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Crecimiento económico, energía renovable y emisiones de CO_2:

la identidad Kaya y la curva Kuznets medioambiental

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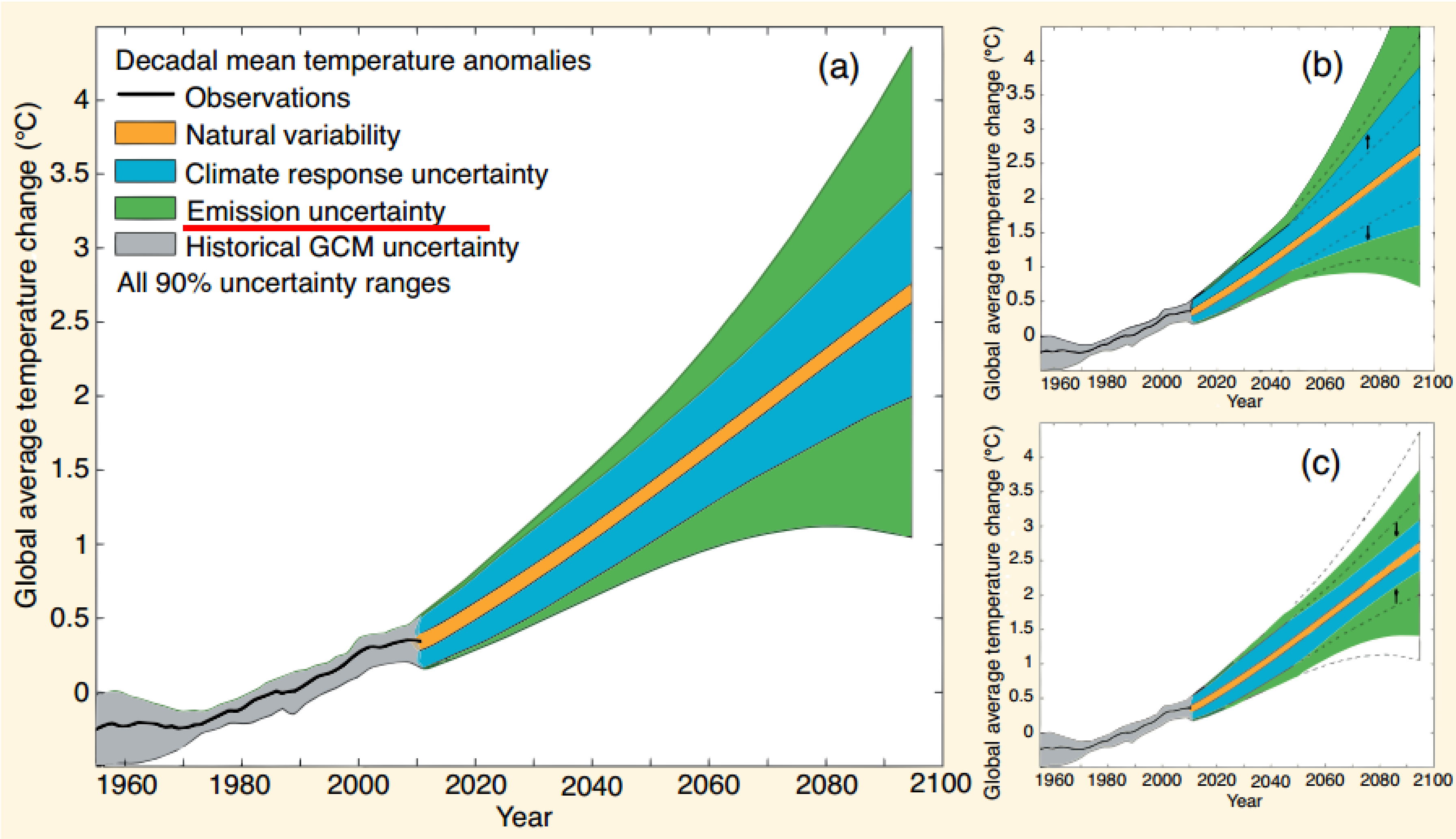
Summary

1. Motivation.
2. The Kaya identity.
3. Integrating the Kaya identity, scenarios industrial structure and renewable energies.
4. A case of study: Ecuador.
5. (The Environmental Kuznets Curve).
6. Conclusions.

