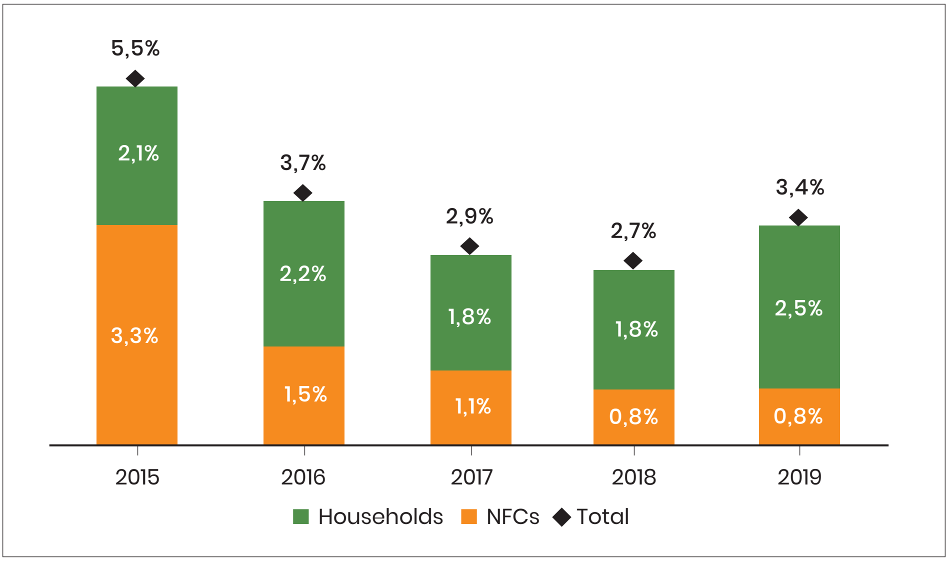


Source: DANE, Superfinanciera and authors' computations.

46 This idea aims to better represent the liquidity provision to FCs since the bonds purchased by the central bank in the secondary market represent a type of permanent liquidity provision, which is hidden in the TFM due to the assumption that financial corporations and the rest of the world hold all the domestic public bonds.

Domestic currency loans for the private sector are taken from the Superfinanciera. On the side of households, it corresponds to consumer and mortgage loans. On the side of NFCs, it refers to working capital loans, ordinary and preferential commercial loans, corporate credit cards, loans for the construction industry, and micro-credits. Figure 11 presents the flow of loans for these two sectors, which averaged 3.6% of GDP between 2015 and 2019.

Figure 11. ***Flow of domestic currency loans for the private sector (%GDP)***



Source: DANE, Superfinanciera and authors' computations.

The flow of FX loans that NFCs take out with local banks was also collected from the Superfinanciera. However, the flow of FX loans of NFCs and FCs with non-resident financial entities was taken from the balance of payments (BoP). In order to better match the financial flows of the economy and simplify the calculations of the interest payments, this entry aggregates the following BoP transactions: debt instruments, loans, credit and commercial advances, and other accounts receivable and payable.

The flow of general government FX debt is obtained from the Ministerio de Hacienda y Crédito Público. However, the disaggregation of this flow between loans and bonds was done using BoP statistics. Thus, general government FX loans were defined as the sum of the following BoP transactions: loans, commercial advances, and other accounts receivable and payable. As a residual, the flow of FX bonds purchased by non-residents was defined as the difference between the total flow of FX debt reported by the Ministerio de Hacienda y Crédito Público and the flow of FX loans taken from the BoP. This procedure implies the assumption that all the FX-denominated bonds issued by the government are purchased by non-resident investors in international capital markets.

As the Colombian bonds market is developing well, it is assumed that all the domestic currency debt of the government reported by the Ministerio de Hacienda y Crédito Público corresponds to domestic currency bonds. When it comes to distributing these bonds between purchasers, it is important to highlight that the debt instruments issued by the government and held by non-residents in the BoP include both domestic and FX bonds (see equation 7). Therefore, domestic currency bonds purchased by the rest of the world can be calculated as the total debt instruments reported in the BoP minus the FX government bonds previously calculated (see equation 8). Consequently, the domestic bonds purchased by FCs are calculated as a residual between the total domestic bonds issued and those purchased by the rest of the world[47] (see equation 9).

$$\begin{aligned} &\textit{Debt instruments}_{BoP}^{W} \\ &\quad = \textit{Domestic debt instruments}_{BoP}^{W} \\ &\quad + \textit{FX debt instruments}_{BoP}^{W} \end{aligned} \tag{7}$$

