Structural change: sectoral effect of carbon pricing

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Why can carbon pricing policies induce structural changes?

Climate mitigation policies frequently focus on carbon-intensive sectors.

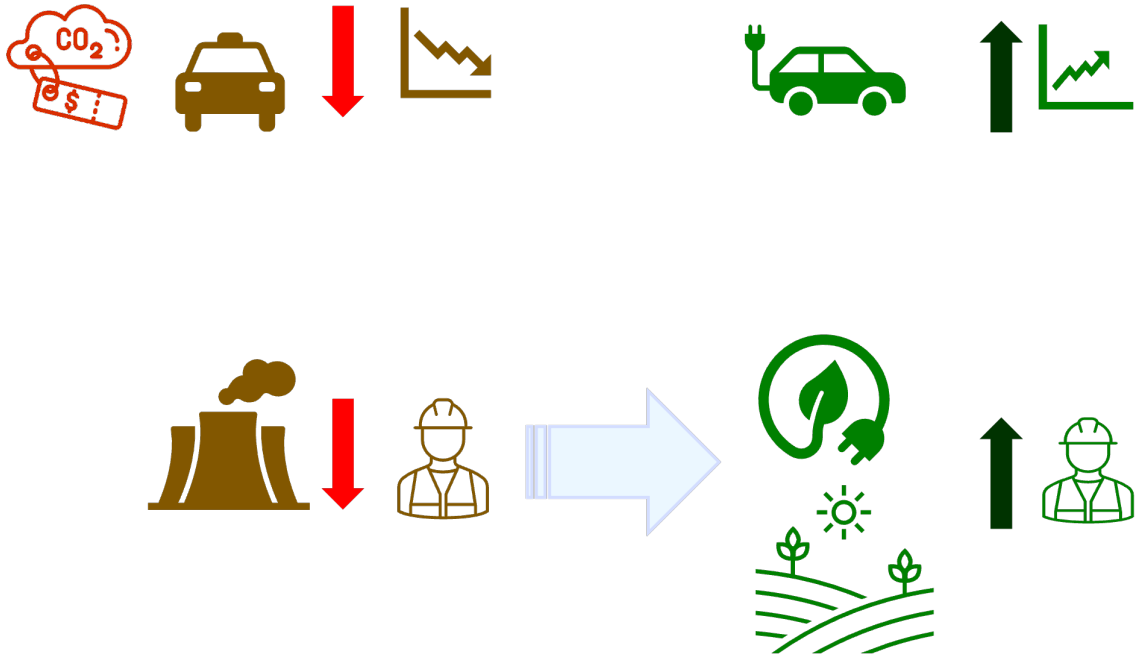

Figura: Directed Technological Change process

Creating incentives to reduce energy intensity by:

- adopting energy-saving technologies,
- transitioning to less energy-intensive industries.

The KAYA identity expresses the main drivers of CO2 emissions. View

How will climate actions reshape GDP shares and energy consumption across sectors?

This article addresses the following questions:

- Which sectors have the potential to drive economic growth?
- Which sectors are more negatively impacted by climate policies?

How?

- Decomposition Analysis to identify the drivers behind the reduction in energy intensity.
  - Structural changes,
  - Improvements in energy efficiency.
- Empirical exercises: OLS and Event Study (Staggered).
  - The effect of climate mitigation policies on energy intensity.
  - The effect of climate mitigation policies on structural changes, and on energy efficiency.

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Data

Panel data: 27 countries, (1990 to 2021).

- Annual Gross Domestic Product by economic activity. *CEPAL- STATS*
- Energy Balances (1970-2023)*Latin American Energy Organization (OLADE)*
- Climate policies (over 5000 laws, policies, and UNFCCC submissions related to climate change laws) *Climate Policy Radar Database*

