A Multi-Model Regional Decomposition of CO_2 Emissions: Socio-Economic Developments vs Energy Efficiency and Carbon Intensity Improvements

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Overview

Objectives of the Study

The study has 2 goals:

1. To explore regional distribution of CO_2 emission variations and their drivers from 2010 to 2100 and across different socio-economic scenarios
2. To examine how different integrated assessment models predict regional distributions of CO_2 emissions

Motivation

- To determine the implications of each of the 4 drivers in evaluating the impacts of socio-economic scenarios on global and regional economic systems and exploring the differences between short-term (2030 vs 2010), medium-term (2050 vs 2010) and long term (2100 vs 2010) effects

Data

Models

- AIM-CGE
- GCAM
- MESSAGE
- IMAGE
- REMIND
- WITCH

Time

2010-2100

Regions of the world

Advanced Economies: EUROPE, USA
Developing Economies: R5ASIA, R5MAF, R5LAM

Socioeconomic Scenarios

5 SSPs developed by the National Center for Atmospheric Research (NCAR)

Methodology

- Kaya and Yokoburi (1997) decompose carbon dioxide emissions into 4 components, namely Population, GDP per capita, Energy Efficiency and Carbon Intensity:

$$CO_2 = POP * \frac{GDP}{POP} * \frac{PE}{GDP} * \frac{CO_2}{PE} \tag{1}$$

- As in Ang (2000) a difference in an aggregate indicator can be decomposed into the sum of the effects by differences in explaining factors and residual terms. Hence defining: $\Delta CO_2 = CO_{2_t} - CO_{2_0}$

$$\Delta CO_2 = \Delta POP + \Delta\left(\frac{GDP}{POP}\right) + \Delta\left(\frac{PE}{GDP}\right) + \Delta\left(\frac{CO_2}{PE}\right) + \Delta res \tag{2}$$

  - Each driver contributes in the following form (where t is the year (i.e 2030, 2050, 2100), 0 is the starting year (i.e. 2010), i stands for the region and j refers to the scenario):

Log Mean Divisia Index Method (LMDI)

$$\Delta POP = \frac{CO_{2_{t,i,j}} - CO_{2_{0,i,j}}}{lnCO_{2_{t,i,j}} - lnCO_{2_{0,i,j}}} ln\left(\frac{POP_{t,i,j}}{POP_{0,i,j}}\right) \tag{3a}$$

$$\Delta \frac{GDP}{POP} = \frac{CO_{2_{t,i,j}} - CO_{2_{0,i,j}}}{lnCO_{2_{t,i,j}} - lnCO_{2_{0,i,j}}} ln\left(\frac{\frac{GDP_{t,i,j}}{POP_{t,i,j}}}{\frac{GDP_{0,i,j}}{POP_{0,i,j}}}\right) \tag{3b}$$

$$\Delta \frac{PE}{GDP} = \frac{CO_{2_{t,i,j}} - CO_{2_{0,i,j}}}{lnCO_{2_{t,i,j}} - lnCO_{2_{0,i,j}}} ln\left(\frac{\frac{PE_{t,1,j}}{GDP_{t,i,j}}}{\frac{PE_{0,i,j}}{GDP_{0,1,j}}}\right) \tag{3c}$$

$$\Delta \frac{CO_2}{PE} = \frac{CO_{2_{t,i,j}} - CO_{2_{0,i,j}}}{lnCO_{2_{t,i,j}} - lnCO_{2_{0,i,j}}} ln\left(\frac{\frac{CO_{2_{t,i,j}}}{GDP_{t,i,j}}}{\frac{CO_{2_{0,i,j}}}{PE_{0,i,j}}}\right) \tag{3d}$$

$$\Delta res = 0 \tag{3e}$$

The Shared Socio-economic Pathways (SSPs)