Uncertainties in future emissions

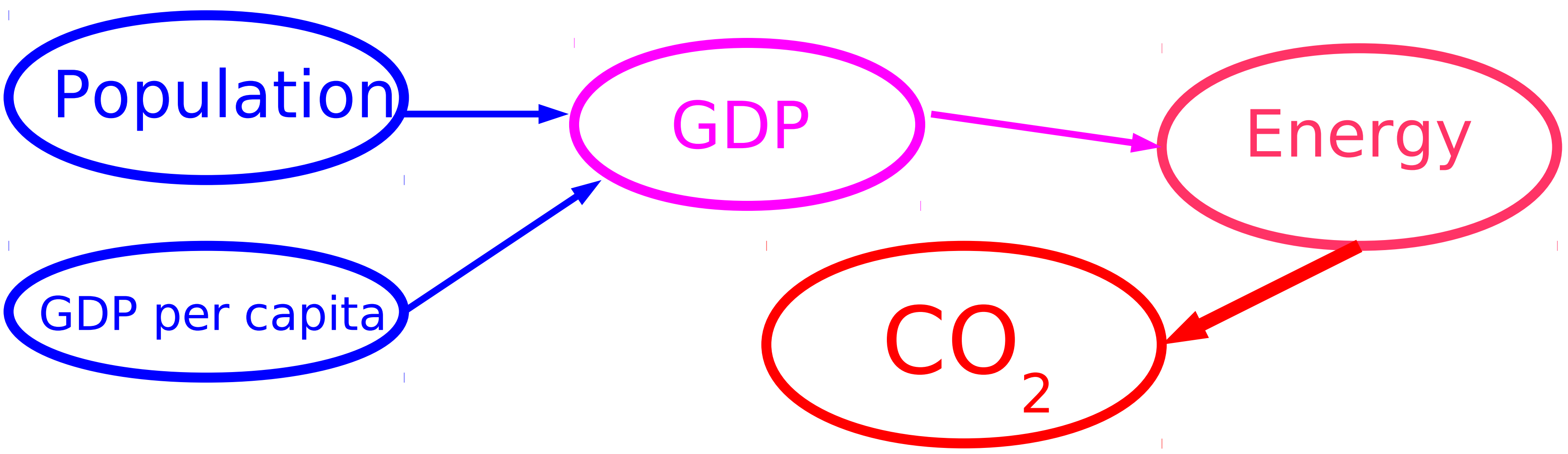


From IPCC 5th Assessment Report: Climate Change 2013

The Kaya indentity

CO_2 vs economic growth

- The gross domestic product (GDP) of a given country is directly connected with its population.
- The energy consumption of a given country is directly connected with its GDP.
- Greenhouse gas emissions of a given country, as CO2 and other contaminants, are directly related with its energy consumption.



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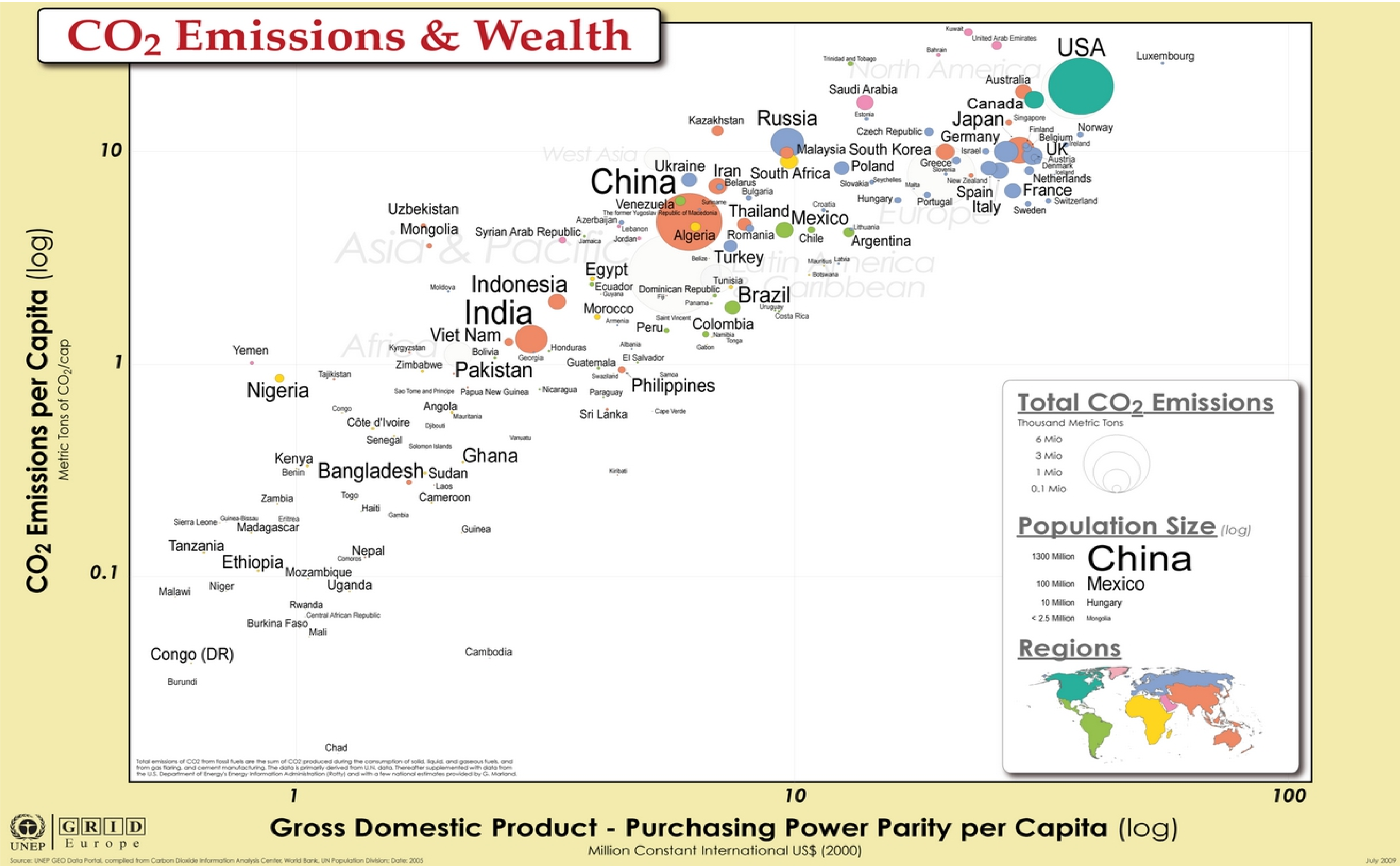
CO_2 and GDP



