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The Future of Jobs and Pensions

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Greening Colombia's energy: the future of jobs and pensions

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Abstract

This paper evaluates the effects of Colombia's transition to a low-carbon economy on employment and pensions. Utilizing a three-stage analysis integrating national energy scenarios, an input-output model, and a pension microsimulation model, we quantify the green transition's effects on employment and pensions. Our results indicate a net reduction in employment requirements, more pronounced without specific transition policies (2.16% long-run reduction) compared to a scenario with active transition measures (0.4% reduction). Job losses are concentrated in high-carbon sectors (oil, coal), with industry and services also affected through intersectoral linkages. Conversely, renewable energy sectors show employment gains. The projected employment changes have a modest negative impact on the pension system. Contributory pension coverage sees a slight decrease, and fiscal pressure and benefits inequality exhibit minimal changes. These limited effects result from the relatively small employment shocks and stringent pension eligibility criteria.

Keywords: Green Transition, Sustainable Development, Pension System, Inequality, Colombia.

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Résumé

Cet article évalue les effets de la transition de la Colombie vers une économie à faibles émissions de carbone sur l'emploi et les retraites. En s'appuyant sur une analyse en trois étapes — intégrant des scénarios énergétiques nationaux, un modèle entrées-sorties et un modèle de microsimulation des retraites —, nous quantifions les effets de la transition écologique sur l'emploi et les pensions.

Nos résultats indiquent une réduction nette des besoins en emploi, plus marquée en l'absence de politiques spécifiques d'accompagnement de la transition (réduction de 2,16% à long terme), contre une réduction plus modérée (0,4%) dans un scénario comprenant des mesures de transition actives. Les pertes d'emplois se concentrent dans les secteurs fortement carbonés (pétrole, charbon), tandis que l'industrie et les services sont également affectés par les effets d'interconnexion intersectoriels. À l'inverse, les secteurs des énergies renouvelables enregistrent des gains d'emplois.

Les changements projetés en matière d'emploi ont un impact négatif modeste sur le système de retraite. La couverture des retraites contributives connaît une légère baisse, tandis que la pression fiscale et les inégalités dans les prestations varient peu. Ces effets limités s'expliquent par l'ampleur relativement réduite des chocs sur l'emploi et par les critères d'éligibilité stricts du système de retraite.

Mots-clés: Transition écologique, développement durable, système de retraite, inégalités, Colombie.

1. Introduction

Following the Paris Climate Agreement in 2015, the green transition has gained momentum as a fundamental element of policy worldwide. The green transition refers to the process by which economies shift from traditional production models that rely heavily on polluting technologies to low-carbon and sustainable practices, aimed to develop climate-safe economies.

The success of the green transition will be measured not only by the decarbonization of the economy but also by the fair distribution of its costs and benefits across sectors and populations (Vanegas Cantarero, 2020). From a policy perspective, achieving fair inclusion requires strong social protection policies to support households negatively affected by the transition (UNFCCC, 2020; Morales, 2023). The green transition involves a structural transformation of the economic model towards producing and consuming goods and services with a lower environmental footprint. These changes are expected to impact job availability, benefiting some workers while leaving others behind. This dynamic will require adjustments in social security systems, especially in developing countries where social safety nets and contributory pension systems are less developed. A key concern is that vulnerable workers left behind may face unequal access to quality job opportunities. This inequality can have negative consequences both in the short term and long term, potentially exacerbating disparities after retirement by limiting access to adequate pensions for the most vulnerable.

This paper analyzes the long-run consequences of transitioning to a low-carbon economy on the economic protection of the elderly in Colombia. We use a framework to measure the effects of greening the energy sector on employment requirements and the pension system. In this analysis, greening the economy focuses on transitioning from high-carbon energy sources to more energy-efficient operations, increasing electricity use by both consumers and industries, reducing external demand for high-carbon commodities, and investing to enhance climate resilience. We characterize three scenarios up to 2052, based on official projections from the Colombian Energy Planning Unit (Unidad de Planeación Minero Energética, 2024a) and World Bank estimates of necessary investments for the transition (World Bank, 2023). The three scenarios considered are: a baseline scenario with no transition policies, a conservative scenario with reductions in oil and coal production due to decreased external demand and production constraints, and an energy transition scenario with rapid reductions in coal and oil exports, local substitution of energy sources, and investments to implement the transition.

We incorporate the transition scenarios into an input-output model to analyze their effects on output and employment. The approach approximates the impact of the transition on employment by aggregating direct and indirect employment changes at the industry level. Using data from national accounts, we compute changes in output and employment at the industry level driven by the demand shocks resulting from the green transition.

Finally, we use the resulting industry-level employment paths as input to the CEDE pension model, a microsimulation tool designed to calculate relevant variables of the Colombian pension system. Sectoral changes in employment levels have different effects depending on the prevalence of informal employment in each industry. Consequently, shifts in future employment trajectories due to the green transition affect workers' probability of qualifying for a pension, as well as their benefit levels. These potential changes in pension coverage and benefits have long-term implications for key aspects of the pension system, including fiscal sustainability, economic vulnerability, and post-retirement income inequality.

Our results indicate that the projected decline in demand for high-carbon energy sources will lead to a long-run reduction in total employment requirements of about 2.16% without transition policies, and a reduction of 0.4% in a scenario with energy transition policies. While the effects are concentrated in high-carbon industries, significant changes also occur in the service and industrial sectors due to intersectoral linkages. For instance, industries like manufacturing, construction, and professional activities rely on intermediate consumption from the mining sector. In contrast, the agricultural sector, which has relatively weak links to high-carbon industries, experiences minimal long-term employment changes.

Because workers have different propensities to work in industries expected to face a reduction in employment requirements, the reduced demand resulting from the green transition would have varying effects across groups. In particular, the analysis suggests that the reduction in employment requirements is more likely to affect formal-sector workers. This implies that the green transition would impact the number of workers contributing to the pension system and the number of older workers receiving a contributory pension. Compared to the baseline, the simulation results show small reductions in the share of older adults receiving a pension in the conservative and energy transition scenarios, from 27.2% to 26.8% and 27.1%, respectively. These small impacts also have moderate effects on the public deficit of the pension system and on income inequality after retirement.

This paper contributes to the growing literature on the implications of the green transition for labor markets and social protection systems by considering the long-term impacts on pension outcomes. Social protection has been identified as a key policy area to achieve a just transition (Rigolini, 2022; International Labour Office, 2024). Most analyses focus on the imperative need for social transfers as a safety net to compensate vulnerable workers for current employment losses (Berthe et al., 2022; Morales, 2023; World Bank, 2023; Gasior et al., 2024). However, the literature assessing the long-term effects of the transition on pensions is scarce. Generally, discussions on pensions have centered on the role of early pensions to compensate displaced workers in carbon-intensive sectors (Pollin and Callaci, 2019), and the role of institutional pension funds in financing the transition (Della Croce et al., 2011; Berg, 2021). The closest reference to this paper is Natali et al. (2022), which discusses potential challenges that the green transition poses to pension systems in the European Union. This study is the first to develop a quantitative assessment in a middle-income country like Colombia.

While the quantitative results are specific to the Colombian case, the analytical framework is relevant for understanding the effects of the green transition beyond Colombia. Many developing and emerging economies face similar risks, as they have high dependence on carbon-intensive industries, labor markets with a high incidence of informal job opportunities, and low economic protection for their older adults.

The rest of the paper is organized as follows. Section 2 discusses the institutional background of Colombia's energy production and consumption, and their economic and social vulnerabilities. Section 3 details the implementation and the data used to quantify the impact of the green transition on employment and post-retirement income inequality. Section 4 presents our results, and Section 5 concludes.

2. Context

One of the main concerns in the discussion about the green transition in Colombia is how to reduce the country's dependency on high-carbon energy sources while minimizing the negative impact on the economy.[1] In this section, we describe three features that will play a role in determining those effects: the country's dependency on high-carbon energy sources, the prevalence of informal jobs, and the design of the pension system.