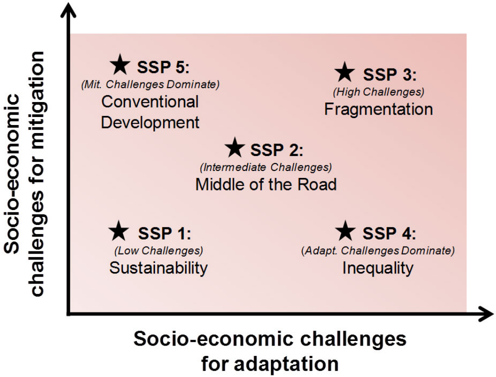


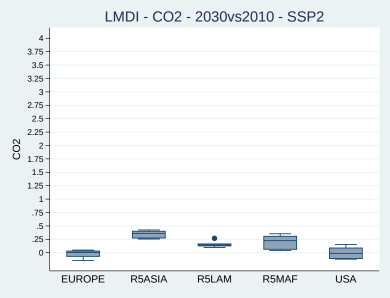
Figure: Conceptual framework and names of new global Shared Socio-economic Pathways (SSPs) for climate change research as defined in O'Neill et al.(2012).

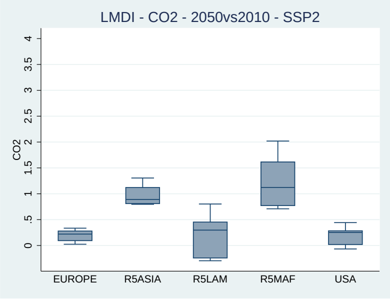
Results of the decomposition of ΔCO_2 - SSP2

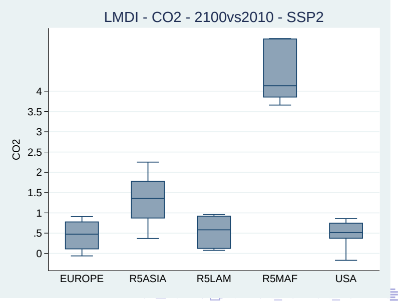
Characterizations of the SSP2 scenario:

- Middle of the Road. This is the most adopted SSP for analysis.
- Medium Technology Growth
- Environmental Awareness
- Medium Energy Demand
- Medium Economic Growth
- Medium Population Growth

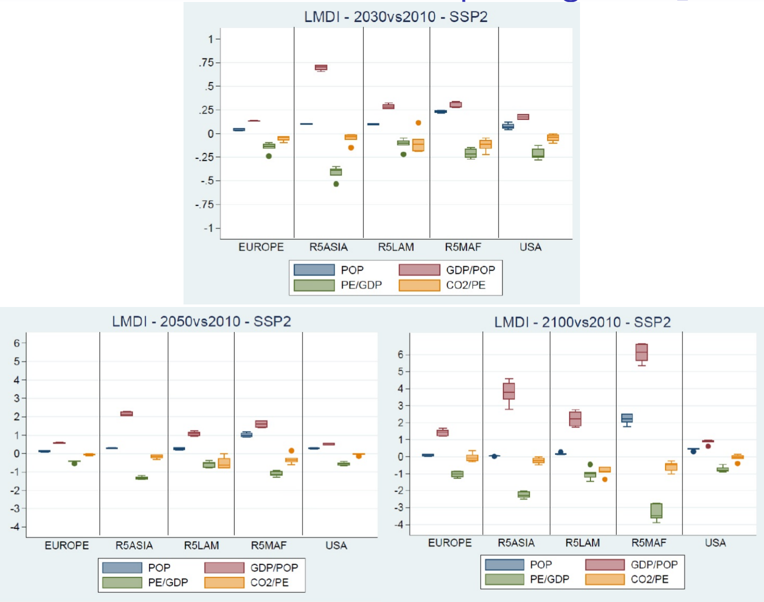
Results of the decomposition of ΔCO_2 - SSP2







Contribution of each driver in explaining ΔCO_2 - SSP2



What We Deduce from the LMDI Decomposition for SSP2

R5MAF and R5ASIA ΔCO_2 emissions Over Time

In such framework, R5ASIA and R5MAF countries will experience the same ΔCO_2 for the period 2010-2050. After 2050 a divergence is shown, largely due to a greater impact of Population growth and GDP per capita on R5MAF carbon dioxide emissions.