Variable		**Mean**	**Median**	**Std. Dev.**
		Latin American Countries		
Carbon intensity	(kt of CO2e/TJ)	0,176	0,133	0,179
Energy intensity	(TJ/$2018 PPP GDP)	11,250	8,324	8,520
Emissions per unit of GDP	(kt of CO2e/$2018 PPP GDP)	1,720	1,193	1,561
GDP	(US Millions, 2018)	119996,05	15057,75	303782,13
Number of climate policies approved		15,320	13,000	14,142
Agriculture, fishing and Mining	(% of GDP)	0,092	0,073	0,091
Manufacturing and Electricity, gas and water supply	(% of GDP)	0,195	0,191	0,072
Construction	(% of GDP)	0,072	0,066	0,029
Transport	(% of GDP)	0,100	0,093	0,032
Hotels and restaurants	(% of GDP)	0,031	0,028	0,033
Commercial, services, public	(% of GDP)	0,507	0,519	0,088
Agriculture, fishing and Mining	(TJ/$2018 PPP GDP)	15,101	3,931	30,440
Manufacturing and Electricity, gas and water supply	(TJ/$2018 PPP GDP)	15,767	9,651	15,957
Construction	(TJ/$2018 PPP GDP)	2,846	0,582	6,361
Transport	(TJ/$2018 PPP GDP)	34,681	32,971	20,328
Hotels and restaurants	(TJ/$2018 PPP GDP)	83,853	38,170	118,818
Commercial, services, public	(TJ/$2018 PPP GDP)	1,012	0,837	0,916

Decomposition analysis to quantify structural change vs. energy efficiency improvements

- Energy intensity can be expressed in terms of energy consumption by sector, total and sectoral production, as equation:

$$\frac{E_{c,t}}{Y_{c,t}} = \sum_{i}^{n} \frac{Y_{s,c,t}}{Y_{c,t}} \frac{E_{s,c,t}}{Y_{s,c,t}} = \sum_{i}^{n} s_{s,c,t} e_{s,c,t} \tag{1}$$

  - The components of change in energy intensity were:

$$\Delta\left(\frac{E_{c,t}}{Y_{c,t}}\right) = \underbrace{\sum_{i}^{n} \Delta\left(\frac{Y_{s,c,t}}{Y_{c,t}}\right) \frac{E_{s,c,t}}{Y_{s,c,t}}}_{\text{Structural Change}} + \underbrace{\sum_{i}^{n} \frac{Y_{s,c,t}}{Y_{c,t}} \Delta\left(\frac{E_{s,c,t}}{Y_{s,c,t}}\right)}_{\text{Changes in Energy Efficiency}}$$

$$+ \underbrace{\sum_{i}^{n} \Delta\left(\frac{Y_{s,c,t}}{Y_{c,t}}\right) \Delta\left(\frac{E_{s,c,t}}{Y_{s,c,t}}\right)}_{\text{Combined Changes}} \tag{2}$$

Empirical Exercises: OLS

- The relationship between national-level climate policies and energy intensity:

$$\frac{E_{c,t}}{Y_{c,t}} = \lambda_0 + \lambda_1 \log Y_{c,t} + \lambda_2 D_{c,t} + \lambda_3 X_{c,t} + \gamma_c + \phi_t + \epsilon_{c,t} \tag{3}$$

  - $\frac{E_{c,t}}{Y_{c,t}}$: Energy intensity in country c and year t
  - $Y_{c,t}$ Annual gross domestic product by country at constant prices (2018).
  - $D_{c,t}$ Number of mitigation climate policies implemented by country c between 1990 and 2021.
  - $X_{c,t}$ Set of control variables including population, CO2 emissions, and carbon intensity $\frac{CO_{c,t}}{E_{s,c,t}}$.
  - γ_c Country-fixed effects.
  - ϕ_t Time-fixed effects .

- Sector-level analysis of each component of EI: Structural change $\frac{Y_{s,c,t}}{Y_{c,t}}$ and Energy efficiency $\frac{E_{s,c,t}}{Y_{s,c,t}}$.

$$\frac{Y_{s,c,t}}{Y_{c,t}} = \beta_0 + \beta_1 \log Y_{c,t} + \beta_2 D_{s,c,t} + \beta_3 X_{c,t} + \gamma_c + \phi_t + \epsilon_{s,c,t} \tag{4}$$

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Energy Intensity Decomposition in Latin America