2.1. The dependency on high-carbon energy sources

Energy production in Colombia is dominated by coal, oil, and natural gas. As presented in Figure 1, these three sources account for 88.3% of the country's energy supply. There is a moderate supply of energy from renewable sources (11.7%), mostly hydropower and biomass, with a minimal participation of wind and solar power (left panel). A significant share of this production is exported (over 95% of coal and 45% of oil production), and the rest is used internally by firms and households (right panel). The demand for energy varies depending on the type of consumer: while households consume electricity and biomass, industrial processes and passenger and freight transport rely heavily on fossil fuels.[2]

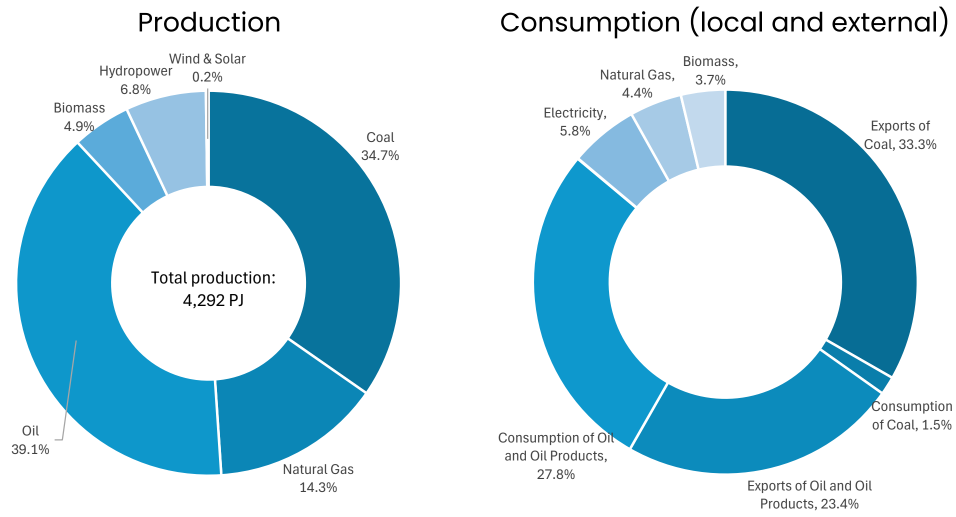
The dominance of high-carbon energy sources in both production and domestic consumption underscores the challenges of transitioning to a low-carbon economy. A successful energy transition implies changes in both internal and external demand for high-carbon energy sources. Regarding internal demand challenges, despite being a relatively small contributor to global greenhouse gas (GHG) emissions,[3] the country has committed to an ambitious reduction plan to cut emissions by half by 2030 and reach net-zero emissions by 2050 (Government of Colombia, 2020).[4] These commitments require substituting high-carbon energy sources with renewable ones, especially in the energy and transportation sectors, and reducing the carbon footprint in AFOLU (Agriculture, Forestry, and Other Land

[1]Our analysis focuses on specific economic aspects of Colombia's vulnerability to the green transition and climate change. For more comprehensive diagnostics, including other social and environmental dimensions, see Colombia's Nationally Determined Contributions (NDCs) (Government of Colombia, 2020) and the World Bank's Country Climate and Development Report (World Bank, 2023).

[2]Local energy production is not equal to the sum of external and local energy consumption. The energy matrix also includes energy imports and energy transformation processes.

[3]Overall, Colombia's emissions represent 0.57% of global emissions in 2021, ranking 30th in total GHG emissions and 88th in per capita terms (Climate Watch, 2025).

[4]According to World Bank estimates, achieving the net-zero emissions target proposed in Colombia's Nationally Determined Contributions (NDCs) will require annual emission reductions of approximately 3% (World Bank, 2023).



Notes: This Figure shows the total local energy production (left) and the external and internal energy consumption (right) by source in 2022. Local energy production is not equal to the sum of external and local energy consumption. The energy matrix also includes energy imports and energy transformation processes.
Source: Unidad de Planeación Minero Energética (2024b)

Figure 1: Colombia's energy supply and consumption by source, 2022

Use) primarily through deforestation control and ecological restoration, as these three sectors account for 88% of Colombia's GHG emissions (see Figure A.1 in the appendix).

Changes in external demand pose additional challenges for Colombia's transition to a low-carbon economy. Global decarbonization efforts pose a significant macroeconomic risk for developing countries heavily reliant on these exports, as they are major sources of foreign exchange earnings and fiscal revenues (Godin et al., 2023; Magacho et al., 2023). In Colombia, the oil and coal sectors represent approximately 40% of total exports, constitute 20% of foreign direct investment, and account for between 10% and 20% of the country's fiscal revenues, including taxes, royalties, and revenues from Ecopetrol, the state-owned oil company (Ríos et al., 2023). Nonetheless, while Colombia has been steadily exporting oil and coal, prospective analyses project that the production of these resources will decrease in the coming decades due to diminishing proven reserves and planned closures of existing coal mines (Willis Towers Watson, 2023). If this scenario materializes, the production of oil and coal will decline even without transition policies.

Taken together, a decline in external demand for oil and coal due to the green transition can have a significant impact on the rest of the economy (Hernández et al., 2023). Reducing the production of high-carbon energy sources has direct effects on jobs in communities and regions where economic activity is concentrated in oil and coal. Furthermore, there are indirect upstream and downstream effects in other industries that supply and purchase from the mining sectors. The expected decline in government revenues and foreign exchange earnings will be difficult to replace in the coming years, complicating the financing of necessary investments for the transition.

2.2. The Colombian labor market

The Colombian labor market is characterized by a high prevalence of informal (unregulated) job opportunities and a significant concentration of employment in the services sector. These characteristics are relevant for understanding the pass-through effects of the green transition on employment and the pension system. Because informal employment is more prevalent in specific industries, the changes in employment resulting from the green transition may disproportionately affect the balance between formal and informal employment and, consequently, access to pensions.

Table 1 presents summary statistics of the Colombian labor market based on household surveys (GEIH) of 2023.[5] Overall, total employment during this period accounted for 22.8 million workers. For each economic sector, the table presents the share of employment, the informality rate, and the monthly earnings in the formal and informal sectors (normalized to the statutory monthly minimum wage). In this analysis, we define a formal-sector job as one in which the worker reported contributing to the pension system.

	Share of total (%)	Informality rate (%)	Ave. earnings (min wage = 1)	
			Informal	Formal
Agriculture, forestry and fishing	13.2	84.9	0.74	1.29
Mining and quarrying	1.3	49.9	0.83	2.29
Manufacturing	10.7	43.6	0.85	1.60
Electricity and water supply	1.4	31.4	0.57	1.97
Construction	7.2	64.8	0.92	1.68
Trade, transport and storage	32.2	64.5	0.87	1.54
Information and communication	2.0	11.2	1.48	2.59
Financial and insurance activities	2.0	10.2	1.34	2.63
Real estate activities	1.2	13.7	1.69	1.43
Professional and admin activities	8.3	39.3	1.09	2.14
Public administration	12.5	10.0	1.47	2.57
Other service activities	8.1	73.0	0.96	1.75
Total	100.0	53.4	0.89	1.96

Notes: The table presents statistics on the Colombian labor market for 2023. Workers are classified as informal if they did not contribute to the pension system. Economic sectors follow the International Standard Industrial Classification (ISIC) Revision 4. Source: Author calculations based on GEIH.

Table 1: Labor market indicators, 2023

Despite their economic importance, mining constitutes a small share of employment, accounting for 1.3% of total employment. However, compared to the average worker, workers in the mining industry are less likely to hold informal jobs (49.9% versus 53.6%) and earn more in formal employment (2.29 versus 1.96). Thus, a reduction in mining jobs may negatively impact contributions to the pension system. The aggregate effect is expected to be small due to the relatively low share of employment in mining.

Along with the anticipated contraction of formal-sector employment in the mining sector, other factors amplify and offset the effects of the green transition on formal employment and pension contributions. The overall effect will depend on the relative strength of these factors and the prevalence of informal employment in affected industries. On one hand,

[5] We restrict our analysis to workers aged 20 and over and younger than the minimum retirement age.

the transition will have indirect effects on the rest of the economy through upstream and downstream industries. For instance, sectors such as manufacturing, construction, and professional activities rely on intermediate inputs from the mining sector, while sectors like transport and oil derivatives depend on mining production as inputs in their processes. The overall effect on employment contributing to the pension system depends on the specific industry affected: for example, a negative impact on sectors with low informal employment rates and higher formal sector earnings (e.g., professional activities) would negatively affect the number of workers contributing to the pension system.