Kaya identity

Definition

An equation that mathematically relates the factors that determine the level of human impact on climate. It was developed by Japanese energy economist Yoichi Kaya in his book Environment, Energy, and Economy: strategies for sustainability.

From The Dictionary of the Climate Debate (DCD)
http://www.odlt.org/dcd/ballast/kaya_identity.html

Original reference: Y. Kaya. Impact of Carbon Dioxide Emission Control on GNP Growth:Interpretation of Proposed Scenarios. Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris, (mimeo), 1990.

Kaya identity

CO2= Population x
PIB_pc x
Energy_intensity x
CO2_intensity

CO2= Population x
PIB/Population x
Energy/PIB x
CO2/Energy

Kaya identity:

A real equation or just an educated guess

- It can be seen as a trivial identity or a tautology: it's just saying C=C.
- It is not a real equation because all the unknowns are really not known.
- It is a useful tool to design energy and environmental policies.
- The IPCC uses it to estimate emissions from fossil fuels.
- Once an scenario is defined it is very convenient for calculating CO_2 emissions.

Kaya identity

Kaya identity drawbacks

- All factors correspond to aggregated quantities.
- The size of the different sectors is not taken into account.
- The differences in energy intensity are not considered.
- There is no way to consider different CO_2 intensities.
- Only emissions from fossil energies are considered.

Integrating the Kaya identity, scenarios, industrial structure and renewable energies

Sources of data

WORLD BANK GROUP http://data.worldbank.org/

International Energy Agency http://www.iea.org/

Working together to ensure reliable, affordable and clean energy

INTERGOVERNMENTAL PANEL ON climate change http://www.ipcc.ch/

http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/8108.php

+ Local agencies and Central Banks

The disaggregated Kaya formula

Energy intensity

GDP

Emission factors

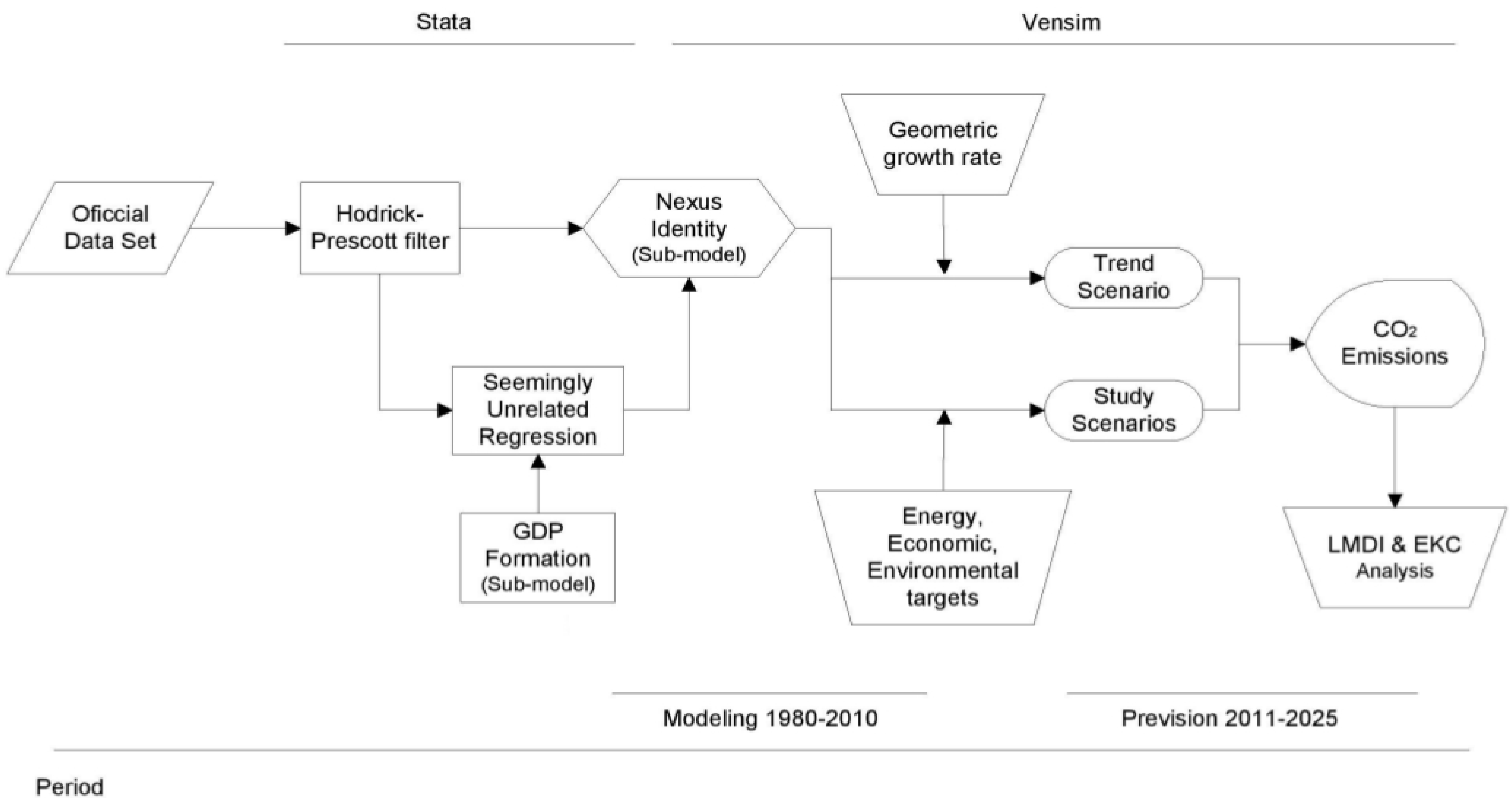
$$C = \sum_{ij} C_{ij} = \sum_{ij} Q \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}} = \sum_{ij} Q \cdot S_i \cdot EI_i \cdot M_{ij} \cdot U_{ij}$$