Europe, USA and R5LAM ΔCO_2 emissions Over Time

These 3 regions will once again manage, to keep CO_2 emissions constant over time. This partially due to a slow population growth and GDP per capita.

Role played by each factor

Population and GDP per capita will affect positively CO_2 emissions, while Energy Efficiency and Carbon Intensity will play a negative role in terms of carbon dioxide pollution.

General Conclusion I

- Over the period 2010 to 2050 R5ASIA and R5MAF will pollute more than EUROPE, R5LAM and USA. While from 2050 to 2100 R5MAF will experience a divergence in CO_2 Emissions, R5ASIA will keep CO_2 emissions at the same levels of 2050, this is mainly due to a decrease of population and a minor increase of GDP per capita.

- This can be also seen by taking the Average yearly Growth Rates of CO_2

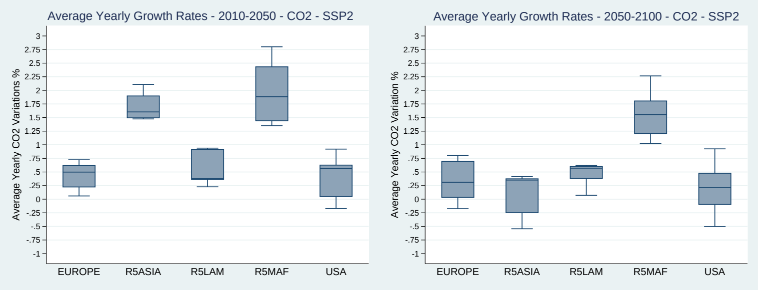
$$log(1+g_{CO_2}) = log(1+g_{POP}) + log(1+g_{\frac{GDP}{POP}}) + log(1+g_{\frac{PE}{GDP}}) + log(1+g_{\frac{CO_2}{PE}}) \quad (4)$$

where $g_x = \left(\frac{x_{t+n}}{x_t}\right)^{\frac{1}{n}} - 1$

For small values of x we obtain

$$g_{CO_2} = g_{POP} + g_{\frac{GDP}{POP}} + g_{\frac{PE}{GDP}} + g_{\frac{CO_2}{PE}} \quad (5)$$