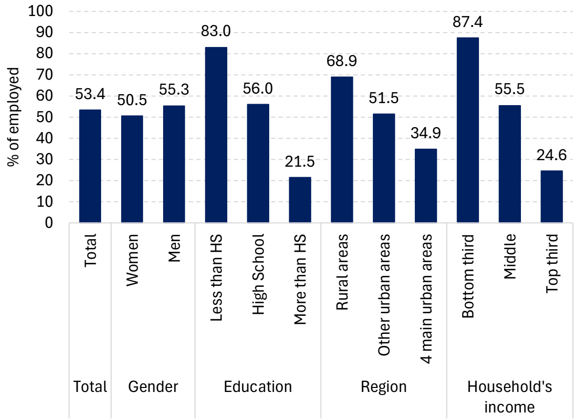
On the other hand, the green transition will demand other types of jobs that may increase employment contributing to the pension system. For instance, the shift from a fleet primarily based on fossil fuels to electric vehicles in the transport sector would require increased demand for employment in electricity supply, an industry with lower levels of informal employment than mining (31.4% versus 49.9%). In this case, the effect of the green transition on the number of workers contributing to the pension system are expected to be positive and moderate, given the relatively small size of the mining sector (1.4%). Similar to the case of mining, the expected changes in the demand for electricity will also have indirect effects through sectoral linkages.

An additional consideration in the analysis of the labor market is that its composition is key to understanding current socioeconomic vulnerabilities to the green transition. If the expected employment changes resulting from the transition to a low-carbon economy disproportionately affect more vulnerable workers, the green transition may exacerbate poverty and inequality. This is a particular concern for Colombia, where the national poverty headcount ratio reached 33% of the total population in 2023, with 11% experiencing extreme poverty. Furthermore, income inequality, measured by the Gini index, reached 0.528 in 2023, placing Colombia among the most unequal societies globally (DANE, 2024). Figure 2 presents the formal employment rate for various demographic groups in 2023. As the figure shows, informality is strongly prevalent among workers with lower levels of education and those living in rural and small urban areas. Consistent with these patterns, labor informality exhibits a strong correlation with economic vulnerability: while the informal employment rate for workers in households within the bottom third of the income distribution is 87.4%, the corresponding figure for workers in the top third is 24.6%.

2.3. The Colombian pension system

The potential reallocation between formal and informal employment resulting from the green transition represents an important challenge for the economic protection of older adults in Colombia. This section describes the main features of the pension system.

Following a major reform in 2025, the Colombian pension system, which previously involved competition between a defined benefit (DB) pay-as-you-go plan and a defined contribution (DC) individual account plan, was replaced with a complementary system integrating these two plans.



Notes: The figure presents the informal employment rate for various demographic groups as reported by household surveys in 2023. Workers are classified as informal if they did not contribute to the pension system.
Source: Author calculations based on GEIH.

Figure 2: Informal employment rates by group, 2023

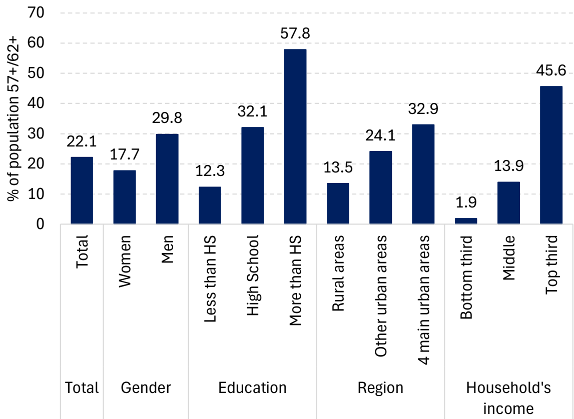
The new system comprises three pillars: contributory, solidarity, and voluntary. The core is the contributory pillar, which features complementarity between the DB and DC components. All salaried and self-employed workers are required to contribute 16% of their taxable income, with contributions to the DB component capped at 2.3 times the legal minimum wage; any excess contributions are allocated to the DC component. In practice, this rule means that approximately 85% of workers contribute only to the DB component.

The eligibility requirements for accessing a pension are based on age and contribution time. The minimum retirement age is 57 years for men and 62 years for women, while the minimum contribution period is 1300 weeks (about 25 years) for men. For women, this requirement will gradually decrease from 1300 to 1000 weeks over the next 10 years. The pension benefit is determined by the combination of a fixed formula in the DB component plus a lifetime annuity financed with the worker's DC individual account.

Unfortunately, the high prevalence of informal employment means that a significant proportion of workers do not qualify for a contributory pension upon reaching retirement age. For instance, by 2020, Colombian women and men had accumulated an average of 10.3 and 12.4 years of contributions at retirement age, and by 2023, only 31% of men and 20% of women of retirement age received a contributory pension (Becerra et al., 2023). For those who do not qualify for a pension from the contributory pillar, the system includes two complementary elements within the solidarity pillar. The first is a means-tested, non-contributory pension that covers approximately 25% of older adults identified as vulnerable according to SISBEN (a household vulnerability index). Eligible individuals receive a lump-sum transfer of $160 PPP (in 2023 US Dollars, adjusted for Purchasing Power Parity) per month, which is lower than both the minimum contributory pension ($1160 PPP in 2023) and the national poverty line ($310 PPP in 2023). The second element is that individuals who contributed to the contributory system for at least 300 weeks but did not qualify for a pension are eligible to receive a lifetime annuity based on their pension contributions (including those in the DB plan).

In general, the new system represents an improvement over its predecessor, as it strengthens the safety net for vulnerable populations ineligible for a pension. However, the system is still subject to two main criticisms. First, it tends to perpetuate existing income inequality after retirement. The formula used to compute pension benefits in the DB plan typically implies a transfer larger than the pensioner's contributions during their working years (Bosch et al., 2015; Becerra et al., 2022), and also larger than the transfers made to vulnerable older adults. Because pension eligibility is based on contributions, pensioners are typically workers with stable employment histories in formal sector jobs who also tend to have higher earnings (see Table 1), and government transfers tend to concentrate on the upper part of the income distribution (Becerra et al., 2023).

Figure 3 displays the coverage of the pension system in 2023 by demographic characteristics, estimated from household surveys. We define pension system coverage as the percentage of the population older than the minimum retirement age that reports receiving a contributory pension. The overall coverage of the pension system is approximately 22% of the older population, but there are substantial differences across groups. Consistent with the evidence presented in Figure 2, workers belonging to groups with lower access to formal job opportunities are less likely to be eligible for a pension. The figure shows that coverage is higher for men than for women (29.8% versus 17.7%); the population with less than a high school education has significantly lower coverage (12.3%) than workers with medium and high levels of education (32.1% and 57.8%, respectively); and older adults living in rural areas have lower pension system coverage (13.5%) than those living in small urban areas (24.1%) and large urban areas (32.9%). Overall, these differences are negatively correlated with income vulnerability: while the coverage of the contributory pension system is only 1.9% and 13.9% for the population in the lower and middle parts of the income distribution, 45.6% of the population in the upper part of the income distribution is covered by the contributory pension system.



Notes: The figure presents the fraction of older adults receiving a pension for various demographic groups as reported by household surveys in 2023.

Source: Author calculations based on GEIH.

Figure 3: Coverage of contributory pensions by demographic characteristics, 2023

The second concern is that, despite a relatively low number of pensioners, pension payments represent a significant burden on the government's fiscal accounts, accounting for 4% of GDP and 12% of total government expenditures. Two-thirds of these expenditures are concentrated on a minority of public employees, while the rest is spent on the defined-benefit component of the general pension system (Azuero-Zuñiga, 2020). In contrast, it is estimated that the annual expenditure of the solidarity pillar, which covers the population of vulnerable adults, will account for less than 1% of GDP per year.

3. Methodological approach

The greening of the economy is a broad concept with multiple impacts on employment and pension systems. To analyze these effects, we employ a three-step analysis. First, we develop plausible scenarios for demand shifts resulting from the green transition. Second, we incorporate these shifts into an input-output model to determine the sectoral employment effects. Finally, we use the industry-level employment projections to quantify the impact of the transition on key pension system variables.