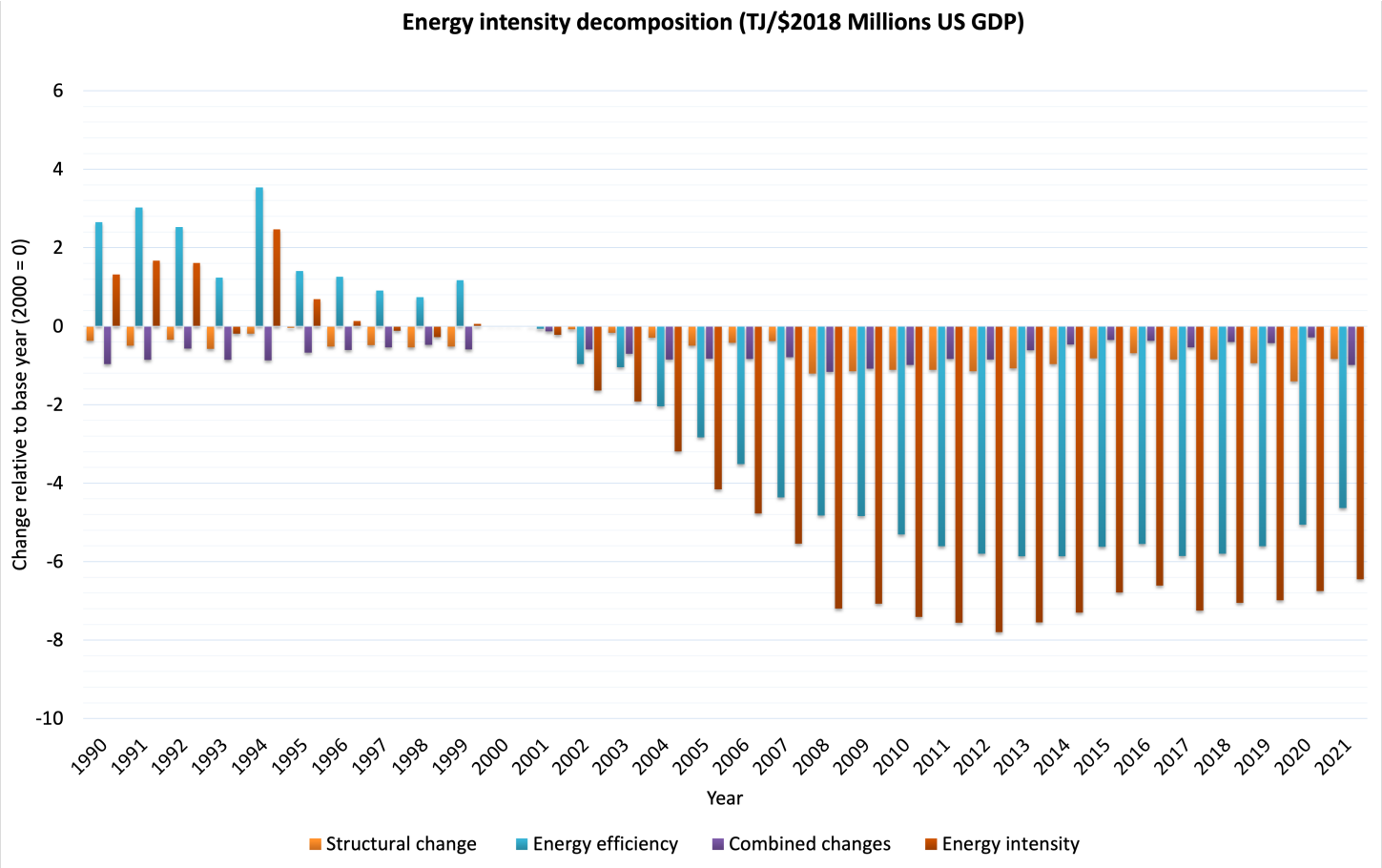

Figura: Variation of energy intensity and its components.

- Energy efficiency is responsible for 75 % of energy intensity reductions.
- Structural change has played a more minor role, contributing around 15 % to decreased energy intensity.