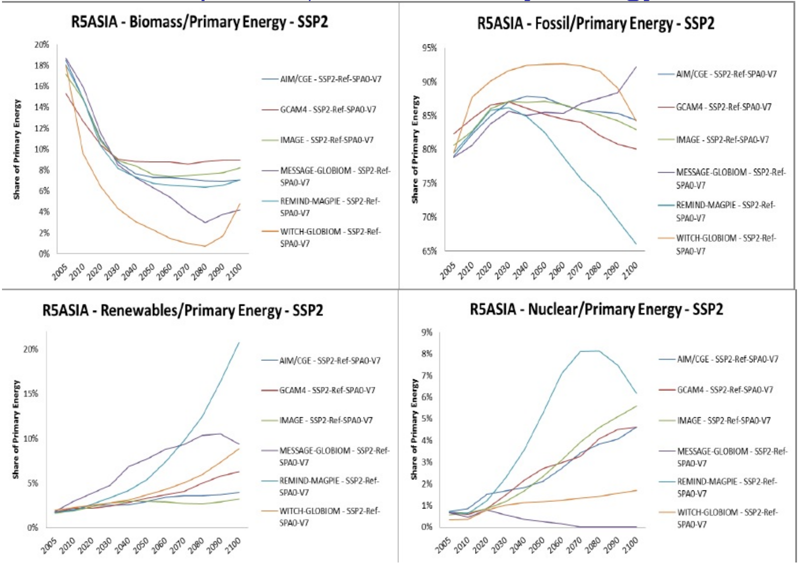
Results Average Yearly Growth Rates



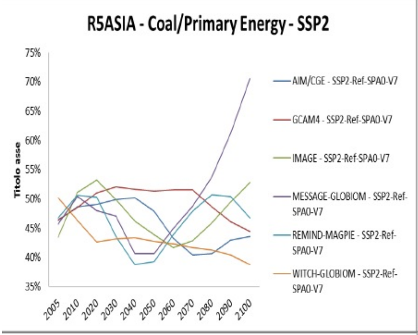
General Conclusion II: Uncertainty Among Models

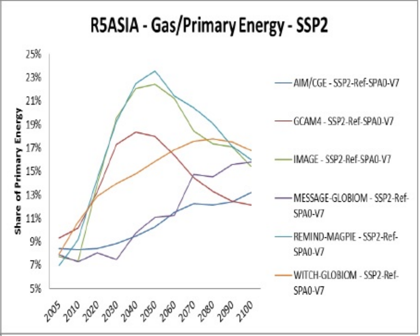
- The source of uncertainty among the 6 models considered was assessed by using Principal Component Analysis
- Considerable degree of homogeneity among models. However the PCs associated to IMAGE and MESSAGE differ from those associated to WITCH, REMIND, GCAM and AIM
- Results of the PCA show a greater difference among models in assessing Energy Efficiency in 2020 with respect to 2050, suggesting that the assumptions that models make on Primary Energy consumption are different, while converging over time.

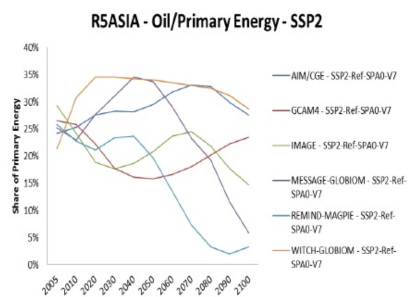
Example: R5ASIA - SSP2 - Primary Energy Component/Total Primary Energy



Fossil Components







Thanks for your attention

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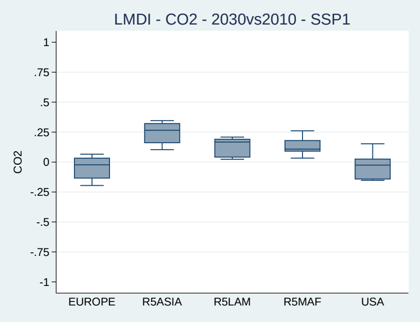
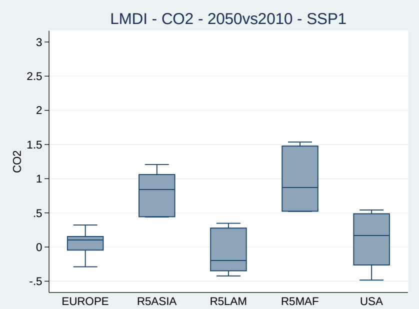
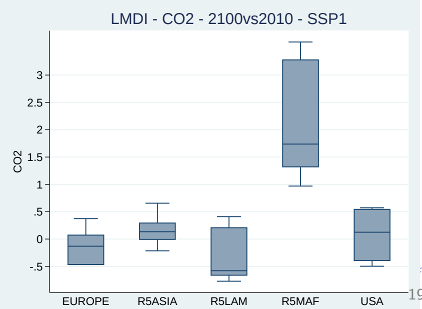
Appendix:

