# Carbon reduction targets and productive-structure adjustment: Evidence from a goal programming model

José Carlos M Grizendi (UFJF) - **Fernando S Perobelli (UFJF)**
Gabriel Arcanjo (UFJF) - Douglas Silveira (UFJF)

June 25, 2026

# Content



LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Introduction

- The transition to a low-carbon economy poses major challenges for public policy design.
- Reducing greenhouse gas emissions does not depend solely on an **aggregate contraction** in economic activity, but also on *how productive adjustments are distributed across sectors with different emission intensities, different shares in output, and distinct intersectoral linkages*.
- **Productive structure** is a central factor in economic growth and, consequently, an important determinant of emissions.

LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Introduction

- Countries and institutions have adopted **strategies** aimed at transforming production and consumption patterns, as well as **establishing targets for mitigating environmental impacts** under the Paris Agreement and as systematized by the Intergovernmental Panel on Climate Change (IPCC).
- These strategies include the restructuring of production systems and the promotion of changes in consumption patterns, often associated with climate policy instruments such as carbon pricing, environmental regulation, and decarbonization targets.

# Introduction

- Brazil is part of these global concerns and hosted the 30th United Nations Climate Change Conference (COP30), whose main objectives include accelerating the implementation of concrete actions to contain global warming and reviewing and strengthening the targets established under the Paris Agreement after its first decade in force.
- Brazil's new Nationally Determined Contribution (NDC), submitted in November 2024 during the 29th Conference of the Parties (COP29), reinforces the country's voluntary commitment to reducing greenhouse gas (GHG) emissions by 2035

# Introduction

- The document establishes a GHG emission **reduction target within a range from a minimum reduction of 59% to an ideal target of 67%**, using 2005 levels from the National Inventory of Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases as the reference.
- A growing concern, however, is that **international cooperation** aimed at imposing limits on the expansion of emission-intensive activities also entails economic transition costs and potential impacts on activity levels in specific sectors.

LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Objective

- We formulate a goal programming problem in which the production vector is adjusted to minimize deviations from the baseline structure, subject to restrictions on emissions, employment, final demand, and minimum sectoral floors.
- Eight emission-reduction scenarios are simulated, corresponding to *rho* = 5%, 10%, 15%, 20%, 25%, 30%, 35%, and 40%. The exercise seeks to measure the effects of these constraints on gross output and to identify the sectoral heterogeneity of these impacts.

# What are our contributions?

- Show that progressively more restrictive climate targets can be achieved with relatively small aggregate changes in the production vector, provided that the adjustment is concentrated in the sectors that contribute most to emissions.
- The results indicate that the optimal restructuring is not generalized but strongly selective, falling mainly on carbon-intensive sectors such as livestock, transport, and specific industrial segments.

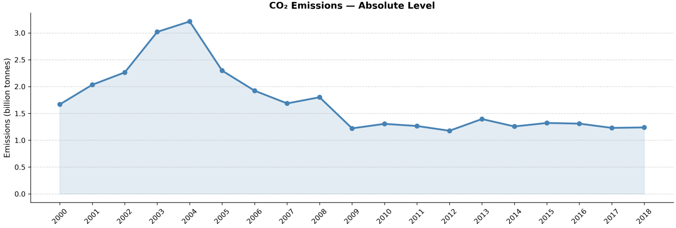
LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

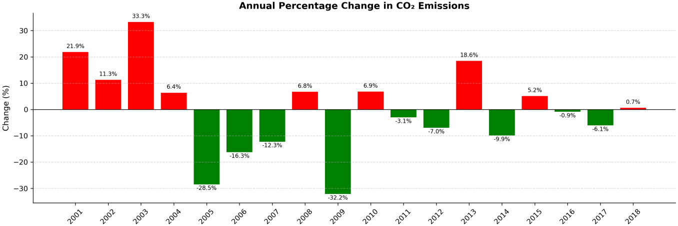
# Data

- Input-output matrices developed by the Regional and Urban Economics Center of the University of São Paulo (NEREUS), constructed from data from the System of National Accounts (SCN).
- The matrix is disaggregated into 68 sectors for Brazil and refers to the year 2018.
- Information on CO emissions is obtained from the Greenhouse Gas Emissions and Removals Estimation System (SEEG Brasil), which provides annual estimates disaggregated by sector and by spatial divisions of the Brazilian economy.