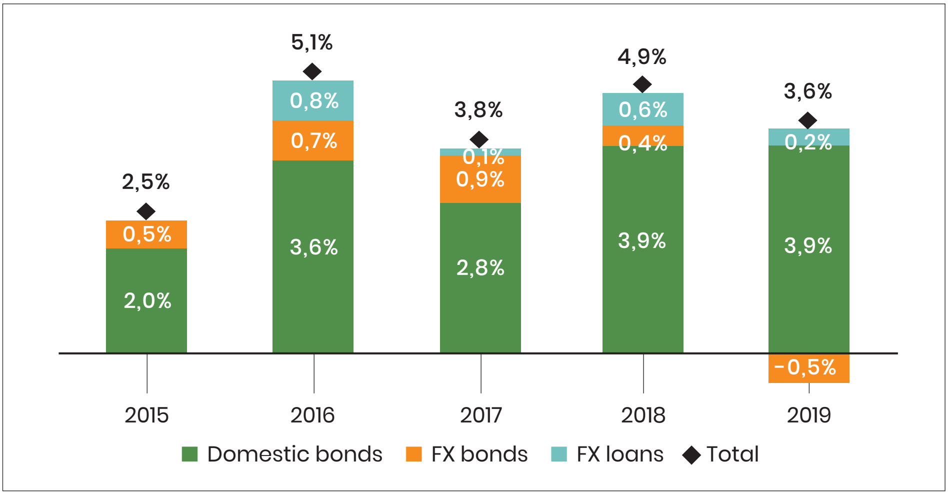
$$\begin{aligned} &\textit{Domestic public bonds}_{TFM}^{W} \\ &\quad = \textit{Debt instruments}_{BoP}^{W} - \textit{FX public bonds}_{TFM}^{W} \end{aligned} \tag{8}$$

$$\begin{aligned} &\textit{Domestic public bonds}_{TFM}^{FCs} \\ &\quad = \textit{Domestic public debt}_{MF} - \textit{Domestic public bonds}_{TFM}^{W} \end{aligned} \tag{9}$$

Both the domestic and FX flow of public debt are presented in Figure 12, which averaged 4.0% of GDP in total during the period 2015–2019.

47 This procedure assumes that apart from foreign investors, FCs hold all the domestic government bonds, which seems plausible according to the statistics on TES holders.

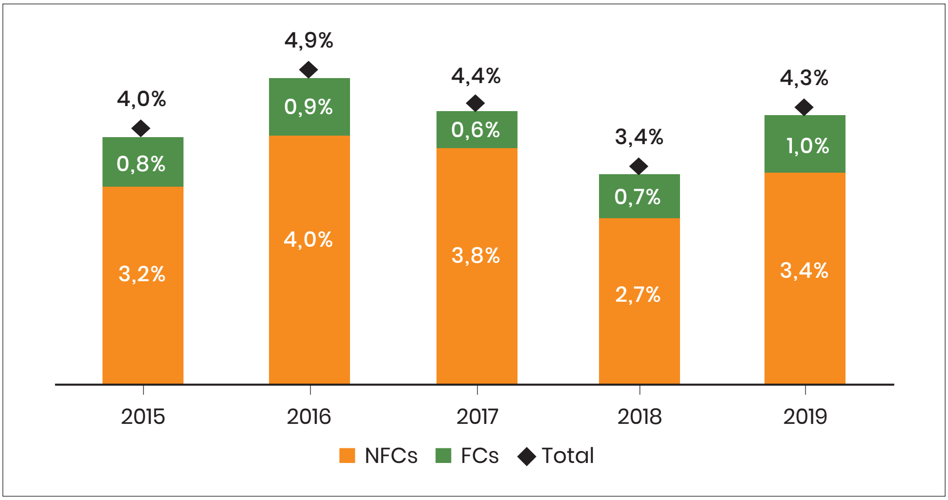
Figure 12. ***Flow of general government debt (%GDP)***



Source: DANE, Superfinanciera and authors' computations.

The total inflow of FDI in Colombia is taken from the BoP. The distribution of inward FDI between NFCs and FCs is made on the basis of the FDI statistics by economic activity reported by the Banco de la República. In the case of FCs, it corresponds to financial and business services FDI, while the remaining economic activities are allocated to NFCs. To illustrate, Figure 13 shows total FDI inflows between 2015 and 2019, which averaged 4.2% of GDP.

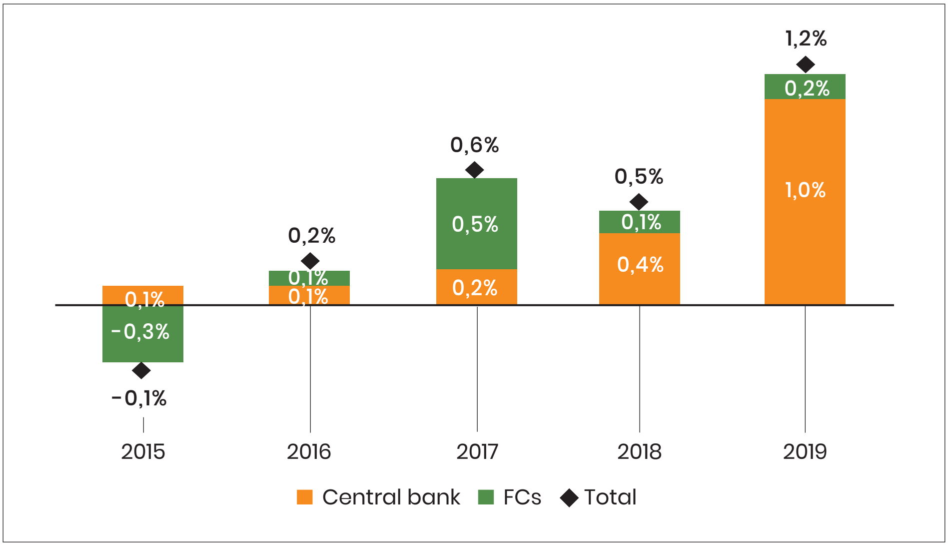
Figure 13. ***FDI inflows (%GDP)***



Source: BanRep and authors' computations.