Results of Regional ΔCO_2 for the rest of SSPs

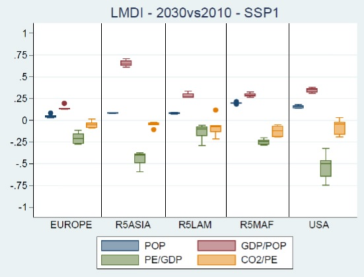
Results of the Decomposition SSP1

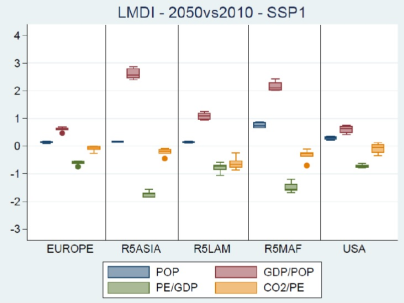


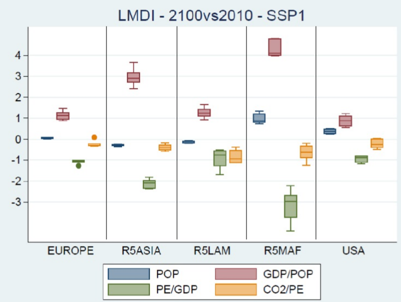




In depth: The contribution of each driver in explaining ΔCO_2 - SSP1







Characterizations of the SSP1 scenario:

- Most Optimistic Scenario in terms of Challenges to Mitigation and Adaptation
- Rapid Technology
- High Environmental Awareness
- Low Energy Demand
- Medium-High Economic Growth
- Low Population

What We Deduce from the LMDI Decomposition for SSP1

Middle East and Africa ΔCO_2 emissions Over Time

R5MAF countries will experience a greater increase in CO_2 emissions over time than the other regions. This is largely due to an increase in GDP per capita.

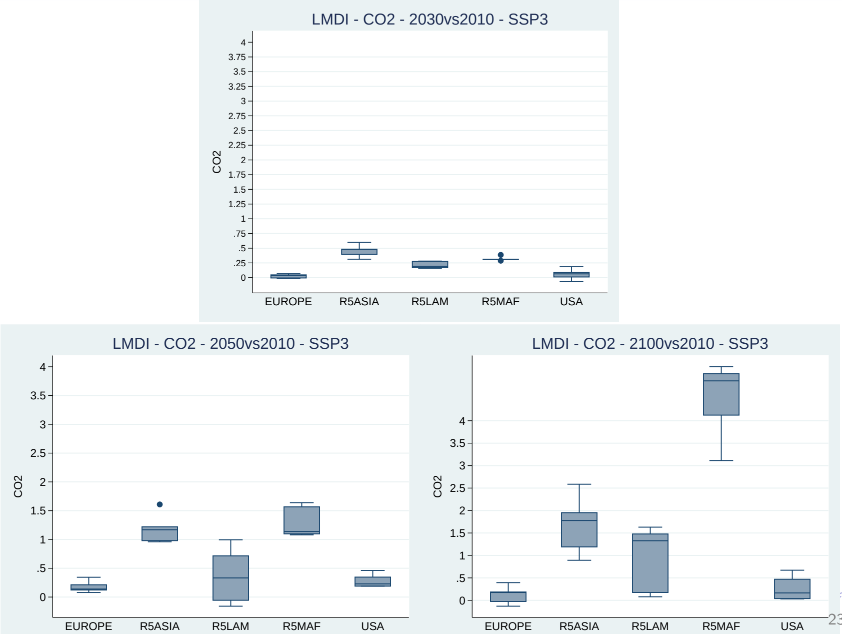
Europe, USA and R5LAM ΔCO_2 emissions Over Time

These 3 regions will manage, in this Scenario, to keep CO_2 emissions constant over time. This partially due to a slow population growth and GDP per capita. Low primary Energy demand will also play a large impact on pushing down CO_2 for R5LAM.