Sectors

Energy matrix

i labels sector
j labels kind of fuel

General structure of this analysis



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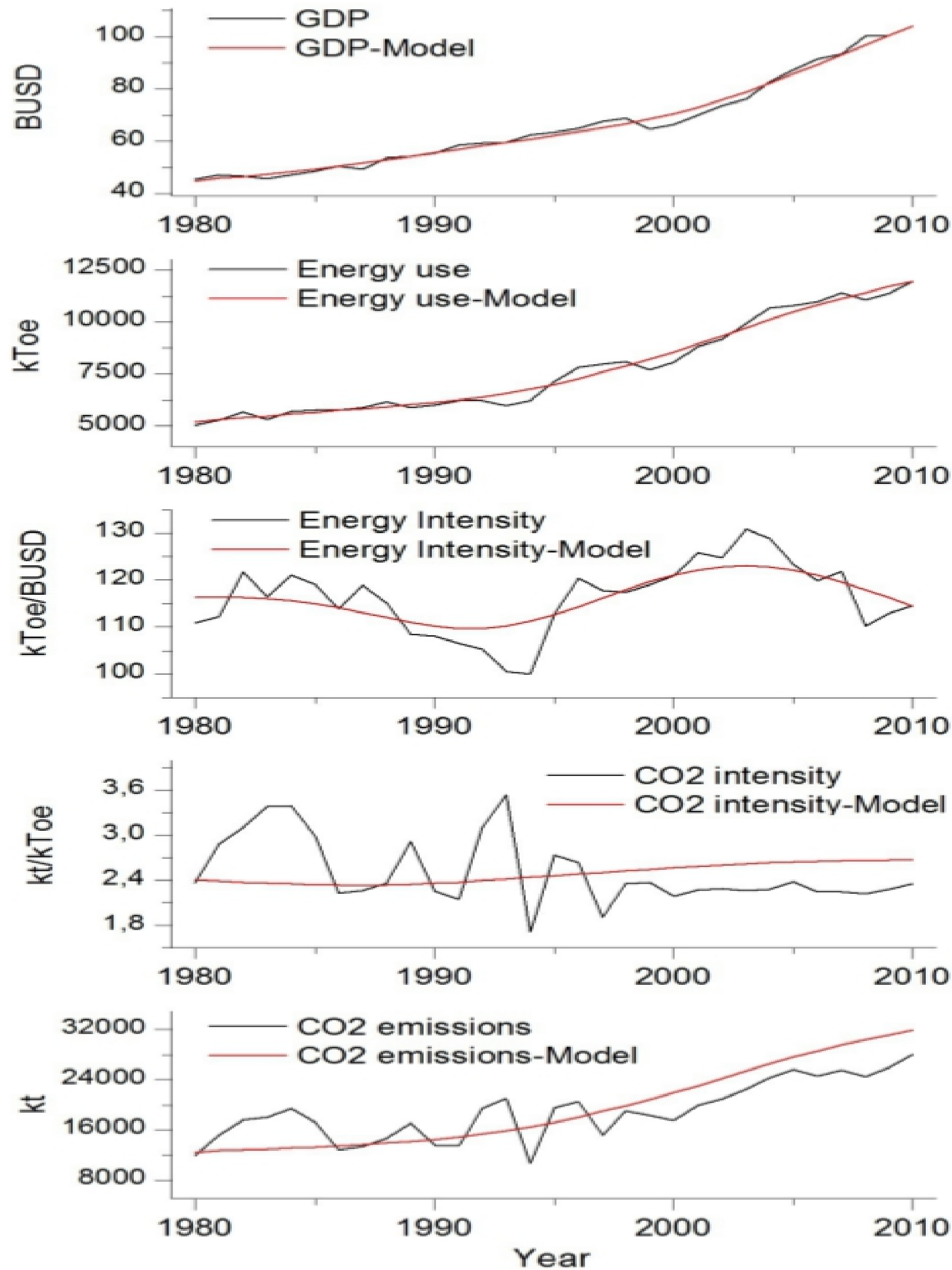
Hodrick-Prescott filter and validation