Finally, as with most of the FX-denominated financial flows, the flow of FX reserves is taken from the BoP. They are accumulated by two institutional sectors: the central bank and financial corporations. In the former case, it corresponds to the accumulation of official FX reserves by the central bank for foreign exchange regulation and macrofinancial management. In the latter case, it refers to the debt instruments accumulated by FCs against non-residents, which make it possible to better match the financial position of this sector. Figure 14 shows the accumulation of FX reserves between 2015 and 2019, which averaged 0.5% of GDP.

Figure 14. ***FX reserves accumulation (%GDP)***



Source: BanRep and authors' computations.

3.7. Other transfers

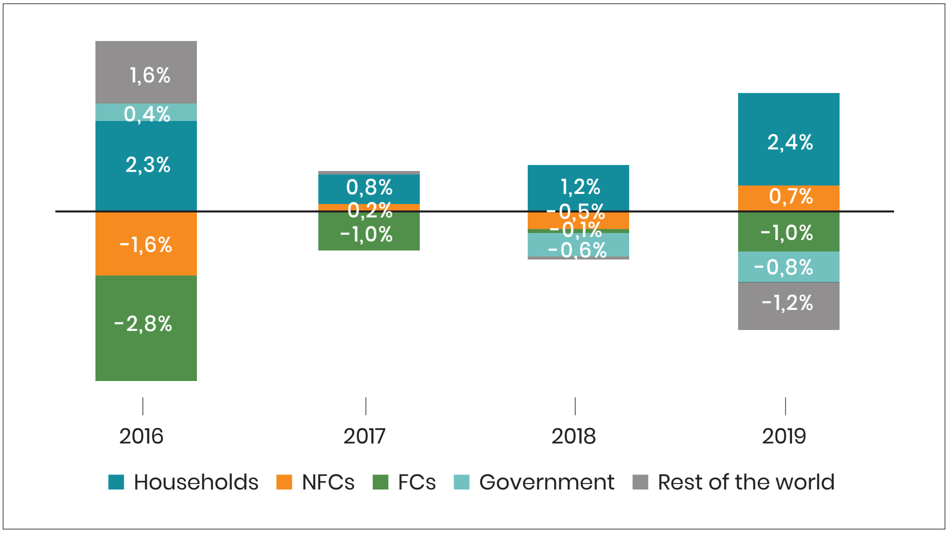
The row other transfers shown in the secondary income distribution account plays an important role in the construction of the empirical TFM for two reasons presented below.

First, it adds a number of flows present in the SNA which, although analytically irrelevant for the model, cannot be deleted because they would affect the net lending/borrowing position of the institutional sectors involved. The reasons for not including these flows are that their low monetary value does not compensate for the additional complexity they would add to the model, coupled with the difficulty of deriving behavioural equations and the fact that some of them are accounting imputations and are not relevant to the research question. Thus, the flows that are aggregated correspond to net non-life insurance premiums (D.71), net non-life insurance claims (D.72), current transfers within the government (D.73), international cooperation (D.74), miscellaneous current transfers (D.75) excluding remittances inflows, and transfers from the central bank to the government (D.76).

Second, it also adds a balancing item that ensures that each institutional sector respects its budget constraint and thus that all columns of the TFM sum to zero vertically. This is because, although in theory the net lending/borrowing position calculated from the flows of funds on the financial sphere and the flows of revenues and expenditures on the real sphere should be equal, in practice there are discrepancies. Even in the SNA, the net lending/borrowing position calculated from the integrated economic accounts and the financial account differ because the two use different data sources, make different assumptions and imputations, and both omit flows and transactions due to data collection limitations. Apart from the SNA discrepancies, given that additional data sources were used and harmonised for the development of the empirical TFM, it is normal that additional discrepancies arise.

Figure 15 shows the flow of other transfers for each of the institutional sectors in the model between 2016 and 2019, which add up to zero because any income or financial flow received by one sector comes from another. As can be seen, the value for each sector indicates that the discrepancies and other flows aggregated are not very high as a percentage of GDP.

Figure 15. ***Other transfers (%GDP)***



Source: DANE and authors' computations.

4. Additional remarks

This section briefly discusses some additional empirical aspects that were not covered in the previous sections.

4.1. TFM entries not discussed

Due to space constraints, some of the entries in the real part of the TFM were not discussed or were addressed without sufficient detail. This is because all income and expenditure flows of the TFM were taken directly from the integrated economic accounts of the SNA and were not modified in any way, with the exception of the transactions discussed in the previous section, for which assumptions were made and additional information was integrated.

4.2. Balance sheet

Details on the empirical balance sheet are not presented because exactly the same procedures described in section 4.6 on the flow of funds are followed. In this sense, additional sources to the financial account of the SNA are integrated and harmonised to obtain more detailed and accurate data on the financial stocks of the Colombian economy by resorting to the Banco de la República (mainly the BoP), the Superfinanciera, and the Ministerio de Hacienda y Crédito Público.