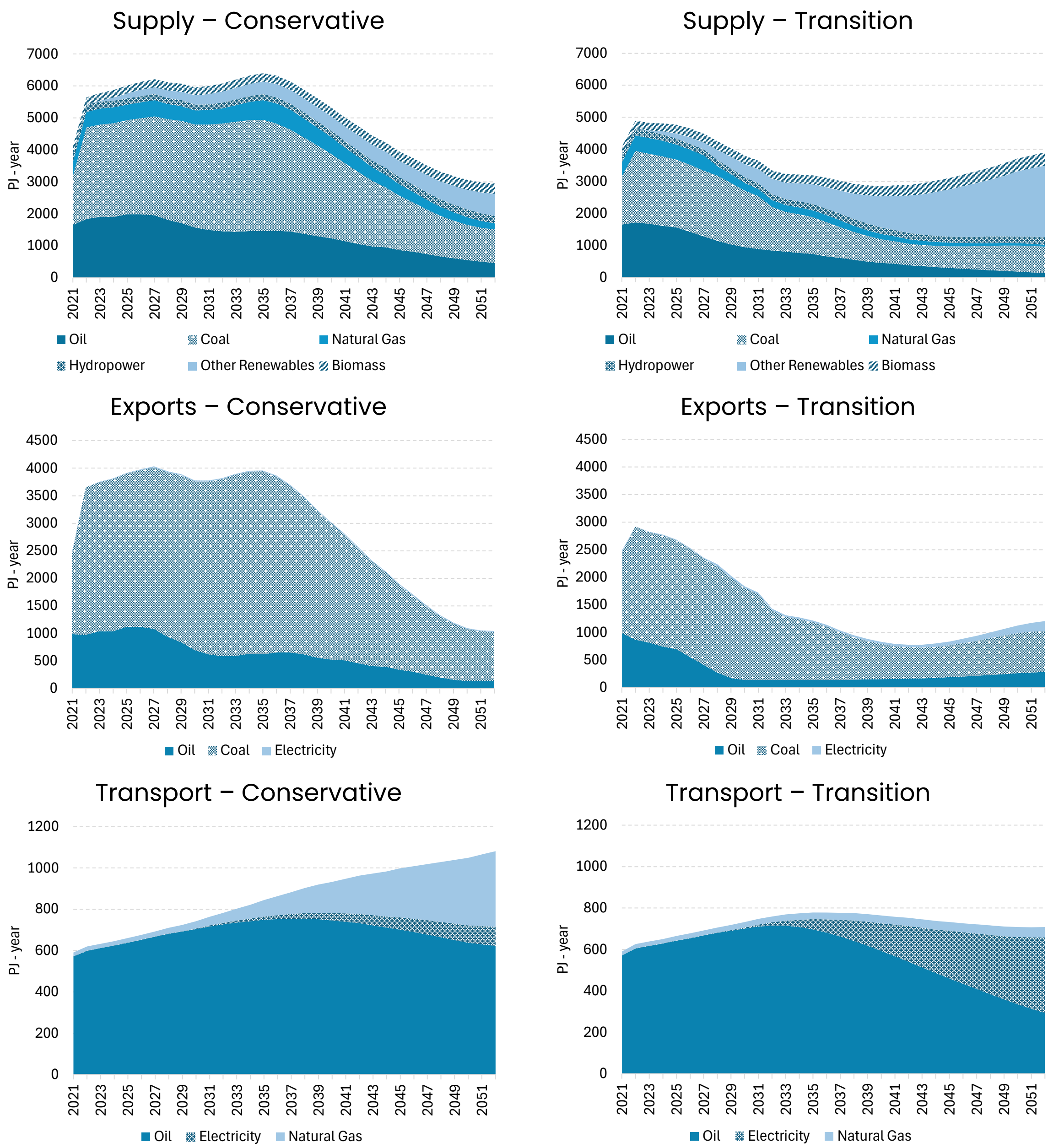
3.1. Transition scenarios

The green transition involves a series of changes in how economic agents produce and consume. To develop plausible scenarios for Colombia's transition, we rely on the National Energy Plan 2022-2052, prepared by the Mining and Energy Planning Unit (UPME). We complement these scenarios with projections of required investments to carry out the transtion and enhance climate resilience developed by the World Bank (World Bank, 2023).

Regarding the energy transition scenarios, the Plan presents pathways for the transition from high-carbon energy sources to more energy-efficient operations, increased electricity use by both consumers and industries, and reduced external demand for high-carbon commodities. We focus on two contrasting scenarios: the conservative and the energy transition.[6] In the conservative scenario, Colombia advances in diversifying its energy matrix and modernizing transport and consumption technologies. However, efficiency improvements are moderate relative to national targets. The energy transition scenario, on the other hand, is an ambitious plan accelerating the transformation of the energy system. Prioritizing mature and emerging energy technologies, it aligns with national just energy transition goals (Unidad de Planeación Minero Energética, 2024a). According to the UPME, the observed trends in the energy sector are similar to those observed in the conservative scenario.

Figure 4 summarizes the time trends of energy production and demand under the conservative and transition scenarios. Both scenarios illustrate the extent of changes associated with the energy transition, as energy production and consumption shift towards low-carbon energy sources. The top panel of Figure 4 compares energy supply by scenario. In the conservative scenario, energy production is expected to increase between 2022 and 2035, primarily from oil and coal, followed by a decline due to anticipated lower international demand and reduced production capacity. Renewable energy sources maintain stable hydropower contributions and gradually increase the share of solar and wind energy. In contrast, the transition scenario anticipates a rapid reduction in energy production driven by high-carbon sources, which are partially offset by renewable energy sources after 2030.

[6] In the Plan, the names of the scenarios are *Actualización* and *Transición Energética – Límite Superior*.



Notes: This Figure presents scenarios of national production, exports, and consumption of transport sector energy by energy source under the conservative and transition scenarios outlined in the National Energy Plan 2022-2052.
Source: Unidad de Planeación Minero Energética (2024a)

Figure 4: Energy transition scenarios, 2022-2052

The middle and bottom panels of Figure 4 compare scenarios for external demand (exports) and the demand of the transport sector, a critical industry for reaching Colombia's decarbonization goals. Regarding exports, the Plan projects a decline in high-carbon exports due to lower international demand for coal and limited oil reserves, affecting long-term production. While both scenarios show a long-term decline, the decline is faster under the energy transition scenario. In line with the goals for decarbonization of the economy, the intermediate demand of sectors like transport exhibits significant differences between the conservative and the energy transition scenarios. In the conservative scenario, the transport industry continues to rely mostly on oil derivatives, with an increasing demand for alternative sources like natural gas and a small participation of electricity. In the energy transition scenario, electricity gains relevance as an energy source after 2030 and substitutes the use of both oil derivatives and natural gas.[7]

We complement the energy transition scenarios with information about the required investments to implement the transition and to develop a more resilient economy to climate change. Along with the investment required to adopt low-carbon technologies, the need to adapt to climate change is also a relevant policy area in Colombia. In addition to already prominent local climate variability factors, such as the El Niño-Southern Oscillation (ENSO), the country faces substantial climatological risks, including increased risks of floods, landslides, and extreme heat seasons. These risks are significant compared to comparable countries (World Bank, 2023). According to Colombia's Nationally Determined Contributions (NDCs) (Government of Colombia, 2020), while all departments (provinces) face some level of climate change risk, 56% are classified as high risk, especially in the densely populated Andean and Caribbean regions.

Following Godin et al. (2024), we utilize the World Bank's estimates of the investment required to achieve greenhouse gas emission reductions and to develop a climate-resilient economy World Bank (2023). This analysis indicates that achieving these two objectives would require an increase in total investment of approximately 1% of GDP per year. Since this investment requirement assumes an ambitious transition to low-carbon technologies, we include this shock exclusively within the energy transition scenario.

3.2. Effects on employment

The scenarios described above provide the basis for analyzing the green transition's effects on production and employment. To this end, we incorporate projected changes in intermediate and final demand into an input-output model. This widely used economic planning tool assesses the industry output required to meet projected final demand, accounting for inter-industry linkages (Miller and Blair, 2009).