Energy Intensity Decomposition by Income

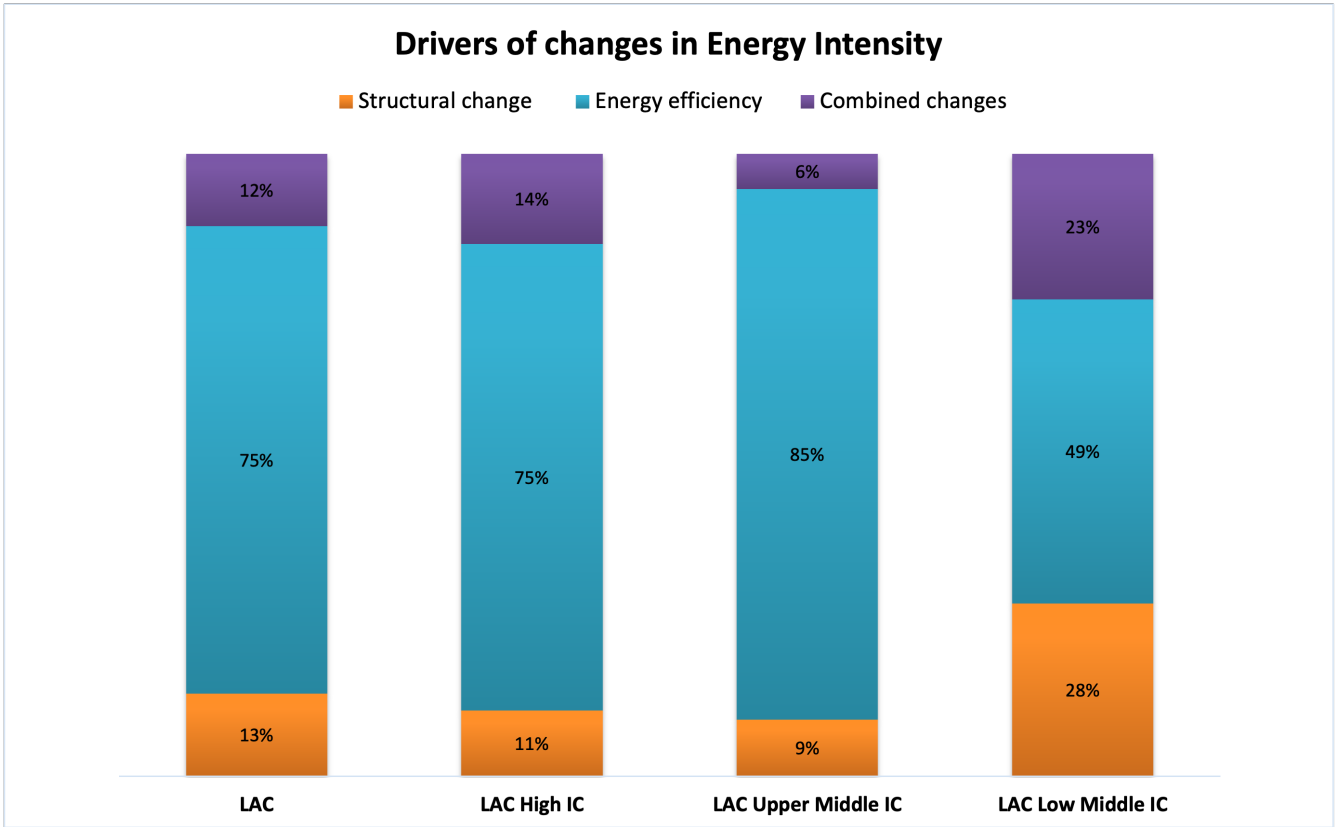

Figura: Components of energy intensity and changes by income from 2000-2021

- Impacts vary by income level - efficiency dominant for higher income countries, structure mattered more in the early 2000s for lower middle income.