4.3. Integrating national accounts and the balance of payments

As mentioned before, the balance of payments (BoP) provides complementary data at a high level of detail for the construction of the empirical TFM. In order to integrate this information properly with the SNA, it is important to consider some differences between the two methodologies. The main difference lies in the way in which financial flows and stocks are classified, insofar as the Balance of Payments Manual (International Monetary Fund, 2009) uses a functional classification and the SNA guidelines (United Nations *et al.*, 2009) use an economic classification. This means that the financial accounts in both methodologies do not have exact counterparts when compared.

The economic classification groups financial flows and stocks according to the types of financial instruments, the legal relationship they establish between creditors and debtors, and their characteristics in terms of currency and maturity. While the functional classification considers the above criteria, it focuses on the economic motivations behind and the characteristics of the transactions that take place between residents and non-residents. As pointed out in the Balance of Payments Manual (2009, p. 99), functional classification recognises that the transaction of a financial instrument may have different risks and implications for the economy as the motivations and relationships between the agents involved differ from case to case and have a different temporality.

For example, loans and equity contributions received by a firm tend to have a greater stability and long-term orientation when provided by direct investors rather than portfolio investors. The former tend to exert a significant degree of control or influence over the firm, while the latter lack such influence and tend to engage in shorter-term transactions external to the firm. Similarly, another example of functional classification is seen in the reserve assets category. While the private sector and the government may accumulate a wide range of financial instruments vis-à-vis non-residents, when these are accumulated by the central bank they are referred to as reserve assets since they perform an economic function of foreign exchange regulation and macrofinancial management even if they purchase similar assets.

In order to establish equivalence between both classifications, Table 2 attempts to associate the functional categories of the BoP with the economic categories of the SNA.

Table 7. ***Equivalences between functional and economic classification***

FUNCTIONAL CLASSIFICATION (BOP)		ECONOMIC CLASSIFICATION (SNA)
Direct investment	Equity and investment fund shares	Equity and investment fund shares (F.5)
	Debt instruments	Debt securities (F.3)
Portfolio investment	Equity and investment fund shares	Equity and investment fund shares (F.5)
	Debt instruments	Debt securities (F.3)
Other investment	Other equity investments	Equity and investment fund shares (F.5)
	Currency and deposits	Currency and deposits (F.2)
	Loans	Loans (F.4)
	Insurance, pensions, and standardised guarantee schemes	Insurance, pension, and standardised guarantee schemes (F.6)
	Commercial credit and advances	Other accounts receivable/payable (F.8)
Financial derivatives (other than reserves) and ESO	Forward-type contracts	Financial derivatives and ESO (F.7)
	Options	Financial derivatives and ESO (F.7)
	Employee stock options (ESO)	Financial derivatives and ESO (F.7)
Reserve assets	Monetary gold	Monetary gold and SDRs (F.1)
	Special drawing rights (SDRs)	Monetary gold and SDRs (F.1)
	Reserve position in the IMF	Equity and investment fund shares (F.5)
	Cash and deposits	Cash and deposits (F.2)
	Debt instruments	Debt securities (F.3)
	Equity and investment fund shares	Equity and investment fund shares (F.5)
	Financial derivatives	Financial derivatives and ESO (F.7)
	Other assets	-

Source: United Nations (2009) and IMF (2009).

4.4. Fictitious income flows in the SNA

Apart from FISIM, the SNA presents some transactions that modify the net lending/borrowing position of the institutional sectors even though they are fictitious or unrealised income flows. The nature of these flows is accounting and not economic, insofar as they do not actually take place in the economy and do not affect the behaviour of the institutional sectors. Recognising these accounting imputations leads to a more cautious interpretation of the net lending/borrowing position presented by the SNA, especially in the case of households, financial corporations, and the rest of the world, whose accounts are more affected by these notional inflows and outflows. However, to keep things simple, these flows were kept in the empirical TFM to avoid further discrepancies with the SNA.

The first of these notional income flows corresponds to reinvested earnings of foreign direct investment (D.43) by non-residents. As noted in the SNA manual (United Nations *et al.*, 2009, p. 154), the decision of non-residents to reinvest profits is accounted for as a payment to the rest of the world in the primary income distribution account of the SNA and as an inflow of new equity investment in the flow of funds of the SNA. However, these monetary flows do not actually take place in the economy and end up inflating property income payments and equity accumulation by foreign investors. Something similar happens with investment income attributable to holders of shares in collective investment funds (D.443), which also includes retained earnings that are not actually paid and inflates the flow of funds.

Other notional income flows in the primary income distribution account correspond to investment income attributable to insurance policyholders (D.441) and investment income payable on pension rights (D.442). These unrealised income flows in favour of insurance and pension fund holders are included in the SNA to minimise discrepancies between the net lending/borrowing position calculated from the real side and the financial side. This is because in the flows of funds, the item insurance, pension, and standardised guarantee schemes (F.6) includes capital gains and returns constituting technical reserves and revaluating these assets. Thus, to match the dynamic of the flow of funds, it is assumed that part of these capital gains and returns is paid out to insurance and pension fund holders even though in reality such payment is notional and is not received by households.