Formally, let **x** denote the $n \times 1$ vector of total industry output, **A** the $n \times n$ matrix of technical coefficients (where the element a_{ij} represents the share of industry i's output used as intermediate input by industry j), and **f** the $n \times 1$ vector of final demands (private consumption, government expenditures, investment, and exports). Assuming fixed-proportion inputs, the

[7] The Plan also presents scenarios for the demand of energy for agriculture, industry, services, and residential sectors. In all cases, the Plan projects reductions in high-carbon energy sources and a higher reliance on electricity.

output **x** required to meet final demand **f** is given by:

$$\mathbf{x} = (I - \mathbf{A})^{-1}\,\mathbf{f}, \tag{1}$$

where I is the identity matrix.

To quantify the green transition's effects on output and employment, we use the 2019 Colombian Input-Output matrix (DANE, 2025) as a baseline and conduct a two-step analysis. First, we incorporate the National Energy Plan's projected changes in intermediate consumption and final demand. Specifically, for energy industries, we adjust the technical coefficients (a_{ij}) and final demands (f_i) to reflect the Plan's projected changes in intermediate, private, and external consumption. For changes in external demand, we assume that local production prioritizes local consumption, with any remaining output being exported; thus, the changes in external demand are net of local final demand. Following Godin et al. (2024), we also increase investment by approximately 1% of GDP, as estimated by the World Bank, to account for green transition investment requirements (World Bank, 2023).

Using the modified final demand and technical coefficient matrix, $\tilde{\mathbf{f}}_t$ and $\tilde{\mathbf{A}}_t$ respectively, we simulate total industry output needs to meet the implied final demands as:

$$\tilde{\mathbf{x}}_t = \left(I - \tilde{\mathbf{A}}_t\right)^{-1}\tilde{\mathbf{f}}_t, \tag{2}$$

where the subscript t indicates the time-varying nature of the projected changes (see Figure 4). For each industry $i = 1, \ldots, n$, the relative impact of the green transition on total production is defined as the deviation from the baseline, $\frac{\tilde{x}_{it}}{x_i}$, where x_i is industry i's baseline total output.

Second, we calculate the changes in employment requirements by assuming sectoral employment is proportional to production. Thus, the relative change in industry i's employment requirements due to the green transition is given by $\frac{\tilde{L}_{it}}{L_{i0}} = \frac{\tilde{x}_{it}}{x_i}$, where L_{i0} is industry i's baseline employment.

While IO models are a convenient and widely used tool to understand the requirements at the industry level given changes in projected demands, they also have limitations that are important to consider in the analysis. The model assumes that each industry uses inputs in fixed proportions, such that the technical coefficients a_{ij} are constant (Hernández, 2012). In practice, this implies that the production technology does not respond to changes in relative prices (there are no substitution effects), which is not a realistic assumption, especially in long-run analysis. The model also assumes that the economy can respond to changes in final demand regardless of their size and that changes in production and employment requirements find available funding for their expansion and technological change. These elements imply that the results should likely be interpreted as an upper bound of the actual effect, as constraints on funding may limit the industries' ability to meet the projected changes in demand.

3.3. Effects on pension system variables

In this final step, we assess the potential impact of the green transition on the pension system by analyzing the implied changes in employment. Because the system relies heavily on contributions from formal sector workers, shifts in sectoral employment can affect both the number of contributors and the number of pensioners.

To understand how the green transition might affect workers' financial security in retirement, we employ the CEDE Pension Model, a microsimulation model designed to project various indicators of the pension system (Becerra et al., 2022). This model uses a generational accounting approach, where it simulates the behavior of representative agents based on historical labor market data and computes pension system variables (Bosch et al., 2013).

The CEDE Pension Model projects pension system indicators as follows:

- The model begins with a distribution of the population by labor market status and the distribution of time of contribution and accumulated assets in the pension system, derived from household surveys (GEIH) for 2023 and administrative data from Colpensiones and the Superintendencia Financiera de Colombia. It then simulates numerous future employment histories using a first-order Markov chain. This chain models individuals grouped by birth cohort, gender, and educational attainment, transitioning between seven states: not employed, employed in agriculture (formal/informal), industry (formal/informal), and services (formal/informal). The transition matrices are calibrated using 2023 GEIH data. The resulting population distribution by labor force status is shown in Figure A.2 in the Appendix.
- For each simulated employment history, the model calculates variables relevant to the pension system, including contribution values, contribution time, and accumulated assets. Within each cohort, gender, and education type, the population is distributed into three main groups: the population for whom the new pension system applies (younger cohorts with few years of contribution),[8] and the population for whom the rules based on competition between the DC and DB plans apply. These histories are then used to determine eligibility and benefits for both the contributory and solidarity pillars, according to the pension eligibility rules that apply to each group.
- The simulated histories are averaged by birth cohort, gender, educational attainment, and year, and then aggregated using United Nations population projections (UN DESA, 2022). Based on the results, we present four indicators describing the behavior of the pension system along social and economic dimensions.

  The first indicator is the coverage of the pension system (coverage). This indicator measures the effectiveness of the system in providing economic protection to older adults. It is computed as the percentage of the population eligible for a benefit from the pension system. We distinguish between workers eligible for a contributory pension and those who would receive a non-contributory (solidarity) pension.

  The second indicator is the net present value (NPV) of government transfers to the

[8] The pension reform keeps the previous conditions of the DB and DC plans for women and men who had accumulated at least 900 and 1000 weeks of contribution by June 2025, respectively.

pension system (fiscal sustainability). This is a measure of the pressure that the pension system exerts on government expenditures and the long-run financial sustainability of the system. Because contributions are not enough to finance pension benefits (see Section 2), the DB plan runs a structural deficit that is covered by the central government budget.[9]

The third indicator is the Gini coefficient of pension benefits for the population that reaches retirement age by 2050 (inequality). This is a measure of the effectiveness of the pension system in reducing economic inequality after retirement, one of the objectives of pension systems (Barr and Diamond, 2006). We focus on the distribution of benefits for a cohort of new pensioners in the long run (2050), as we want to measure the effectiveness of the new pension system's design in terms of redistribution and to avoid the inertia in pension benefits derived from previous pension rules.

The fourth indicator is the size of benefits relative to previous earnings (benefit adequacy). This is a measure of the system's performance in avoiding abrupt changes in income for pensioners, the main objective of a pension system (Barr and Diamond, 2006). It is computed as the ratio between the average benefit and the average earnings of formal-sector workers aged 51 and older. We report this indicator for both contributory and non-contributory pensions.

To link the employment effects derived from the input-output analysis and the microsimulation, we integrate the relative changes in employment within industry i, denoted by $\frac{\tilde{L}_{it}}{L_{i0}}$, into the model's labor market dynamics. Specifically, we recalibrate the transition matrices used in the model—calibrated by gender, educational attainment level, and age—to reflect the employment patterns by sector reported in the previous section.[10]

By incorporating the changes in employment derived from the input-output analysis, the model accounts for the reallocation of workers across industries. Given that each industry has different propensities for formal sector employment (Table 1), these shifts in sectoral employment allocation driven by the greening of the economy may affect the number of workers who contribute to the system, their likelihood of receiving a pension, and the pension benefits.

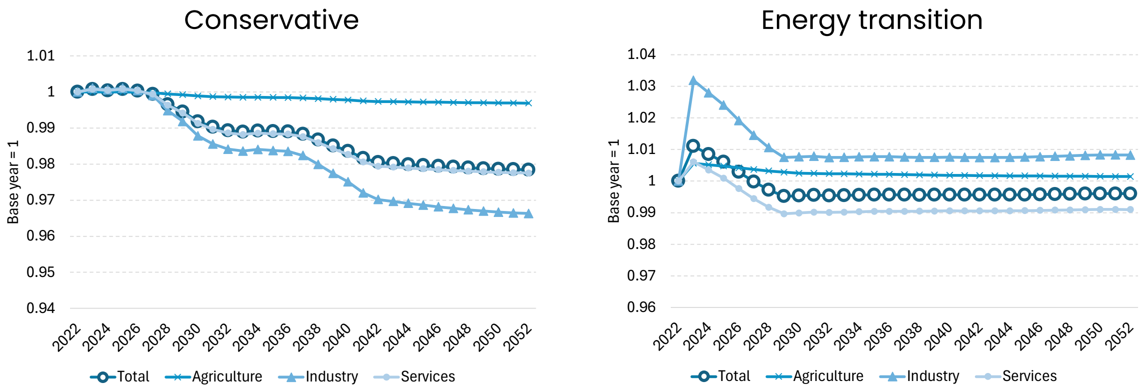
We present the simulation results based on three scenarios: a baseline scenario in which the composition of the labor market remains stable around its observed values in 2023 (so we do not change the transition matrices), and the conservative and energy transition scenarios, where total employment by sector follows the results of the input-output model.