$$\mathrm{MAPE}(\%) = \frac{1}{n}\sum_{t_1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \times 100.$$

VARIABLE	MAPE(%)
GDP	2.2
Energy consumption	3.3
Energy intensity	3.2
CO_2 intensity	16
CO_2 emission	17



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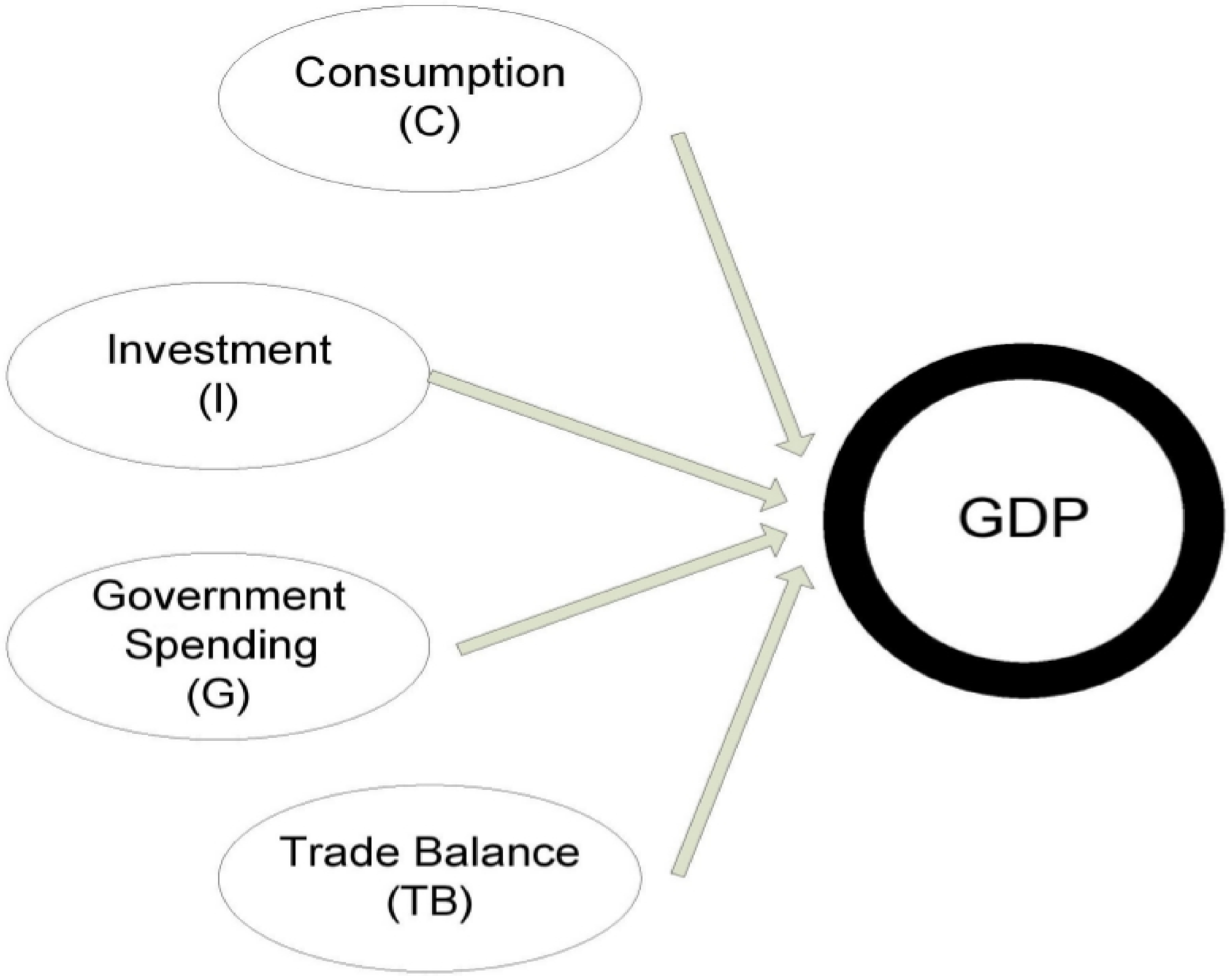
Economic submodel