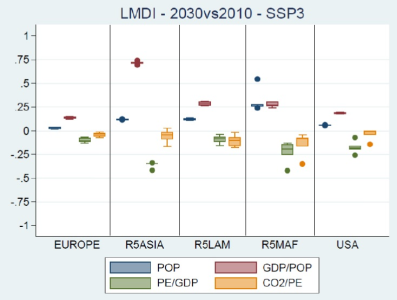
Role played by each factor

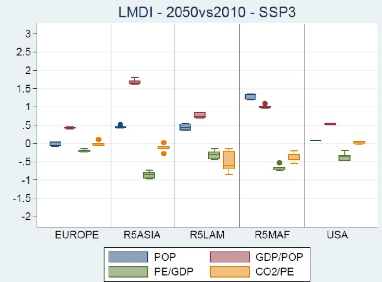
Energy Efficiency will play the largest role in pushing CO_2 emissions down over time, while carbon intensity effect will be more slightly consistent over time

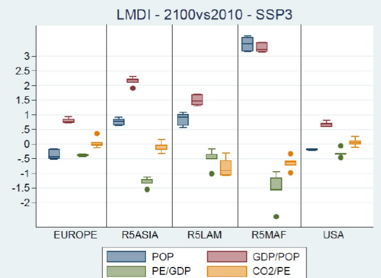
LMDI - ΔCO_2 - Regional Comparison - Over Time - SSP3



In depth: The contribution of each driver in explaining ΔCO_2 - SSP3



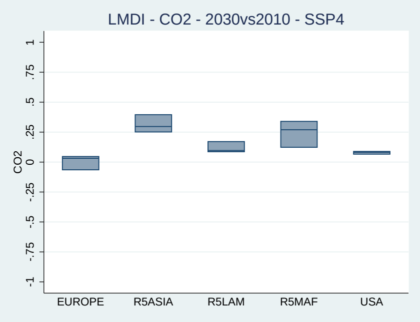


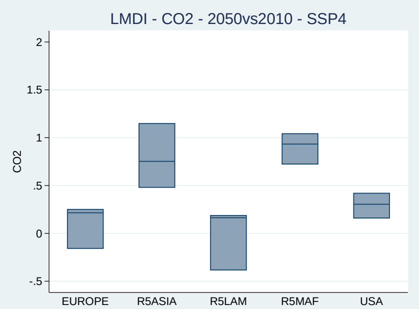


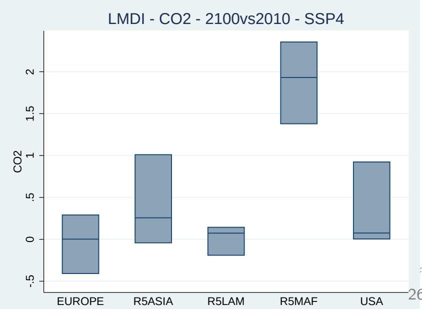
Characterizations of the SSP3 scenario:

- Worst Scenario in terms of Economic Growth
- Slow Technology
- Little Environmental Awareness
- High Energy Demand
- Low/Negative Economic Growth
- Reduced Trade
- Very High Population

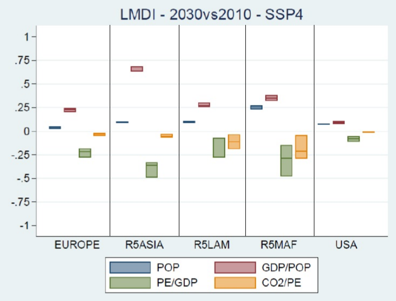
LMDI - ΔCO_2 - Regional Comparison - Over Time - SSP4