[9] Starting in 2003, the DB plan ran deficits covered by the central government.

[10] Formally, let $\pi_{\mathbf{g},a} \in \mathbb{R}^{7\times 1}$ and $M_{\mathbf{g},a} \in \mathbb{R}^{7\times 7}$ be the population distribution by labor market status (such that each element of $\pi_{\mathbf{g},a}$ is non-negative and the sum of the elements of $\pi_{\mathbf{g},a}$ is equal to one) and the transition matrix of group **g** and age a. Using the properties of Markov processes (Ljungqvist and Sargent, 2004), the population distribution by age follows the recursive process:

$$\pi'_{\mathbf{g},a+1} = \pi'_{\mathbf{g},a} M_{\mathbf{g},a}.$$

In the model, the transitions from the out of the labor force/unemployed state were calibrated such that the final distributions $\pi_{\mathbf{g},a}$ were consistent with the paths projected by the input-output model.



Notes: This Figure presents the employment effects of the green transition, derived from the input-output model (2). The figure displays the time trends of total employment (hollow circles) and sectoral employment relative to a no-transition scenario, for both the conservative and the energy transition scenario.
Source: Author's calculations.

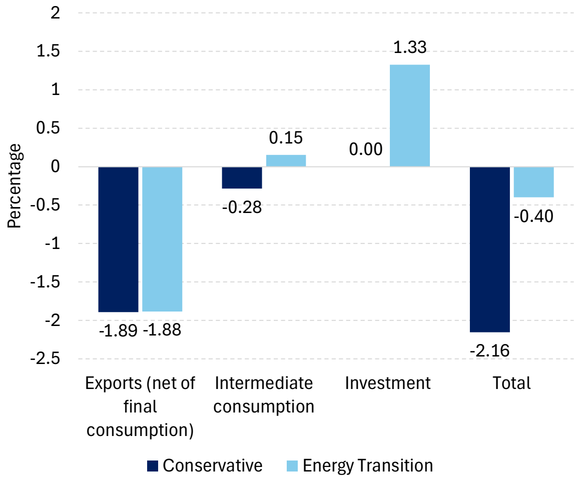
Figure 5: Employment effects of the green transition, 2022-2052

4. Results

This section presents the results regarding the changes in employment requirements due to the green transition in the Colombian labor market. As pointed out in Section 3.1, we incorporate three sources of changes in demand derived from the green transition: reduced external demand for high-carbon commodities, technological change from high-carbon energy sources to more energy-efficient operations and increased electricity use by both consumers and industries, and an increase in investment to finance the transition.

The results of the input-output analysis show a net loss of employment, primarily driven by reductions in high-carbon sectors. Because different sectors have different linkages to the industries affected by the transition, these effects vary by industry. Figure 5 illustrates the changes in employment requirements resulting from the green transition, as calculated by the model. The figure displays the time trends of total employment (hollow circles) and sectoral employment (agriculture, industry, and services) relative to a no-transition scenario $\left(\frac{\tilde{L}_{it}}{L_{i0}}\right)$, for both the conservative scenario (left panel) and the energy transition scenario (right panel).

The results indicate that the expected changes in demand derived from the green transition would generate a reduction in employment requirements due to the decline in production within high-carbon industries. The dynamics of the demand shocks incorporated in each scenario generate differential responses of employment requirements over time. For the conservative scenario, as the projected demands for high-carbon industries remain stable between 2022 and 2028, the employment requirements remain stable and are followed by a negative trend associated with the reduction in external demand for high-carbon sectors after 2028. These observed trends are partially offset in the energy transition scenario, as the increases in investment and changes in production technologies derived from the green transition generate employment requirements in other sectors, such as electricity supply. Overall, the conservative and energy transition scenarios project long-term reductions in employment requirements of 2.16% and 0.4% in the long run, respectively.



Notes: This Figure presents the employment effects of the green transition, derived from the input-output model (2). The figure displays the implied changes by the green transition by external and intermediate demand, and the investment shock relative to a no-transition scenario, for both the conservative and the energy transition scenarios.
Source: Author's calculations.

Figure 6: Employment effects of the green transition by source of shock, 2052

The sectoral response of employment to the changes induced by the green transition depends on each sector's direct and indirect dependence on high-carbon industries. Figure 5 illustrates employment trends in agriculture, industry, and services sectors. In the conservative scenario, the reduction in demand in high-carbon sectors affects the services and industry sectors, with long-term losses of 3.4% and 2.2% of their baseline values. Conversely, employment in the agricultural sector remains relatively stable due to its limited exposure to the oil, coal, and energy sectors, with a projected long-run loss of 0.3% of its baseline. Similarly, in the energy transition scenario, the industry and service sectors experience the most substantial long-run changes in employment requirements driven by the green transition's demand shifts, with a gain of 0.8% and a loss of 0.9%, respectively, while the agricultural sector also exhibits a moderate gain of approximately 0.1%.

The employment effects presented in Figure 5 are the result of changes in external and internal demand, as well as the investment shocks necessary to carry out the transition. The variation in required employment dynamics between scenarios depends on the magnitude of each shock, as illustrated in Figure 6, which presents long-run employment requirements considering only one shock source at a time in each scenario. As the figure shows, the long-run effects of the external shock are almost identical in both scenarios, resulting in reductions of 1.89% by 2052. This negative effect is counteracted by both the investment shock and the intermediate consumption changes in the transition scenario, where the implied employment requirements show increases of 1.33% and 0.15%, respectively. These changes are significantly smaller in the baseline scenario and underscore the role of internal demand shifts in achieving long-run employment resilience.

The employment changes vary across economic sectors, reflecting their linkages to sectors experiencing changes in demand, such as coal, oil, and electricity. Figure 7 illustrates the projected long-run employment effects by 2052 for each industry included in the input-output model. The main reductions in employment requirements are concentrated in high-carbon industries, specifically oil, coal, and their derivatives (coke and refined oil products). Compared to a no-transition scenario, the long-run reductions in employment requirements in these sectors average 45% of total employment in the conservative scenario and 58% in the energy transition scenario. Other sectors that exhibit sizable reductions in employment requirements are those linked with the high-carbon industries, such as the production of chemicals, the mining of other minerals, and transport and storage (reductions of 8.8% and 8.4% in the conservative and energy transition scenarios).

On the other hand, the increases in demand for alternative sources of energy, such as electricity and gas, generate large increases in employment requirements in these industries, with average increments of 16% in the conservative scenario and 76% in the energy transition scenario. In the energy transition scenario, the large increase in the demand for electricity and the investment shocks generate indirect positive effects in related industries, such as construction, financial activities, and information and communication (average increase of 5.5%). Overall, in both scenarios, the reductions are larger than the increases in employment requirements, resulting in a reduction in total employment requirements.

As we argue throughout the paper, the green transition has differential effects on employment allocation across demographic groups. Figure 8 displays the potential exposure of employment by demographic group to the reduced demand for high-carbon industries resulting from the green transition. To compute this, we apply the projected employment changes reported in Figure 7 to the employment by industry and demographic group. The results show that, although changes in employment affect all groups, certain groups are more exposed. In the conservative scenario, the reduction in employment requirements is driven by sectors with high earnings and higher formality rates, and therefore the demographic groups with a higher prevalence in these types of jobs. In particular, the reductions in employment requirements are larger for workers in the formal sector than in the informal sector (2.88% vs. 1.66%), and for workers located in the top third of the income distribution (reductions of 2.69% vs 2.09% and 1.61% for workers in the bottom part of the distribution). The reduction of employment requirements is more likely to be concentrated on workers with higher levels of education (2.76% for workers with higher levels of education), living in urban areas (about 2.4% in urban areas), and men (2.55%).