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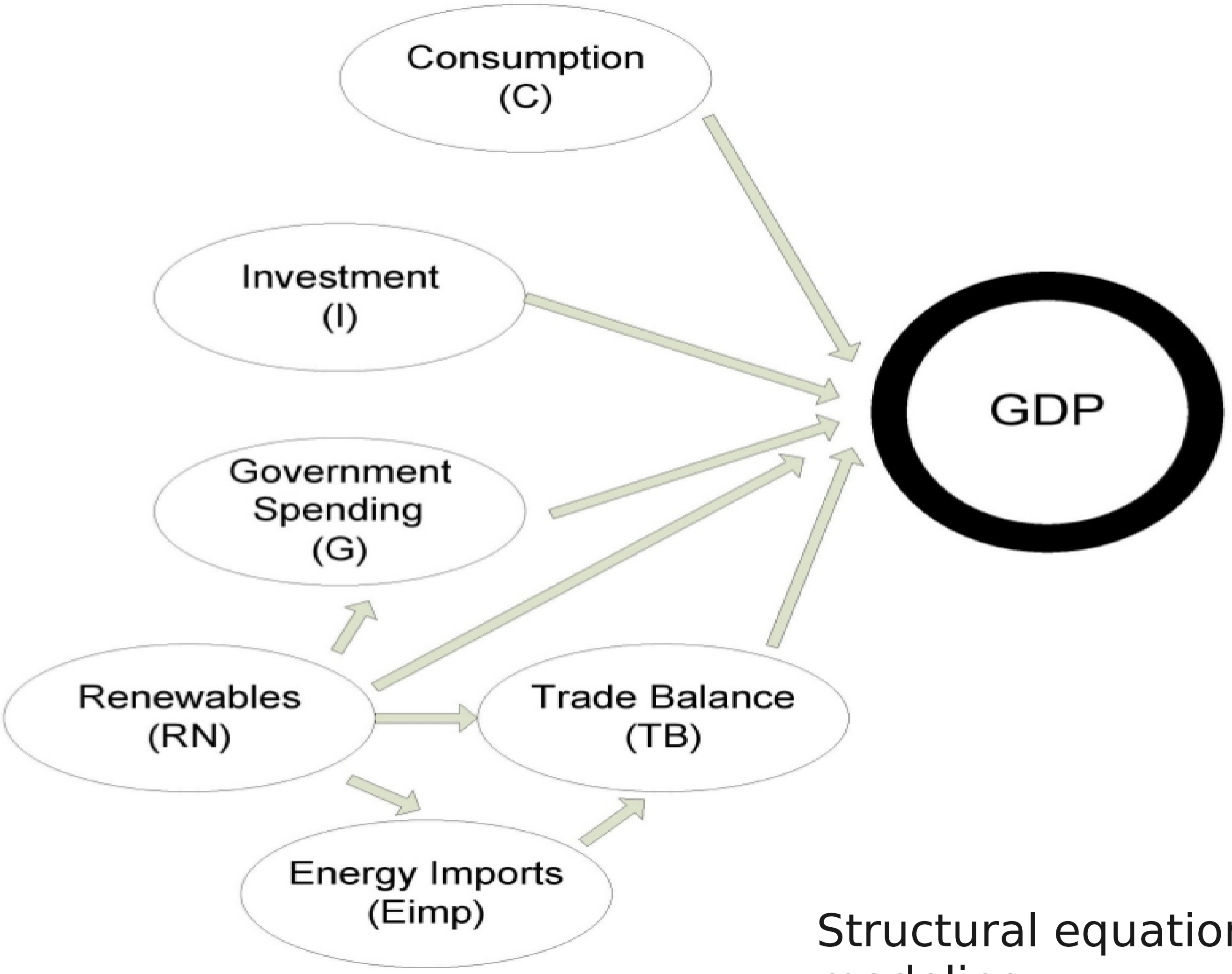
Economic submodel



Structural equation modeling

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Economic submodel

$$GDP = C + I + G + X - M,$$

C: consumption, I: investment, G: goverment spending,
X: exports, M: imports.

$$\begin{aligned}
Q &= a_1 \cdot I + a_2 \cdot TB + a_3 \cdot C + a_4 \cdot Eimp + a_5 \cdot RN + \epsilon_1 \\
I &= b_1 \cdot RN + b_2 \cdot C + \epsilon_2, \\
TB &= c_1 \cdot Eimp + c_2 \cdot RN + \epsilon_3, \\
Eimp &= d_1 \cdot RN + \epsilon_4, \\
C &= f_1 \cdot Eimp + f_2 \cdot TB + \epsilon_5,
\end{aligned}$$

Eimp: energy imports, TB=X-M, RN: renewable energy.