The adjustment for the change in pension entitlements (D.8) is also a source of fictitious income that is included in the SNA to reduce discrepancies between the net lending/borrowing calculated from real flows and that calculated from financial flows. Following the SNA manual (United Nations *et al.*, 2009, p. 182), this item in the IEA captures the differences between the contributions and benefits to the general pension system made by households in individually funded schemes. Thus, when the contributions made by households are higher than the benefits, an equivalent notional income is imputed to households reflecting the aggregate acquisition of pension entitlements. At the same time, this imputation represents a notional outflow from financial corporations and the government that captures an increase in the financial obligations of pension fund managers to households.

As a result, the net lending/borrowing position published by the SNA is affected by unrealised income flows that, in fact, do not influence saving and consumption decisions. Although this was not done for the empirical TFM, it is possible to recalculate the net lending/borrowing of each sector by omitting these fictitious income flows. This also requires excluding from the flows of funds their financial counterparts, which are part of the equity and investment fund shares (F.5) and insurance, pension, and standardised guarantee schemes (F.6) assets.

Conclusion

Throughout this appendix, a brief and schematic description was given of how most of the flows and stocks that constitute the empirical TFM and the BS of the Colombian SFC model were calculated based on information taken from different macroeconomic datasets. This was done by detailing the data sources used, the challenges faced in moving from a theoretical to an empirical TFM, and the assumptions and modifications made to the raw data to deal with them. While some of the results for the period 2015–2019 were illustrated throughout the chapter in many figures, Table 8 shows the empirical TFM and Table 9 shows the empirical BS for the base year 2019 as a percentage of GDP.[48]

48 The ratios as a percentage of GDP presented differ slightly from those in the figures. The reason is that the TFM uses GDP after subtracting the estimated FISIM, while the graphs use GDP reported by DANE that includes FISIM.

Table 8. ***Transaction-flow matrix of the Colombian model for 2019 (%GDP)***

Variable	NFCs Current	NFCs Capital	Households	FCs Current	FCs Capital	CB Current	CB Capital	Government	RoW	Σ
Consumption of NFCs' products	+68.1%		-66.0%					-2.0%		0
Public services								+13.9% -13.9%		0
Consumption of FCs' services			-2.1%	+2.1%						0
Interm. cons. of NFCs' products	+80.4% -71.6%			-3.4%				-5.5%		0
Interm. cons. of FCs' services	-3.7%			+3.7%						0
Gross fixed capital formation	+21.5%	-13.1%	+4.5%		0.3%			-3.5%		0
Change in inventories	+0.1%	-0.1%								0
Imports	-21.6%								+21.6%	0
Exports	+16.0%								-16.0%	0
Taxes on imports	-0.4%							+0.4%		0
Value-added tax	-6.3%							+6.3%		0
Other taxes on products	-2.8%							+2.8%		0
Wages	-21.7%		+29.3	-1.6%				-6.0%		0
Employers' social contributions	-3.6%		+5.5%	-0.3%				-1.6%		0
Mixed-income distribution	-19.4%		+19.4%							0
GOS redistribution	-6.0%		+5.4%					+0.6%		0
Net other taxes on production	-2.7%			-0.1%				+2.8%		0
Int. on deposits	+0.3%		+0.6%	-1.0%				+0.1%		0
Int. on gov. deposits at the CB						-0.1%		+0.1%		0
Int. on domestic loans	-1.4%		-2.7%	+4.1%						0
Int. on domestic FX loans	-0.1%			+0.1%						0
Int. on RoW FX loans	-1.1%			-0.3%					+1.4%	0
Int. on domestic public bonds				+1.7%				-2.1%	+0.4%	0
Int. on FX public bonds								-0.5%	+0.5%	0
Int. on FX public loans								-0.2%	+0.2%	0
Int. on advances				-0.1%		+0.1%				0
Int. on FX reserves				+0.1%		+0.3%			-0.4%	0
Firms' dividends	-9.8%		+7.7%					+1.4%	+0.7	0
Banks' dividends			+0.7	-0.7%					0%	0
Royalties	-0.9%							+0.9%		0
Taxes on income	-4.0%		-2.5%	-0.5%				+7.0%		0
Workers' social contributions			-6.0%					+6.0%		0
Social transfers			+11.1%	-0.8%				-10.3%		0
Remittances			+2.2%						-2.2%	0
Central bank profits						-0.3%		+0.3%		0
Other transfers	0.7%		+2.4%	-1.0%				-0.7%	-1.3%	0
Retained earnings	-9.9%	+9.9%		-2.1%	+2.1%					0
Foreign direct investment		+3.4%			+1.0%				-4.4%	0
Cash and deposits		-0.8%	-1.9%		+2.4%			+0.2%		0
Government deposits at the CB							+0.4%	-0.4%		0
FX deposits		-0.2%			+0.5%			+0.4%	-0.7%	0
Domestic currency loans		+0.9%	+2.5%		-3.4%					0
Domestic FX loans		-0.4%			+0.4%					0
RoW FX loans		+0.5%			+0.3%				-0.8%	0
Domestic government bonds					-3.3%			+4.0%	-0.7%	0
FX government bonds								-0.5%	+0.5%	0
FX government loans								+0.2%	-0.2%	0
Insurance, pensions, and SGS			-1.1%		+1.1%					0
Domestic currency reserves					-1.4%		+1.4%			0
FX reserves					-0.1%		-1.0%		+1.2%	0
Advances					+0.8%		-0.8%			0
Σ	0	0	0	0	0	0	0	0	0	0