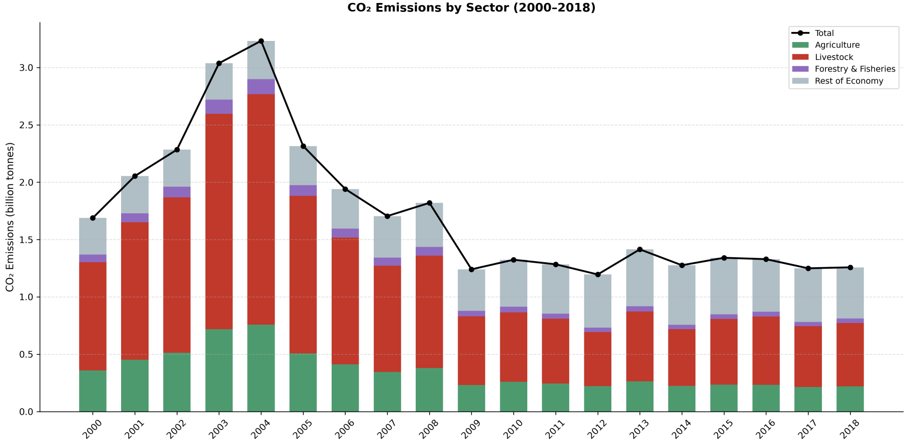
LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Description of emissions over time



# Description of emissions over time by sector



# Methodology

- The model corresponds to a **goal programming problem** whose objective is to identify a new productive structure that minimizes deviations from the production vector observed in the base year.
  - $x_i$ denotes the production level of sector $i$, with $i = 1, \ldots, n$.
  - $x_{\text{base},i}$ denotes the production level of sector $i$ in the baseline structure.
  - $d_i^+$ and $d_i^-$ are deviation variables representing positive and negative deviations of $x_i$ from $x_{\text{base},i}$, respectively.

LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Optimization Problem

## Objective Function

$$\min_{\{x, d^+, d^-\}} \sum_{i=1}^{n} \left( d_i^+ + d_i^- \right)$$

$$x_i + d_i^- - d_i^+ = x_{\text{base},i}, \qquad i = 1, \ldots, n$$

- $x_{\text{base}}$: observed production structure (2018).
- $d_i^+$ and $d_i^-$: positive and negative deviations from the baseline.
- Objective: minimize adjustments relative to the observed economy.

We start from the observed economy in 2018. The model searches for a new production vector $X$ while minimizing deviations from the original production structure.

## Environmental and Employment Targets

$$g_{CO_2}^{\top} X \leq b_{CO_2}(1-\rho)$$

- Emission target: $g_{CO_2}$ denotes sectoral emission coefficients, $b_{CO_2}$ baseline emissions, and $\rho$ the required reduction rate.

## Feasibility Constraints

$$(I-A)X \leq d_{\text{Base}}$$

$$x_i \geq \pi x_{\text{base},i}$$

$$x_i,\ d_i^-,\ d_i^+ \geq 0$$

- Input-output consistency: $(I-A)X$ denotes the final demand associated with production vector $X$.
- Sectoral floor: output in each sector cannot fall below a minimum share of its base-year level.

# Simulated scenarios

- Eight climate policy scenarios were simulated, defined by different values of the parameter $\rho$.
- $\rho$ represents the proportional reduction in emissions relative to the baseline scenario.