Structural Change by Sectors

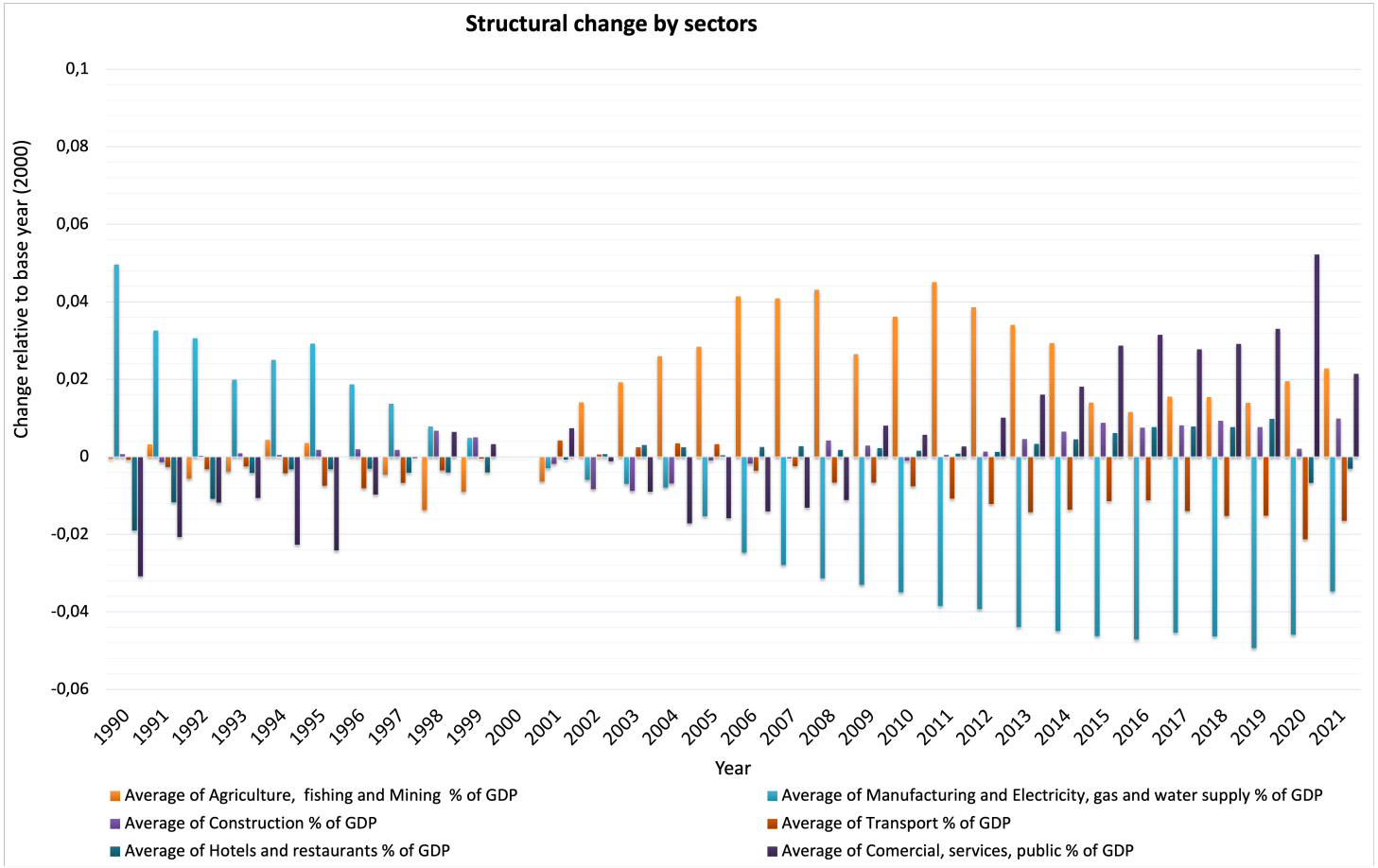

Figura: Structural change by sectors.

- Economic sectors reducing their GDP share compared to 2000 are manufacturing and transportation.
- Sectors increasing their share are agriculture, mining, commerce, services, construction, and hotels.