Table 9. ***Balance sheet of the Colombian model for 2019 (%GDP)***

Variable	NFCs	Households	FCs	CB	Government	RoW	Σ
Capital stock	242%	+40%	1%		55%		+238
Inventories	13%						+13%
[Non-financial assets]	+255%	+40%	1%		55%		+251%
Foreign direct investment	-56%		-10%			+66%	0
Cash and deposits	+9%	+18%	-31%		+4%		0
Government deposits at the CB				-1%	+1%		0
FX deposits	+2%		+1%		+0.5%	-4%	0
Domestic currency loans	-23%	-21%	+44%				0
Domestic FX loans	-2%		+2%				0
RoW FX loans	-12%		-9%			+21%	0
Domestic government bonds			+28%		-36%	+8%	0
FX government bonds					-9%	+9%	0
FX government loans					-7%	+7%	0
Insurance, pensions, and SGS		+35%	-35%				0
Domestic currency reserves			+10%	-10%			0
FX reserves			+5%	+17%		-22%	0
Advances			-2%	+2%			0
[Financial assets]	-82%	+31%	5%	+8%	-48%	+86%	0

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Afterword
Epílogo
Épilogue

The challenges Colombia faces in carrying out its low-carbon transition are enormous: the structural change that this productive transformation entails, the macroeconomic risks on the external front, and the financing of this type of policy, to mention just a few of those covered in this book. All of these occur against the backdrop of the macroeconomic, fiscal, and inflationary transition that the country is undergoing (Chapter 1).

One of the most critical challenges facing policy makers is that of responding to an incentive-based productive policy mix, which requires complex exercises to establish the comparative and potential advantages of the demand for goods and services in the near future. That is, determining which sectors or set of sectors active policies should focus on in order to increase their participation within the country's economic structure, or to establish them as alternatives to compensate for the decrease in foreign exchange inflows and reserves—given the reduction in international demand for and/or national production of coal and oil (Chapters 2 and 3).

At this point, it is necessary to consider how this structural change will affect the labour market and, therefore, how people earn an income. A large part of the structural change will be accompanied by technological change: some workers will have to relocate to other sectors of the economy, and others may lose their jobs. It is, therefore, essential to have a social protection system that serves as a safety net for the latter. In addition, active policies for digitalisation, retraining, and upgrading of people's skills are needed to help absorb these shocks (Chapter 6).

On the other hand, after overcoming the COVID-19 pandemic, the global economic system has become increasingly fragile (Chapter 5). It has been hit once more by the conflicts that have arisen in the last two years, such as Russia's invasion of Ukraine and the events in the Middle East. Such conflicts have raised energy prices, as well as gas and food prices as a result of grain shortages and increases in fertiliser prices, leading to persistent global inflation. As a monetary policy response, the world interest rates have been increased, making external indebtedness more expensive for Colombia and slightly contracting external demand, which affects the country's non-traditional exports.

One of the big questions that the energy transition will have to answer is the following: What sources of financing are the most adequate for carrying out this type of transformation? One option is the exchange of debt for climate action and creating and deepening a green bond market in Colombia (Chapter 4). However, for this kind of policy to succeed, it is necessary to consider the valuation of both environmental assets and liabilities, since this is fundamental in order to attract the foreign currency needed to finance the various policies implemented. Additionally, as specified in many different sections of the book, the diversification of exports—through productive transformation and a search for markets abroad, especially in Latin America—can help replace the income lost due to reduced exploitation of coal and oil.

As can be seen, the policy challenges that Colombia will face in the coming years are significant and testing. For the transition to be a success in the medium and long term, a set of interrelated policies (such as energy transition, productive transformation, and financing of such policies) are needed to achieve economic growth, improve the socioeconomic conditions of the population, and contribute to the environmental sustainability of the country.

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Los desafíos que enfrenta Colombia ante una transición baja en carbono son enormes, solo por mencionar algunos abarcados en el libro: el cambio estructural que conlleva esta transformación productiva, los riesgos macroeconómicos en el frente externo y el financiamiento de este tipo de políticas. Los cuales se dan en un contexto, en el que el país está viviendo una transición en lo macroeconómico, en lo fiscal y en lo inflacionario (Capítulo 1).Uno de los retos más importantes que está enfrentando los hacedores de política es responder a una combinación de política productivas con base en incentivos, lo cual exigen ejercicios complejos para establecer las ventajas comparativas y potenciales de las demandas de bienes y servicios en el futuro próximo. Esto es, a cuáles sectores o conjunto de sectores deben enfocarse políticas activas para aumentar su participación dentro de la estructura económica del país o como alternativa para reemplazar la disminución de entradas de divisas y reservas internacionales, ante una reducción de la demanda internacional y/o producción nacional de carbón y petróleo (Capítulos 2 y 3).