- **Scenarios considered:**

$$\rho = 5\%, 10\%, 15\%, 20\%, 25\%, 30\%, 35\%, 40\%$$

- For each scenario, the model computes a new production vector $X$ that satisfies the carbon-reduction target.
- Comparing scenarios reveals how the productive structure adjusts as climate constraints become progressively more stringent.

# Results

Table: Aggregate statistics by carbon-reduction scenario

| Reduction target ($\rho$) | Simple average variation in GVP | GVP-weighted average variation | Largest sectoral reduction | Most affected sector |
|---|---|---|---|---|
| 5% | -0.33% | -0.25% | -10.84% | Livestock |
| 10% | -0.65% | -0.49% | -21.68% | Livestock |
| 15% | -0.98% | -0.74% | -32.51% | Livestock |
| 20% | -1.30% | -0.98% | -43.35% | Livestock |
| 25% | -1.63% | -1.23% | -54.19% | Livestock |
| 30% | -1.95% | -1.47% | -65.03% | Livestock |
| 35% | -2.28% | -1.72% | -75.87% | Livestock |
| 40% | -2.60% | -1.96% | -86.70% | Livestock |

- The aggregate results indicate that the economic costs of the decarbonization policy, measured by the variation weighted by gross value of production (GVP), are relatively modest for the economy as a whole

# Results

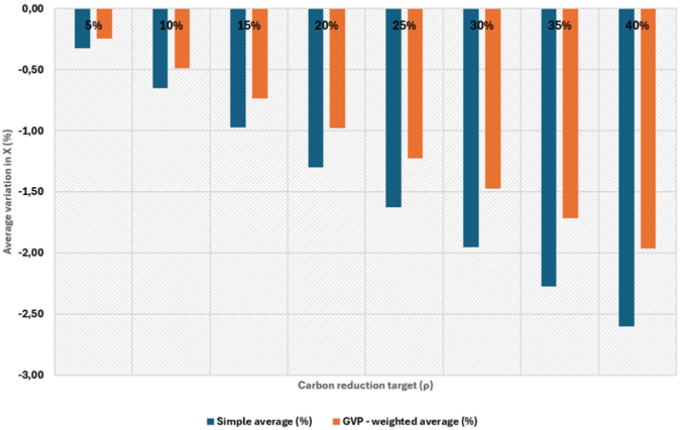
Table: Aggregate statistics by carbon-reduction scenario

| Reduction target ($\rho$) | Simple average variation in GVP | GVP-weighted average variation | Largest sectoral reduction | Most affected sector |
|---|---|---|---|---|
| 5% | -0.33% | -0.25% | -10.84% | Livestock |
| 10% | -0.65% | -0.49% | -21.68% | Livestock |
| 15% | -0.98% | -0.74% | -32.51% | Livestock |
| 20% | -1.30% | -0.98% | -43.35% | Livestock |
| 25% | -1.63% | -1.23% | -54.19% | Livestock |
| 30% | -1.95% | -1.47% | -65.03% | Livestock |
| 35% | -2.28% | -1.72% | -75.87% | Livestock |
| 40% | -2.60% | -1.96% | -86.70% | Livestock |

- The sectoral distribution of the adjustment, however, is markedly asymmetric. The livestock sector concentrates a disproportionate share of policy costs in all simulated scenarios, recording reductions ranging from -10.84% under the 5% target to -86.70% under the 40% target.

# Results

Figure: Aggregate variation in the productive structure under different carbon-reduction targets



# Results

- The systematic divergence between the two metrics, visible in all scenarios, becomes progressively more pronounced in absolute terms as rho increases: in the 40% scenario, the simple average reaches approximately -2.60%, whereas the GVP-weighted average remains at -1.96%, indicating that sectors with greater economic weight respond to the regulatory shock with a proportionally smaller contraction.