Structural Change by Income

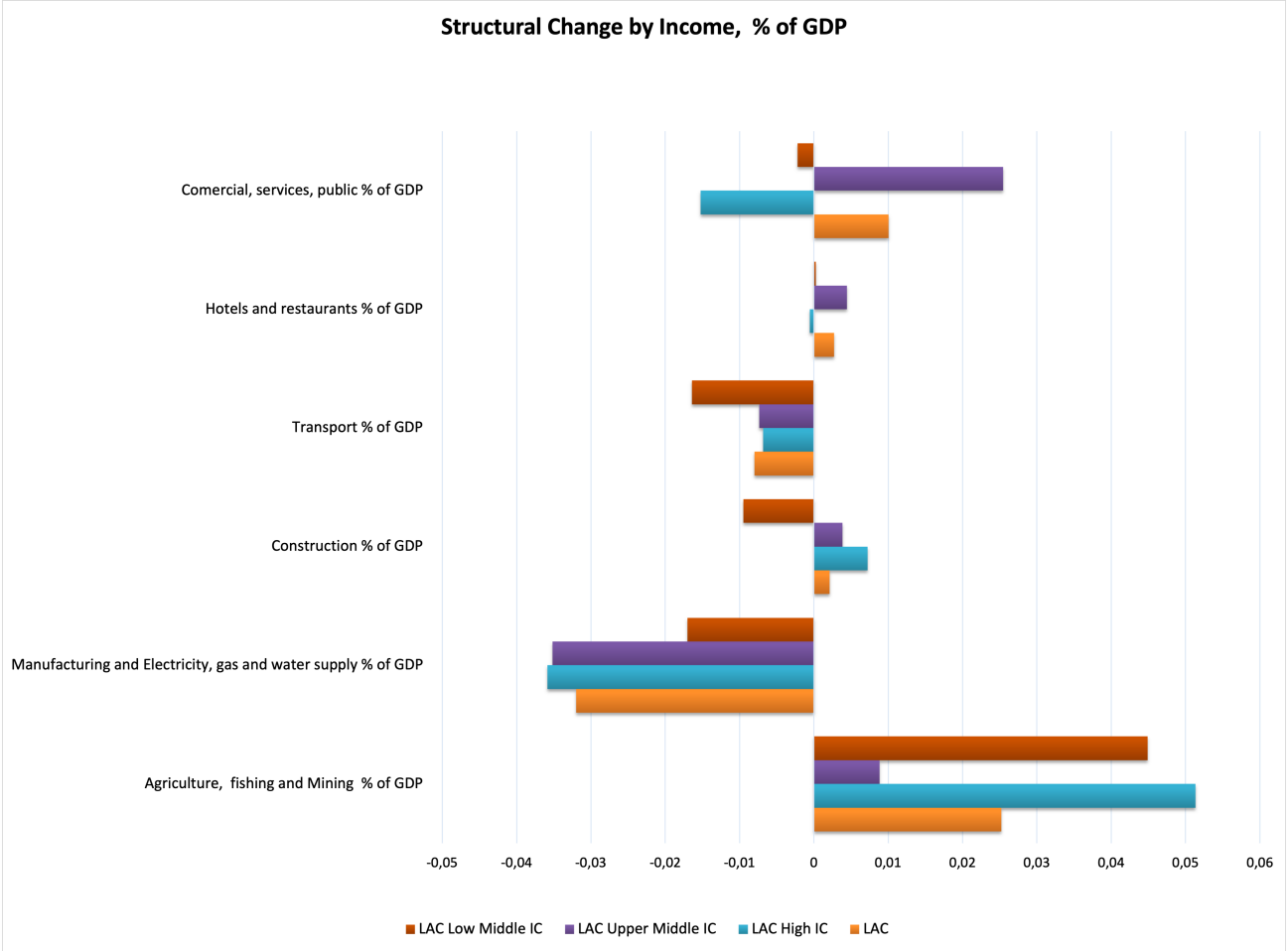

Figura: Changes in shares of GDP by sector from (2001 - 2021)

- In high-income countries, the structural shifts particularly benefit less energy-intensive sectors like agriculture and construction, while reducing the manufacturing sector.
- For upper-middle-income countries, services stand out with a GDP share growth of around 4 % since 2010.

Key Empirical Results

- National-Level Climate Policies:
  - National climate change mitigation policies associated with lower energy intensity (0.023 to 0.44 TJ reduction per policy).
  - Interaction between higher carbon intensity and more climate policies leads to larger energy intensity decreases.
- Sectoral Policies and Structural Change:
  - Agriculture & mining policies reduce the share in GDP by 1 %.
  - Industrial and buildings policies shrink manufacturing sector share
  - Transport policies have no significant impact on transport GDP share
  - Energy policies weakly but positively associated with services' share
- Sectoral Policies and Energy Efficiency:
  - Industrial climate policies successfully reduce manufacturing's energy use per GDP.
  - But agriculture, buildings, and transport policies increase energy intensity for those sectors.