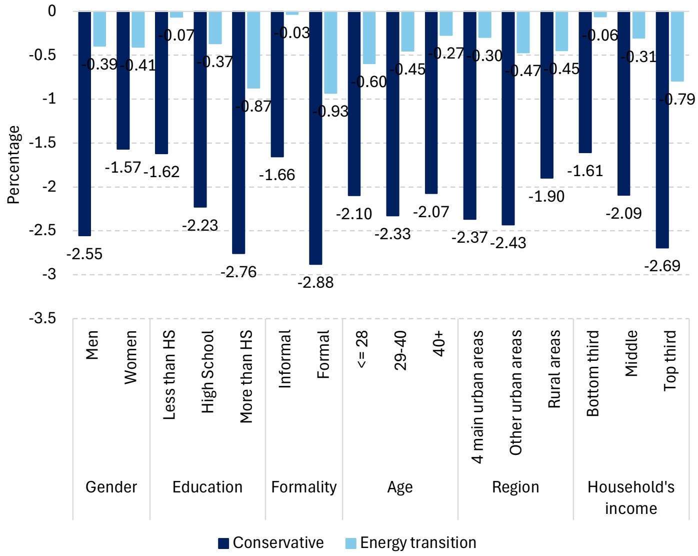
In the energy transition scenario, transition policies associated with the increased demand for electricity and gas and the aggregate increase in investment offset the reductions in employment requirements. Compared with the conservative scenario, the expected reductions in employment requirements are smaller, but they maintain similar patterns regarding workers' risk. Potential employment risks are concentrated on workers with higher levels of schooling (0.87% for workers with more than a high school diploma, and 0.37% and 0.07% for workers with a high school diploma and less than a high school education, respectively), workers in the formal sector (0.93% versus 0.03% in the informal sector), younger workers (0.60% for those younger than 28 years), workers in urban areas (0.47% in other metropolitan areas), and workers located in the top third of the income distribution (0.79%). Regarding gender, while the effects are larger for men compared to women, the gap in risk exposure considerably narrows (0.41% versus 0.39%).

These results suggest that the potential employment effects of the green transition are

Notes: This Figure presents the changes in employment requirements derived from the green transition by industry in 2052, derived from the input-output model (2). The effects are computed using a no-transition scenario as a baseline. *The projected variation for electric power in the energy transition scenario is 138%.

Source: Author's calculations.

Figure 7: Long-run effects of the green transition by sector



Notes: This Figure presents the employment effects of the green transition by worker's groups, derived from the input-output model (2). We apply the projected employment changes reported in Figure 7 to the total employment by industry and demographic group. Source: Author's calculations.

Figure 8: Long-run effects of the green transition by worker's characteristics

more concentrated among workers who are more likely to work in the formal sector and who are in the upper part of the income distribution. The workers whose jobs are more at risk due to the green transition also have characteristics indicating a greater potential for transitioning to occupations with a higher green content. Based on the idea of occupational mobility (Gathmann and Schönberg, 2010), workers whose current job's tasks are closer to the tasks of jobs with growth potential in the green transition are more likely to transition to these jobs. Consistent with international evidence, Becerra and Piñeros (2024) find that Colombian workers in jobs with green potential share many of the characteristics described as vulnerable above: they tend to be highly skilled, typically male, living in urban areas, more likely to work in the formal sector, and located at the top of the income distribution.

4.1. Effects on the pension system

The previous section shows reductions in employment requirements needed to meet the projected final demand affected by the green transition, and that those effects are more likely to affect formal-sector employment. Because the contributory pension system relies on a minimum number of contributions to be eligible for a contributory pension (Section 2), changes in the number of formal job opportunities alter the balance between the recipients of contributory and solidarity pensions.

We use the projected changes in required labor demand presented in Figure 5 to adjust the labor market prospects in the CEDE pension model.[11] Table 2 presents a summary of the results. The table includes indicators to evaluate the performance of the pension system

[11]Because we simulate the employment dynamics from 2025 to 2100, we implement the long-run effects of the transition on the projected levels by 2052.

	Eligible population, 2025-2100 (% of older adults)		NPV of deficit, 2025-2100 (% of GDP)	Benefits Gini 2050 (Gini 0-1)	Benefits' adequacy 2025-2100 (% of wages 51+)	
Scenario	Contributory	Solidarity	Total	Total	Contributory	Solidarity
Baseline	27.2	41.1	157.5	0.519	52.2	11.4
Conservative	26.8	41.1	156.7	0.524	52.2	11.5
Energy transition	27.1	40.9	157.2	0.523	52.3	11.4

Notes: This table shows statistics of the pension system's performance across four dimensions: coverage (average share of elderly receiving pensions), fiscal pressure (NPV of government transfers to the pension fund as a percentage of GDP), inequality (Gini index for those reaching retirement age in 2050), and benefit adequacy (average benefit as a percentage of the average wage for workers aged 51+). These indicators are computed for three scenarios: the 2023 labor market structure, and two scenarios based on baseline and energy transition employment paths.
Source: Author's calculations.

Table 2: Effects of the projected changes in labor demand on pension system variables

along four dimensions: coverage, fiscal sustainability, inequality, and benefit adequacy. The results are presented for three scenarios: a baseline scenario in which the labor market follows a similar behavior to that observed in 2023, and the two scenarios based on the employment paths from the conservative and the energy transition scenarios.

Consistent with the labor market results, the findings presented in Table 2 show that the potential changes in formal employment implied by the green transition would decrease the share of older adults receiving a contributory pension in both the conservative and energy transition scenarios. Nonetheless, the effect is likely to be moderate. The column 'Eligible population' shows the average fraction of older adults receiving a pension between 2025 and 2100. Compared to the baseline, where the labor market dynamics are similar to those observed in 2023, the changes in the composition of the labor market observed in the conservative and energy transition scenarios generate a reduction in the share of older adults receiving a pension. The changes in formal employment in the conservative scenario imply a modest reduction in the average system's coverage, from 27.2% to 26.8%, and a similarly modest reduction in the energy transition scenario, from 27.2% to 27.1%.

The relatively small effect on coverage is explained by the combination of two complementary characteristics of the pension system. First, while the reduction of employment requirements is more likely to affect formal sector jobs, the relative sizes of the shocks in both the conservative and energy transition scenarios are small, especially in the case of the energy transition. Second, as discussed in Section 2.3, the qualifying conditions for a pension are difficult for most workers to meet, so the marginal changes in employment requirements due to the green transition are not large enough to significantly alter the general pension outcomes for most older adults.

Regarding fiscal sustainability, the changes implied by the green transition are likely to have a low fiscal impact on the pension system. Compared to the baseline scenario, the reductions in formal employment and the subsequent reduction of pensioners in the contributory system generate a reduction in the total net present value (NPV) of the pension system's deficit of 0.8% of GDP in the conservative scenario, from 157.5% to 156.7% of GDP between 2025 and 2100, and a reduction of 0.3% of GDP in the energy transition scenario, from 157.5% to 157.2% of GDP in the same period. Since the pension benefits in the DB plan are subsidized (Section 2.3), a reduction in formal employment implies a reduction of the system's revenues, but also implies a larger reduction in the expenditures derived from a lower number of pensioners.

The third column of Table 2 presents the simulation results for the inequality of benefits for new retirees in 2050. This measure provides information to assess the redistributive effects of the pension system. The baseline scenario shows a Gini index for new pensioners of 0.519, aligned with the level of income inequality for the general population (0.528 in 2023). In the conservative and energy transition scenarios, the simulation shows that the lower coverage of the contributory pension system derived from the green transition leads to a moderate increase in income inequality after retirement, increasing from 0.519 to 0.524 in the conservative scenario and 0.523 in the energy transition scenario. As a small share of workers loses access to a contributory pension, this reduction generates a moderate increase in income inequality after retirement in both scenarios.

Regarding the adequacy of pension benefits, the results suggest that the green transition has a minimal effect on the average benefits received by workers. The average replacement rate for pensioners of the contributory system is approximately 52.2% of the average earnings of formal-sector workers aged 51 and over across all scenarios, while the solidarity pensions amount to about 11.4% of the earnings of the average formal-sector worker aged 51 and over.