# Results

Table: Sectors with the largest reduction in GVP under the $\rho = 40\%$ scenario

| Rank | Sector | Variation in $X$ under $\rho = 40\%$ | Interpretation |
|---|---|---|---|
| 1 | Livestock, including support activities | -86.70% | Main sector of climate adjustment |
| 2 | Water transport | -23.52% | Strong adjustment in emission-intensive transport |
| 3 | Organic and inorganic chemicals, resins, and elastomers | -4.18% | Relevant industrial adjustment |
| 4 | Pesticides, disinfectants, paints, and miscellaneous chemicals | -4.09% | Adjustment in the chemical industry |
| 5 | Other food products | -4.04% | Adjustment associated with the agri-food chain |
| 6 | Forestry production, fishing, and aquaculture | -3.84% | Adjustment in primary activities |
| 7 | Land transport | -3.54% | Relevant sector due to its share in emissions |
| 8 | Coal and non-metallic mineral extraction | -3.29% | Carbon-intensive extractive activity |
| 9 | Non-metallic mineral products | -2.58% | Adjustment in an intensive industrial segment |
| 10 | Electricity, natural gas, and other utilities | -2.40% | Adjustment in the energy sector |

- The productive adjustment induced by the climate target is highly selective.
- Livestock, including support activities, is the most affected sector in all simulated scenarios, with an estimated contraction of up to -86.70%, far exceeding that of other sectors.

# Results

Table: Sectors with the largest reduction in GVP under the $\rho = 40\%$ scenario

| **Rank** | **Sector** | **Variation in $X$ under $\rho = 40\%$** | **Interpretation** |
|---|---|---|---|
| 1 | Livestock, including support activities | -86.70% | Main sector of climate adjustment |
| 2 | Water transport | -23.52% | Strong adjustment in emission-intensive transport |
| 3 | Organic and inorganic chemicals, resins, and elastomers | -4.18% | Relevant industrial adjustment |
| 4 | Pesticides, disinfectants, paints, and miscellaneous chemicals | -4.09% | Adjustment in the chemical industry |
| 5 | Other food products | -4.04% | Adjustment associated with the agri-food chain |
| 6 | Forestry production, fishing, and aquaculture | -3.84% | Adjustment in primary activities |
| 7 | Land transport | -3.54% | Relevant sector due to its share in emissions |
| 8 | Coal and non-metallic mineral extraction | -3.29% | Carbon-intensive extractive activity |
| 9 | Non-metallic mineral products | -2.58% | Adjustment in an intensive industrial segment |
| 10 | Electricity, natural gas, and other utilities | -2.40% | Adjustment in the energy sector |

- Besides livestock, transport and industrial sectors are also affected, particularly water transport (-23.52%), land transport (-3.54%), chemicals, non-metallic minerals, food products, and utilities.
- This pattern indicates that the carbon constraint affects both sectors with high direct emissions and activities linked to carbon-intensive production chains.

# Results

Table: Sectoral pattern of productive-structure adjustment under progressive carbon-reduction targets