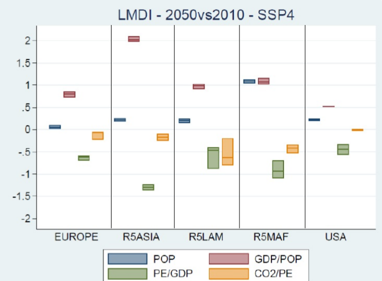


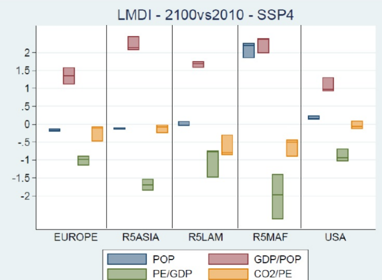




In depth: The contribution of each driver in explaining ΔCO_2 - SSP4





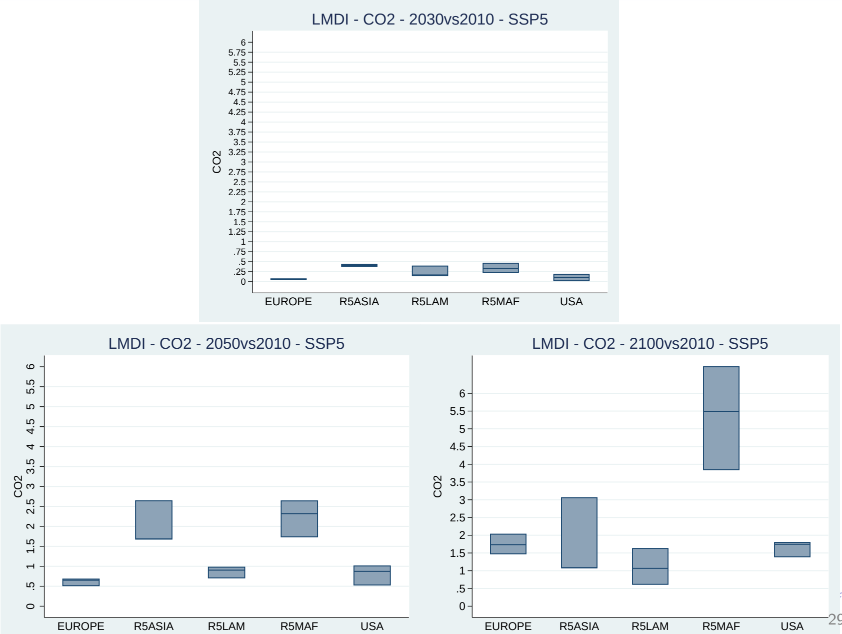


Characterizations of the SSP4 scenario:

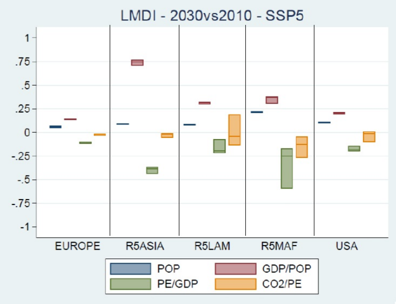
Notes: For SSP4, No Data Available for IMAGE, MESSAGE and REMIND.

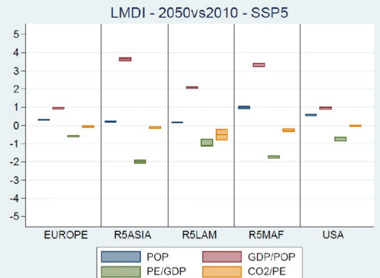
- Low Level of Challenges to Mitigation, but High Level of Challenges to Adaptation
- Slow Technology
- High Inequality
- Low Energy Demand
- Low Economic Growth
- High Population

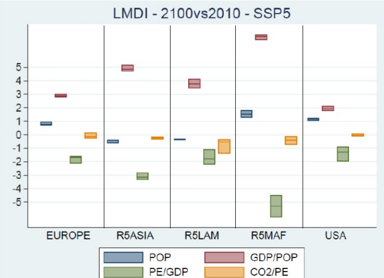
LMDI - ΔCO_2 - Regional Comparison - Over Time - SSP5



In depth: The contribution of each driver in explaining ΔCO_2 - SSP5







Characterizations of the SSP5 scenario:

Notes: For SSP5, No Data Available for IMAGE, MESSAGE and REMIND.

- Worst Scenario in terms of CO_2 Emissions
- High Level of Challenges to Mitigation, but Low Level of Challenges to Adaptation
- Rapid Technology for Fossil
- High Energy Demand
- High Economic Growth
- Low Population