5. Final remarks

In this paper, we evaluate the potential effects of the transition to a low-carbon economy on both employment levels and the performance of the pension system in Colombia.

Our results indicate that the transition towards a low-carbon economy would have a net negative impact on employment requirements. Nonetheless, these reductions are more pronounced in the absence of transition policies. The long-run projected reduction in employment requirements is 2.16% of total employment in a conservative scenario where there are no transition policies and the economy faces a reduction in the total production of oil and coal industries. In contrast, the reduction is 0.4% of total employment in an energy transition scenario, as the reductions in employment requirements of high-carbon industries are partially compensated by increases in the sectors boosted by the transition, especially electricity, and the increased investment for financing the transition and reach a climate-resilient economy.

The reduction in employment requirements is concentrated in coal and oil, but also in the industry and services sectors via intersectoral linkages. The effects on employment depend on whether energy transition policies are implemented. In the conservative scenario, the long-term reductions in employment requirements in the industry and services sectors are 2.2% and 3.4%, respectively. In contrast, in the energy transition scenario, the increased demand for electricity and associated investments imply changes in long-run employment requirements in the industry and services sectors of 0.8% and -0.9%. Due to their relatively weak connection with high-carbon sectors, employment in agriculture exhibits minimal long-run changes.

An implication of the differential results by sector is that the reduction in employment requirements is concentrated in sectors where there is a higher prevalence of formal sector employment and workers with higher earnings, which in turn are concentrated in certain demographic groups such as more educated workers and workers living in urban areas. While those demographic groups are expected to be the most affected, occupational mobility suggests that they can transition more easily to new jobs with green potential. To take full advantage of the green job potential of the displaced workers, it is necessary to develop and implement labor market policies focused on upskilling and reskilling these workers, targeting more vulnerable workers and supporting formal job creation.

A second implication of the labor market results is that, because the reduction in employment requirements is larger in formal-sector jobs, the green transition has a small negative effect on the performance of the pension system. Since the changes in employment requirements are small and the qualifying conditions for a pension are too stringent for most workers, the changes in the share of older adults receiving a contributory pension are minimal. Using as a baseline a scenario in which the labor market dynamics are those observed in 2023, the share of older adults eligible for a contributory pension is smaller in the conservative scenario, from 27.2% to 26.8%, and has even smaller changes in the energy transition scenario, from 27.2% to 27.1%.

Consistent with the moderate changes in the share of adults receiving contributory pensions, the effects of the green transition on the fiscal pressure caused by the pension system are rather small. Due to the design of the defined-benefit component of the pension system, the expected reductions in the number of pensioners reduce the pension system's deficit. The net present value of the pension system deficit changes from 157.5% of GDP in the baseline to 156.7% and 157.2% in the conservative and energy transition scenarios. A similar result is observed in the case of benefits inequality after retirement, where the Gini coefficient for the benefits of future pensioners changes from 0.519 in the baseline to 0.524 and 0.523 in the conservative and energy transition scenarios.

This paper contributes to the analysis of social protection systems by providing a comprehensive approach to assessing the macro, labor, and social protection effects of decarbonizing the economy. While offering a tractable approach, our framework also reveals limitations that warrant further research. First, the input-output analysis assumes that the required resources for supporting the transition are available, which is a strong assumption given the government's high dependency on oil and coal revenues, and the economy's reliance on coal and oil exports for foreign exchange earnings. The effects of the energy transition scenario rely on the assumption that the required investments are carried out to implement the transition; in that sense, the reported employment effects are an upper bound of the changes in the required employment requirements.

A second important dimension to consider is related to the potential regional heterogeneity of these employment effects. Even in the absence of transition policies, limited reserves and reduced external demand for coal and oil would generate reductions in employment requirements in the coal and oil sectors. While the transition contributes to partially offsetting those effects, some regions will face a higher risk of poverty and increasing inequality. This is particularly important in the modeling of the labor market, as it assumes a frictionless reallocation of labor at the national level, which may amplify the negative effects of the negative demand shocks.

Despite its limitations, the paper proposes a framework to measure the potential effects of the green transition on employment and the economic protection of the elderly, accounting for economic vulnerabilities. While the specific results of this prospective analysis may change due to new technological and policy developments, the study contributes to understanding the complex challenges posed by the green transition and provides additional considerations for its implementation.

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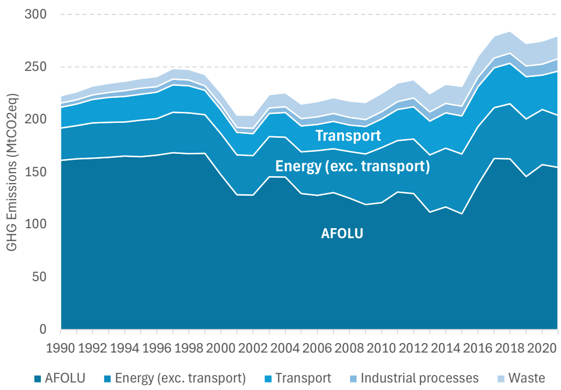
A. Additional figures



Notes: This Figure presents the greenhouse gas (GHG) emissions by source between 1990 and 2021, based on official statistics of the GHG emissions inventory. AFOLU encompasses the Agriculture, Forestry, and Other Land Use sectors.
Source: Instituto de Hidrología, Meteorología y Estudios Ambientales (2024)

Figure A.1: Colombia's GHG emissions by source, 1990-2021

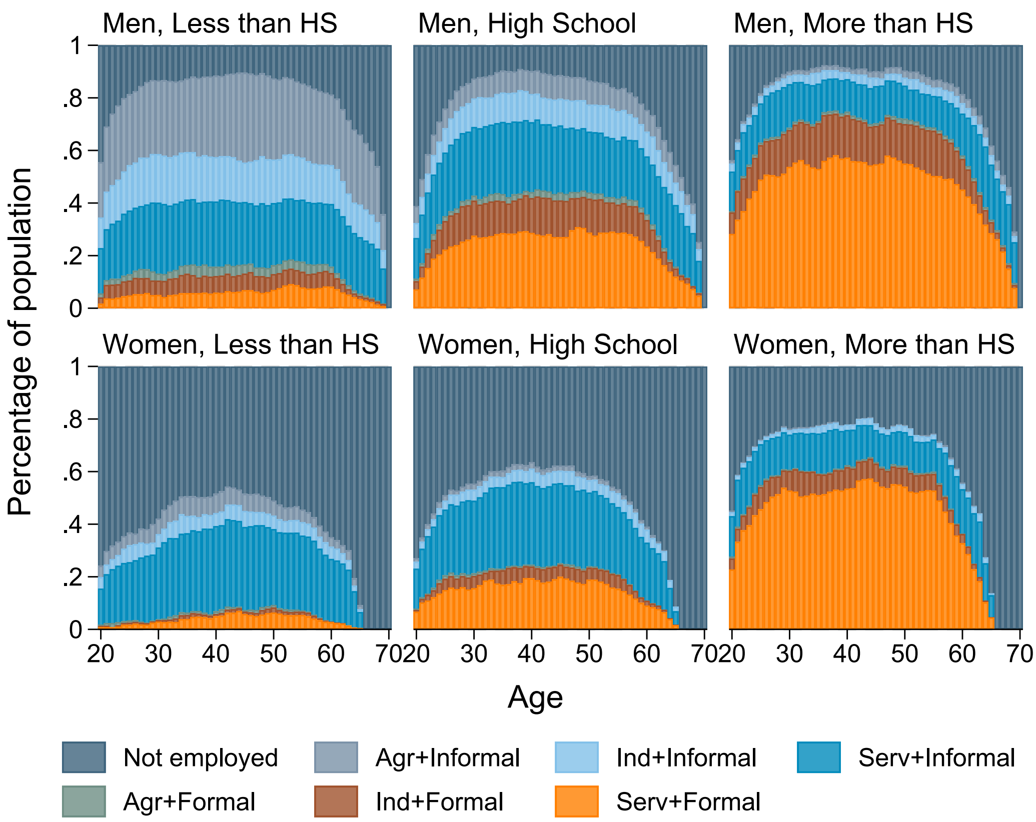


Figure A.2: Distribution of the labor force by gender, age, and educational attainment, 2023

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