| Sector | 5% | 10% | 15% | 20% | 25% | 30% | 35% | 40% |
|---|---|---|---|---|---|---|---|---|
| Livestock, including support activities | -10.84 | -21.68 | -32.51 | -43.35 | -54.19 | -65.03 | -75.87 | -86.70 |
| Water transport | −2.94 | -5.88 | -8.82 | -11.76 | -14.70 | -17.64 | -20.58 | -23.52 |
| Manufacture of organic and inorganic chemicals, resins, and elastomers | −0.52 | −1.04 | −1.57 | −2.09 | −2.61 | −3.13 | −3.65 | −4.18 |
| Manufacture of pesticides, disinfectants, paints, and miscellaneous chemicals | −0.51 | −1.02 | −1.53 | −2.05 | −2.56 | −3.07 | −3.58 | −4.09 |
| Other food products | −0.51 | −1.01 | −1.52 | −2.02 | −2.53 | −3.03 | −3.54 | −4.04 |
| Forestry production; fishing and aquaculture | −0.48 | −0.96 | −1.44 | −1.92 | −2.40 | −2.88 | −3.36 | −3.84 |
| Accommodation | −0.45 | −0.91 | −1.36 | −1.81 | −2.27 | −2.72 | −3.18 | −3.63 |
| Land transport | −0.44 | −0.89 | −1.33 | −1.77 | −2.21 | −2.66 | −3.10 | −3.54 |
| Architectural and engineering services, technical testing/analysis, and R&D | −0.42 | −0.84 | −1.27 | −1.69 | −2.11 | −2.53 | −2.95 | −3.37 |
| Coal and non-metallic mineral extraction | −0.41 | −0.82 | −1.23 | −1.65 | −2.06 | −2.47 | −2.88 | −3.29 |
| Security, surveillance, and investigation activities | −0.36 | −0.72 | −1.08 | −1.44 | −1.79 | −2.15 | −2.51 | −2.87 |
| Manufacture of non-metallic mineral products | −0.32 | −0.65 | −0.97 | −1.29 | −1.62 | −1.94 | −2.26 | −2.58 |
| Non-real-estate rentals and intellectual-property asset management | −0.32 | −0.64 | −0.96 | −1.28 | −1.60 | −1.92 | −2.24 | −2.56 |
| Electricity, natural gas, and other utilities | −0.30 | −0.60 | −0.90 | −1.20 | −1.50 | −1.80 | −2.10 | −2.40 |
| Manufacture of pharmaceutical and pharmaceutical products | −0.29 | −0.57 | −0.86 | −1.15 | −1.44 | −1.72 | −2.01 | −2.30 |
| Agriculture, including support activities and post-harvest activities | −0.27 | −0.54 | −0.80 | −1.07 | −1.34 | −1.61 | −1.88 | −2.14 |
| Petroleum refining and coke ovens | −0.26 | −0.51 | −0.77 | −1.03 | −1.29 | −1.54 | −1.80 | −2.06 |
| Manufacture of wood products | −0.19 | −0.39 | −0.58 | −0.77 | −0.97 | −1.16 | −1.36 | −1.55 |
| Oil and gas extraction, including support activities | −0.15 | −0.30 | −0.45 | −0.60 | −0.75 | −0.89 | −1.04 | −1.19 |
| Manufacture of metal products, except machinery and equipment | −0.13 | −0.26 | −0.39 | −0.52 | −0.64 | −0.77 | −0.90 | −1.03 |

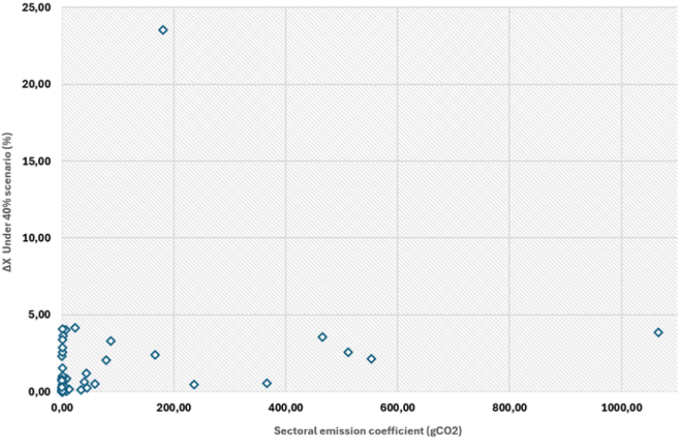
# Results

- Present the adjustment trajectory of sectors to be observed across the different climate policy scenarios.
- The sectors most affected in the 5% scenario remain the main adjusted sectors in the more restrictive scenarios.
- This suggests stability in the pattern of productive restructuring: increasing the carbon-reduction target does not qualitatively change the set of most exposed sectors but instead intensifies the magnitude of the adjustments.
- The transition to more ambitious climate targets does not abruptly shift the mitigation effort toward new sectors.
- The response structure of the productive system is relatively predictable, which may facilitate the design of sectoral transition policies.

LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Results

Figure: Emission intensity and magnitude of sectoral productive adjustment



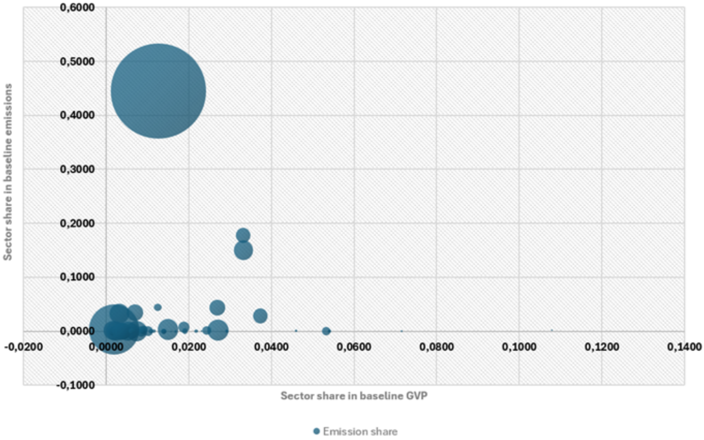
# Results

- The correlation between the sectoral emission coefficient and the absolute magnitude of productive adjustment under *rho* $= 40\%$ is high, approximately 0.92.
- Intersectoral linkages also influence the distribution of adjustments, since sectors that are less directly emission-intensive may be affected through their relationships with emission-intensive production chains.

LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Results

Figure: Economic weight, environmental weight, and productive adjustment



# Results

- The comparison between economic and environmental shares reveals a strong misalignment between sectors' productive importance and their contribution to emissions. Some sectors have a relatively small share of gross value of production but account for a large share of total emissions.
- Policy perspective. It suggests that climate policies designed solely based on a sector's share in output may underestimate the importance of environmentally critical sectors

# Results

Table: Concentration of productive adjustment under the $\rho = 40\%$ scenario

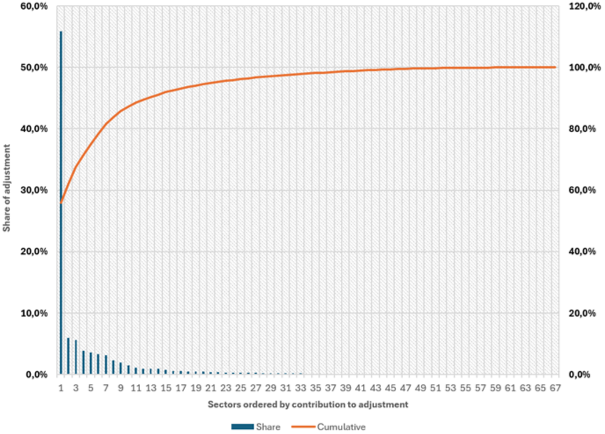
| Group of sectors | Cumulative share of adjustment |
|---|---|
| Most important sector | 55.91% |
| Top 3 sectors | 67.48% |
| Top 10 sectors | 87.29% |

- Under the 40% emission-reduction scenario, the most relevant sector alone accounts for approximately 55.91% of the total weighted reduction in the GVP. The three leading sectors explain about 67.48% of the adjustment, while the ten leading sectors account for 87.29%.

LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Results

Figure: Sectoral concentration of productive adjustment induced by the climate target



# Results

Table: Distribution of sectors by classes of reduction in GVP under the $\rho = 40\%$ scenario

| Class of reduction in $X$ | Number of sectors | Share of GVP | Share of emissions | Interpretation |
|---|---|---|---|---|
| Reduction greater than 20% | 2 | 1.46% | 44.81% | Critical adjustment |
| Reduction between 5% and 20% | 0 | 0.00% | 0.00% | No sectors in this range |
| Reduction between 2% and 5% | 15 | 21.32% | 47.34% | Relevant adjustment |
| Reduction between 0.5% and 2% | 13 | 15.81% | 5.75% | Moderate adjustment |
| Reduction below 0.5% | 37 | 61.41% | 2.11% | Preserved sectors |

- Two sectors exhibit reductions greater than 20% in the most restrictive scenario.
- Although they account for only 1.46% of gross value of production, these sectors concentrate 44.81% of initial emissions.
- 37 sectors show reductions of less than 0.5%, accounting for 61.41% of gross value of production but only 2.11% of emissions.