OLS: National-Level Climate Policies

Cuadro: Regression OLS Results at country level

	Dependent variable:		
	Energy intensity (Energy/GDP)		
	(1)	(2)	(3)
Constant	44.905***	141.404***	143.217***
	(2.029)	(4.458)	(4.544)
log(GDP)	-3.205***	-11.955***	-12.641***
	(0.209)	(0.518)	(0.528)
Total Policies	-0.023	-0.437***	0.280***
	(0.022)	(0.030)	(0.044)
Carbon Intensity (CO2/Energy)	-18.630***	-7.907***	8.173***
	(1.533)	(1.302)	(1.320)
Total Policies*Carbon Intensity			-2.163***
			(0.294)
Population (Million hab.)	0.079***	0.116***	0.107***
	(0.011)	(0.029)	(0.028)
Lower middle income	3.465***	-15.986***	-16.320***
	(0.798)	(0.972)	(1.243)
Upper middle income	-0.759	26.378***	18.401***
	(0.617)	(1.972)	(2.056)
Renewable energy consumption			-0.066***
			(0.021)
Country FE	-	X	X
Time FE	-	X	X
Observations	797	797	797
R^2	0.363	0.841	0.853
Adjusted R^2	0.358	0.828	0.841
Residual Std. Error	6.826 (df = 790)	3.530 (df = 738)	3.401 (df = 736)
F Statistic	75.000*** (df = 6; 790)	67.219*** (df = 58; 738)	70.999*** (df = 60; 736)

OLS: Sectoral Policies and Structural Change

Cuadro: Results for Structural Change by sectors

	Dependent variable: % GDP				
	Agro&Mining	Manufacture	Hotel&Restaurant	Transport	Services
	(1)	(2)	(3)	(4)	(5)
Constant	0.034	1.100***	-0.036**	0.376***	0.719***
	(0.055)	(0.048)	(0.016)	(0.023)	(0.046)
log(GDP_SUM)	0.016**	-0.070***	0.006***	-0.030***	-0.022***
	(0.006)	(0.004)	(0.002)	(0.003)	(0.006)
Policies in Agriculture	-0.113***				
	(0.022)				
Energy/GDP Agriculture	-0.0005***				
	(0.0001)				
Policies in Industry		-0.093***			
		(0.013)			
Energy/GDP Industry		-0.001***			
		(0.0001)			
Policies in Buildings			-0.010*		
			(0.006)		
Energy/GDP Buildings			-0.00004***		
			(0.00001)		
Policies Transport				0.089***	
				(0.008)	
Energy/GDP in Transport				-0.001***	
				(0.0001)	
Policies Energy					0.004**
					(0.002)
Energy/GDP in Services					-0.024***
					(0.002)
Observations	765	797	600	797	797
R^2	0.814	0.880	0.939	0.785	0.809
Adjusted R^2	0.799	0.871	0.933	0.769	0.794
Residual Std. Error	0.041 (df = 708)	0.026 (df = 739)	0.008 (df = 544)	0.015 (df = 739)	0.038 (df = 739)
F Statistic	55.166*** (df = 56; 708)	95.433*** (df = 57; 739)	153.075*** (df = 55; 544)	47.442*** (df = 57; 739)	54.932*** (df = 57; 739)
Note:					*p<0.1; **p<0.05; ***p<0.01