En este punto hay que considerar como este cambio estructural va a afectar el mercado de trabajo y, por ende, la generación de ingresos de las personas. Ya que una gran parte del cambio estructural vendrá acompañado por un cambio tecnológico, en la que algunos trabajadores deban de reacomodarse hacia otros sectores de la economía, y otros puedan perder su empleo. Entonces, es importante contar con un sistema de protección social que sirva como red de seguridad para estos últimos. Además, contar con políticas activas de digitalización, reentrenamiento y cualificación de las habilidades de las personas, para ayudar en la absorción de este tipo de choques (Capítulo 6).

De otra parte, después de superar la pandemia del COVID, la fragilidad del sistema económico, a nivel global, se ha incrementado (Capítulo 5). El cual ha sido nuevamente golpeado por los conflictos que han surgido en los dos últimos años, como la invasión de Rusia a Ucrania y los acontecimientos en Oriente Medio, que han incrementado los precios de la energía, vía incremento en los precios del gas, y de los alimentos, a través del desabastecimiento de cereales e incremento en los precios de los fertilizantes, lo que ha llevado a una inflación mundial persistente. Como respuesta de política monetaria se ha incrementado la tasa de interés, haciendo que el endeudamiento externo sea más caro para Colombia, además de contraer levemente la demanda externa, lo cual afecta las exportaciones no tradicionales del país.

Uno de los grandes interrogantes que debe responder la transición energética es cuáles pueden ser las fuentes de financiamiento con las que se quiere llevar a cabo este tipo de transformación. Una de las alternativas es el canje de deuda por acción climática y la creación y profundización de un mercado de bonos verdes en Colombia (Capítulo 4). Ahora bien, para el éxito de esta clase de políticas hay que considerar que la valoración tanto del activo y el pasivo ambiental, ya que es fundamental para la captación de divisas para el financiamiento de las diversas políticas implementadas. Adicionalmente, la diversificación de las exportaciones, a través de la transformación productiva y una búsqueda de mercados en el exterior, especialmente entre los países del continente, pueden ayudar a reemplazar los ingresos perdidos por una menor explotación de carbón y petróleo.

Como se puede apreciar los retos de política a los que se enfrentará Colombia en los próximos años son significativos y desafiantes. Ya que pasan por un conjunto de políticas como la transición energética, la transformación productiva y el financiamiento de tales políticas, las cuales están interrelacionadas entre sí, para lograr el crecimiento de la economía, mejorar las condiciones socioeconómicas de la población y contribuir con la sostenibilidad ambiental del país sean un éxito en el mediano y largo plazo.

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Les défis auxquels la Colombie est confrontée dans le cadre d'une transition bas carbone sont énormes, pour n'en citer que quelques-uns abordés dans le livre : le changement structurel qu'implique cette transformation productive, les risques macroéconomiques externes et le financement de ce type de politique publique de transition. L'un des principaux enjeux pour les responsables politiques consiste à élaborer une stratégie combinant différentes politiques publiques axées sur les incitations. Cela implique la réalisation d'analyses complexes pour déterminer les avantages relatifs et les bénéfices potentiels liés à la consommation de biens et services dans un futur proche. En d'autres termes, il s'agit de définir quels secteurs ou ensembles de secteurs devraient être ciblés par des politiques actives afin d'accroître leur part dans la structure économique du pays ou en tant qu'alternative pour remplacer les entrées de devises internationales et les réserves en déclin face à la réduction de la demande internationale et/ou de la production nationale de charbon et de pétrole (Chapitres 2 et 3).

À ce stade, il est essentiel d'analyser l'impact de cette transformation structurelle sur le marché de l'emploi et, en conséquence, sur la capacité des individus à générer des revenus. Une grande partie du changement structurel s'accompagnera de changements technologiques, ce qui obligera certains travailleurs à migrer vers d'autres secteurs de l'économie et d'autres à perdre leur emploi. Il est donc important de disposer d'un système de protection sociale qui serve de filet de sécurité pour ces derniers. En outre, des politiques actives de numérition, de recyclage et d'amélioration des compétences doivent être mises en place pour aider à absorber ces chocs (Chapitre 6).

Suite à la pandémie de COVID, la Colombie a été confrontée à une augmentation de la fragilité du système économique mondial (Chapitre 5), exacerbée par les conflits survenus ces deux dernières années. Parmi ces conflits, l'invasion de l'Ukraine par la Russie et les tensions au Moyen-Orient se sont particulièrement démarquées, provoquant une hausse des prix de l'énergie due à l'augmentation des coûts du gaz, ainsi qu'une inflation des prix alimentaires, résultant des pénuries de céréales et de l'escalade des prix des engrais. Ces facteurs ont ensemble contribué à une inflation mondiale persistante. En réponse, la politique monétaire a ajusté les taux d'intérêt à la hausse, rendant ainsi les emprunts internationaux plus onéreux pour la Colombie. Cette mesure a eu pour effet de réduire modérément la demande internationale, impactant négativement les exportations non traditionnelles du pays.