# Results

Table: Distribution of sectors by classes of reduction in GVP under the $\rho = 40\%$ scenario

| Class of reduction in $X$ | Number of sectors | Share of GVP | Share of emissions | Interpretation |
|---|---|---|---|---|
| Reduction greater than 20% | 2 | 1.46% | 44.81% | Critical adjustment |
| Reduction between 5% and 20% | 0 | 0.00% | 0.00% | No sectors in this range |
| Reduction between 2% and 5% | 15 | 21.32% | 47.34% | Relevant adjustment |
| Reduction between 0.5% and 2% | 13 | 15.81% | 5.75% | Moderate adjustment |
| Reduction below 0.5% | 37 | 61.41% | 2.11% | Preserved sectors |

- The climate constraint, therefore, does not generate a generalized process of productive contraction, but rather a recomposition guided by the environmental intensity of sectors.
- A low-carbon transition may preserve most economic activity if mitigation efforts are efficiently allocated across sectors. However, concentrated adjustments may create distributive challenges across regions, production chains, and occupational groups.

# Summary of Results

- First, carbon-reduction targets do not necessarily imply proportional declines in aggregate production. Even under the most restrictive scenario, a 40% reduction in emissions is associated with a weighted average reduction in production of less than 2%. This suggests substantial environmental gains can be achieved through a selective reallocation of production.

- Second, sectoral heterogeneity is crucial for understanding climate policy impacts. High-emission sectors absorb a disproportionate share of the adjustment, while lower-emission activities remain relatively preserved. This finding highlights the limitations of uniform mitigation policies across sectors.

LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

## Summary of Results

- Third, the concentration of productive adjustment reveals a trade-off between environmental efficiency and economic equity. While concentrating reductions in a small number of sectors minimizes aggregate deviations from the productive structure, it may generate significant sectoral, regional, and social costs. This is particularly relevant for sectors such as livestock and transport, which are closely linked to employment, income, land use, infrastructure, and regional production chains.

# Final Remarks

- The results should not be interpreted as a direct recommendation to contract these sectors, but rather as an indication of where the main environmental pressure points of the economic system are located.
- The main evidence from the exercise is that a few sectors concentrate most of the mitigation effort.
- The most relevant sector accounts for 55.91% of the total weighted reduction, while the ten leading sectors explain 87.29% of the adjustment. At the same time, 37 sectors, which represent more than 60% of GVP, show variations below 0.5%, indicating that a large share of the productive structure is preserved.

# Final Remarks

- In policy terms, this suggests the need for transition strategies oriented toward technological innovation, input substitution, efficiency gains, land-use change, electrification, low-carbon logistics, and productive diversification.
- The results suggest that mitigation strategies should be sectorally differentiated.
- Uniform instruments may impose unnecessary costs on low-emission-intensity sectors, whereas targeted policies may concentrate efforts in sectors with the highest environmental returns.

LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Final Remarks

- The article demonstrates that combining input-output models with goal programming provides a relevant tool for evaluating productive-restructuring trajectories compatible with climate objectives.
- The approach makes it possible to identify not only the aggregate cost of mitigation, but also its sectoral distribution, thereby providing evidence for designing more efficient and socially sensitive climate policies.

LATES
LABORATÓRIO DE ANÁLISES TERRITORIAIS E SETORIAIS

# Thanks!
# Gracias!
# Obrigado!

**Contact:** fernando.perobelli@ufjf.br