Economic submodel

Variable	GDP [b]	I	TB	C	Eimp
I [c]	1.16***			-6.07***	
	(5.11)			(-41.44)	
TB [d]	0.99***				
	(3.46)				
C [e]	1.21***	0.50***			
	(7.70)	(100.40)			
E_{imp} [f]	0.05***		0.01***	−0.27***	
	(2.66)		(4.14)	(-100.17)	
RN [g]	−0.50***	−0.84***	0.04		−36.79***
	(-4.44)	(-5.40)	(0.28)		(-5.47)

[a] *** represents significance at the 1% level and numbers in parentheses are t-statistics.

Estimation Method: SUR. Sample: 1980-2010. Included observations: 155.

[b] GDP in 10^{10} USD.

[c] I in 10^{10} USD.

[d] TB in 10^{10} USD.

[e] C in 10^{10} USD.

[f] Eimp in 10^{6} toe.

[g] RN in 10^{6} toe.

Model equations

$$
\begin{aligned}
GDP(t) &= a_1 I(t) + a_2 TB(t) + a_3 C_a(t) + a_4 E_{imp}(t) + a_5 RN(t{-}1) \\
E_j(t) &= \sum_i S_i(t) \cdot EI_i(t) \cdot M_{ij}(t) \cdot GDP(t), \\
RN(t) &= E_4(t) + E_5(t),
\end{aligned}
$$

C: consumption,
I: investment,
TB: exports-imports,
RN: renewable energy,
E(j): energy by source,
Mij: energy matrix.

How do we extrapolate?

- We use the extreme simple *geometric growth rate:*

$$y_{(t)} = y_{(t-1)} \cdot (1 + r_y)$$

- Where y(t) is whatever variable to be extrapolated.
- r_y is defined through the scenario.

Defining a scenario

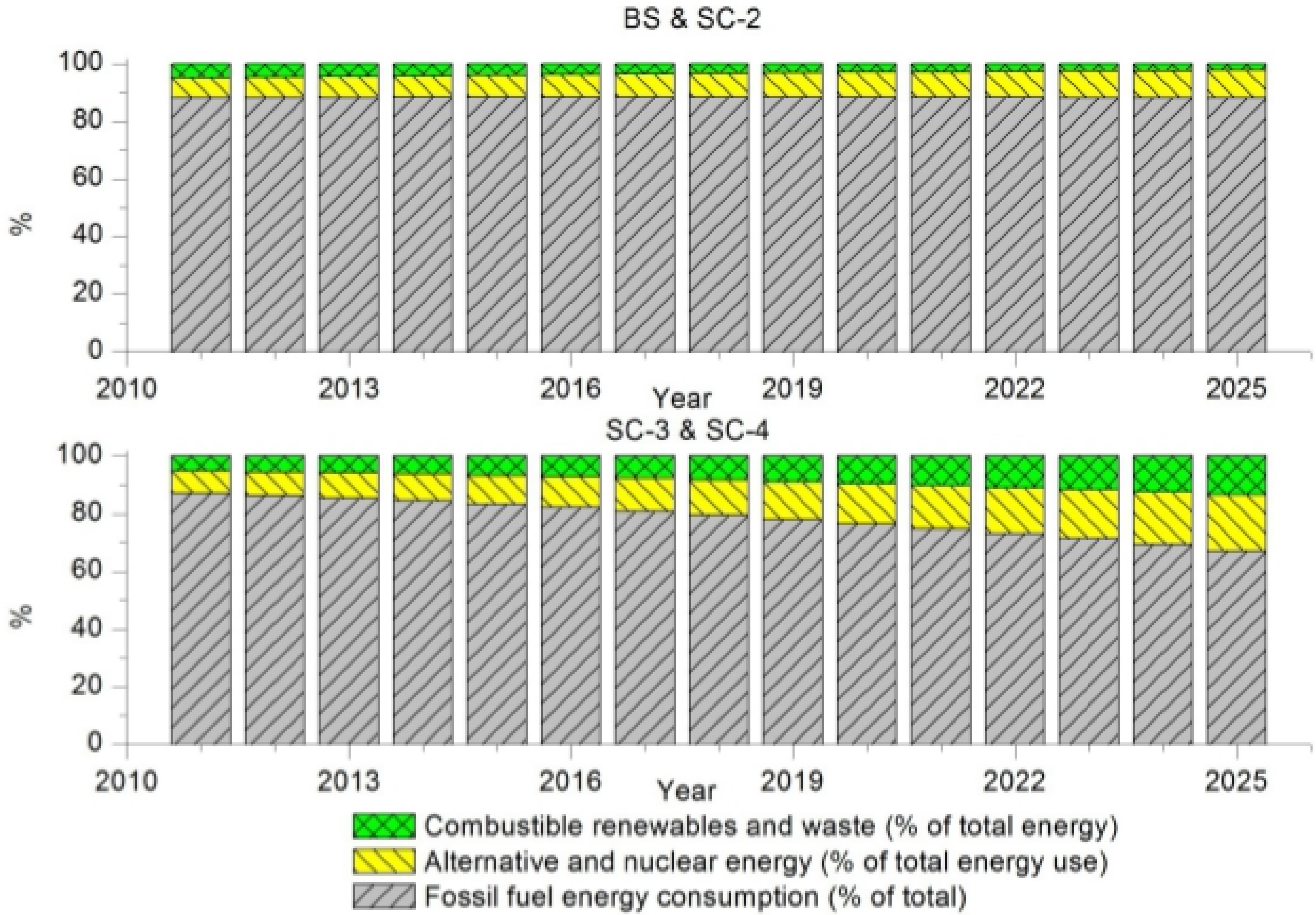
- Define a target for the GDP at the target year.
- Define a target for the use of renewable energy.
- Define a target for the energy intensity.