L'une des grandes questions auxquelles la transition énergétique doit répondre est de savoir quelles sources de financement peuvent être utilisées pour mener à bien ce type de transformation. L'une des alternatives est l'échange de dettes contre des actions en faveur du climat, ainsi que la création et l'approfondissement d'un marché d'obligations vertes en Colombie (Chapitre 4). Cependant, pour que ce type de politique soit couronné de succès, il est nécessaire de prendre en compte l'évaluation des actifs et des passifs environnementaux afin d'attirer des devises étrangères et de financer les différentes politiques mises en œuvre. En outre, la diversification des exportations, grâce à la transformation productive et à la recherche de marchés à l'étranger, notamment parmi les pays du continent, peut contribuer à remplacer la perte de revenus en raison de la réduction de l'exploitation du charbon et du pétrole.

Comme on peut le constater, les défis politiques auxquels la Colombie sera confrontée dans les années à venir sont importants et difficiles à relever. Ils impliquent un ensemble de politiques telles que la transition énergétique, la transformation productive et le financement de ces politiques, qui sont interdépendantes, afin de parvenir à la croissance économique, d'améliorer les conditions socio-économiques de la population et de contribuer à la durabilité environnementale du pays à moyen et à long terme.

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AFD	Agence Française de Développement
AFOLU	Agriculture forestry and other land use
BANREP	Banco de la República (Colombia Central Bank)
BAU scenarios	Business as Usual scenarios
BL	Backward Linkages
BoP	Balance of Payments
BS	Balance Sheet
CB	Central Bank
CEMBI	Corporate Emerging Markets Bond Index
CMA-ES	Covariance matrix adaptation – evolution strategy
COP21	21st Conference of the Parties to the United Nations Framework Convention on Climate Change
COP26	26th Conference of the Parties to the United Nations Framework Convention on Climate Change
CPI	Consumer Price Index
DANE	Departamento Administrativo Nacional de Estadística (Colombian National Statistics Office)
DNP	Departamento Nacional de Planeación
DSGE models	Dynamic Stochastic General Equilibrium models
EMBI	Emerging Markets Bond Index
ECLAC	Economic Commission for Latin America and the Caribbean
ESO	Employee Stock Options
EU	European Union
E2050	Energy 2050 Strategy
FA	Financial Account
FCs	Financial Corporations
FDI	Foreign Direct Investment
FeD	US Federal Reserve
FL	Forward Linkages
FoF	Flow of Funds
FISIM	Financial Intermediation Services Indirectly Measured

GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gas Emissions
GVA	Gross Value Added
IC	Intermediate Consumption
ICT	Information and Communication Technology
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales (Institute of Hydrology, Meteorology, and Environmental Studies)
IEA	Integrated Economic Accounts
IIP	International Investment Position
IMF	International Monetary Fund
MHCP	Ministerio de Hacienda y Crédito Público
MME	Ministerio de Minas y Energía
MRIO	Multi-Regional Input-Output
NDC	Nationally Determined Contributions
NFCs	Non-Financial Corporations
NPI	Non-Profit Institutions
NPISH	Non-Profit Institutions Serving Households
OMOs	Open Market Operations
PPI	Producer Price Index
REPO	Repurchase agreement operations
R&D	Research and Development
RK4 method	Runge-Kutta of order 4 method (numerical technique used to solve ordinary differential equations (ODEs).
SFC models	Stock-Flow Consistent models
SDA	Structural Decomposition Analysis
SDRs	Special drawing rights
SMEs	Small and Medium-sized Enterprises
SNA	System of National Accounts
TFM	Transaction-Flow Matrix
TES	Títulos de Tesorería (Bonds issued by the Colombian government)
UN	United Nations
UNAL	Universidad Nacional de Colombia
VAT	Value-added tax
VAR models	Vector autoregressive models

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Summary

With over fifty percent of its total exports consisting of petroleum and coal, Colombia remains highly vulnerable to both global and domestic energy transitions. With the aim of fostering policy dialogue, this book assesses these long-term macro-financial risks, opportunities and vulnerabilities as it contends with the global shift towards a low-carbon economy and the domestic emission reduction initiatives outlined in the latest Nationally Determined Contribution (NDC). To this end, the authors develop an empirical macroeconomic Stock-Flow model of Colombia (GEMMES - General Monetary and Multisectoral Macrodynamics for the Ecological Shift) to analyze the implications of various global and domestic transition scenarios. The model distinguishes itself from existing literature by its strong focus on the financial system and the explicit feedback loops between the real and financial sectors of the economy. The authors present a comprehensive macroeconomic analysis of the complex interplay between the transformation of the real economy and the dynamics of the financial sector and public balances.

The effective development and implementation of the GEMMES model for Colombia have been achieved through a strong collaboration between key domestic institutions, such as the National Department of Planning (Departamento Nacional de Planeación), the Ministry of Finance (Ministerio de Hacienda y Crédito Público), the National University of Colombia (Universidad Nacional de Colombia), and the GEMMES modelling team at the French Development Agency (Agence Française de Développement). The findings from this collaborative effort highlight the importance of coherent industrial, monetary, and fiscal policies in managing the transition effectively in Colombia. Both to mitigate adverse effects and to accelerate the country's socioeconomic development path, the transition represents an opportunity to diversify the productive structure, integrate into the value chains of new green industries, strengthen public infrastructure, generate quality jobs and reduce dependence on natural resource-based industries.

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