OLS: Sectoral Policies and Energy Efficiency

Cuadro: Results for Energy efficiency by sectors

	Dependent variable: Energy consumption/GDP (Energy Efficiency)				
	Agro&Mining	Manufacture	Hotel&Restaurant	Transport	Services
	(1)	(2)	(3)	(4)	(5)
Constant	190.594***	287.958***	841.738***	269.459***	12.326***
	(26.181)	(18.275)	(103.155)	(11.435)	(0.630)
log(GDP)	-17.525***	-21.507***	-75.781***	-23.976***	-1.310***
	(3.050)	(1.413)	(11.711)	(1.277)	(0.080)
Policies Agriculture	64.324***				
	(12.396)				
GDP Agriculture	-114.661***				
	(17.970)				
Policies Industry		-38.173***			
		(4.948)			
GDP Industry		-114.885***			
		(11.687)			
Policies Buildings			235.701***		
			(46.221)		
GDP Buildings			-1,720.251***		
			(285.694)		
Policies Transport				77.797***	
				(5.072)	
GDP Transport				-255.736***	
				(18.501)	
Policies Energy					0.301***
					(0.025)
GDP Services					-5.115***
					(0.506)
Observations	765	797	600	797	797
R^2	0.597	0.730	0.801	0.835	0.668
Adjusted R^2	0.565	0.709	0.781	0.822	0.642
Residual Std. Error	20.095 (df = 707)	8.608 (df = 738)	55.603 (df = 543)	8.585 (df = 738)	0.548 (df = 738)
F Statistic	18.383*** (df = 57; 707)	34.438*** (df = 58; 738)	39.148*** (df = 56; 543)	64.219*** (df = 58; 738)	25.595*** (df = 58; 738)

Note: *p<0.1; **p<0.05; ***p<0.01

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Conclusions

- Climate mitigation policies can provide incentives that facilitate structural shifts toward less energy-intensive economic activities and promote greater energy efficiency improvements across sectors
- However, there is significant variation in sectoral impacts:
  - Emissions-intensive sectors like manufacturing may see declines in economic share and energy efficiency gains.
  - Meanwhile, services, construction, agriculture seem to structurally benefit
- National-level climate policies are broadly associated with declining aggregate energy intensity.
- But sector-level effects on structure and efficiency changes are heterogeneous

Thank you

What are the drivers that determines the CO2 emissions?

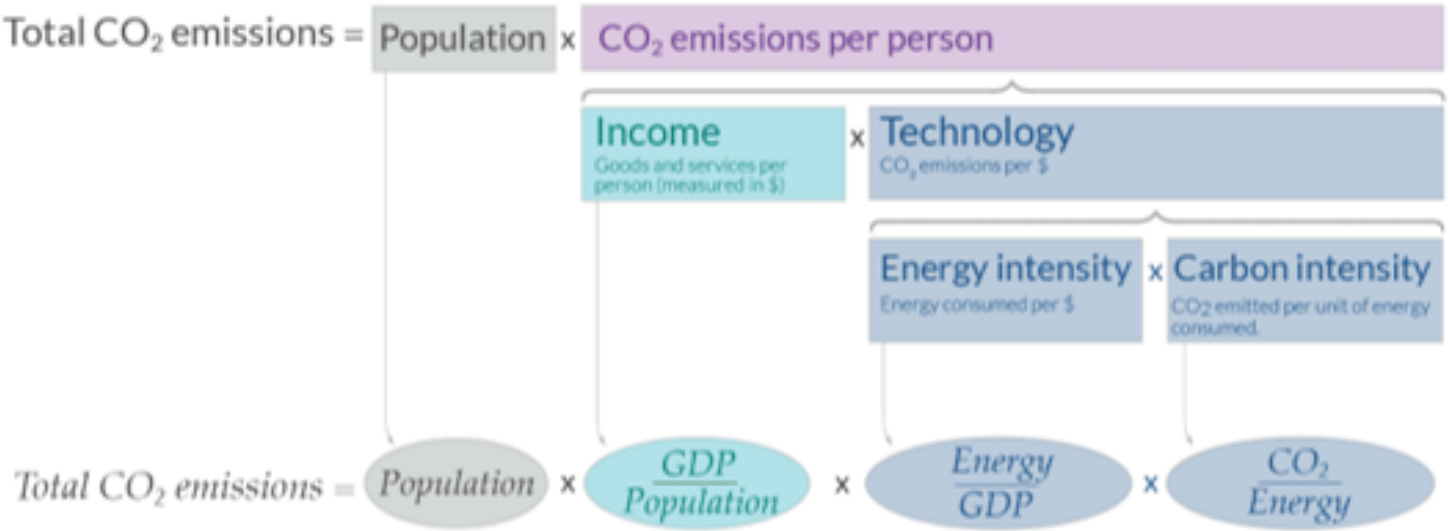

Figura: Drivers of CO2 emissions.

- ↓ energy intensity through improving energy efficiency and/or switching to less intensive industries.
- ↓ carbon intensity through shift to renewable energy, shift to nuclear power, fossil CO2 capture and storage (CCS).

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