Case of study: Ecuador

Scenarios

- Baseline scenario (SC-1): GDP, energy matrix, and productive sectoral structure evolve following a smooth trend.
- SC-2: The GDP increases up to the double of the reference GDP (2010) by 2025. The rest of variables evolve as in SC-1.
- SC-3: the use of renewable energy passes from 12% in 2011 to 23% in 2025. The rest of variables evolves as in SC-2.
- SC-4: the energy intensity drops 1% yearly. The rest of variables evolves as in SC-3.

Scenarios: Renewable energy



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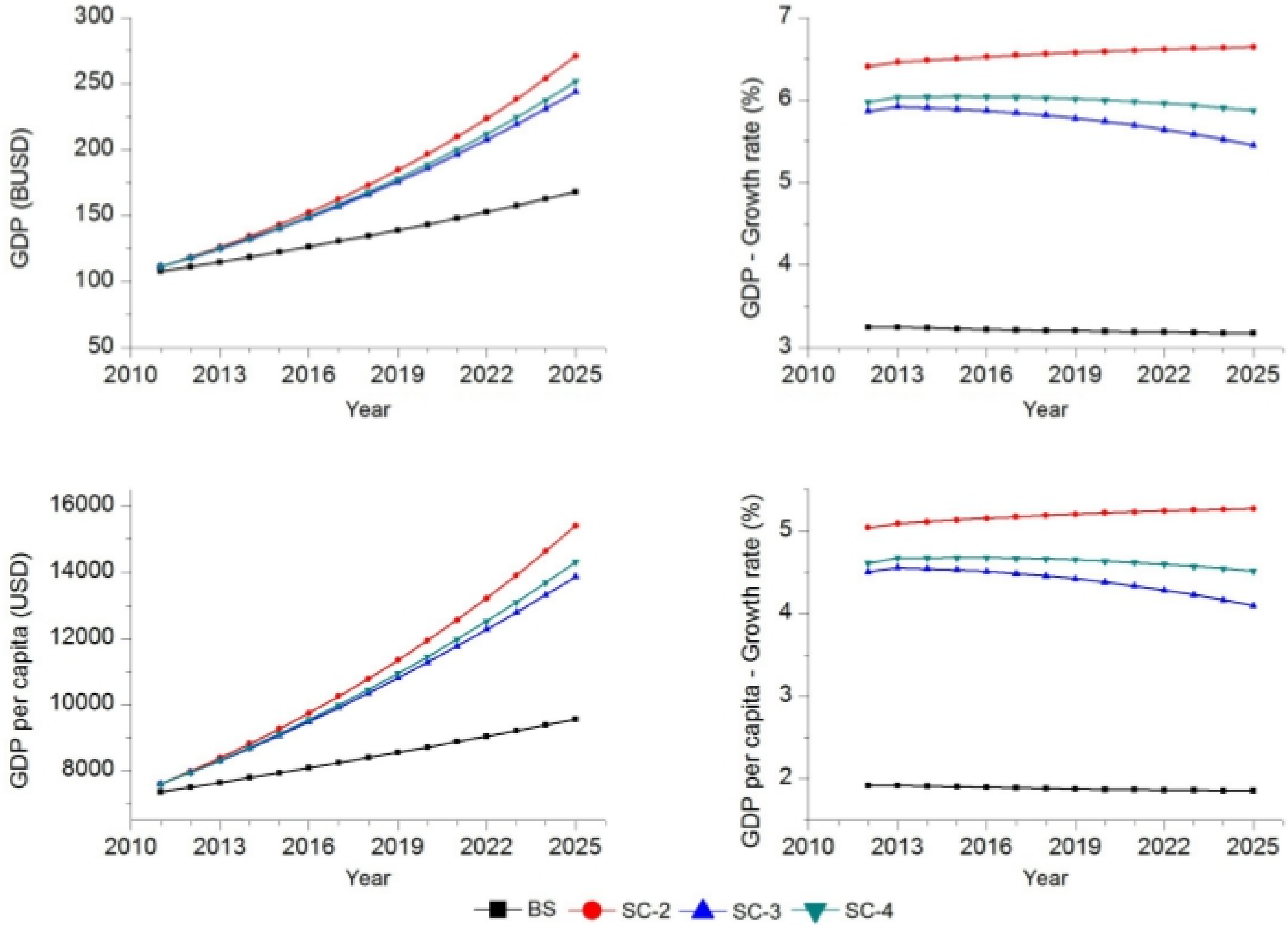
Estimations:GDP



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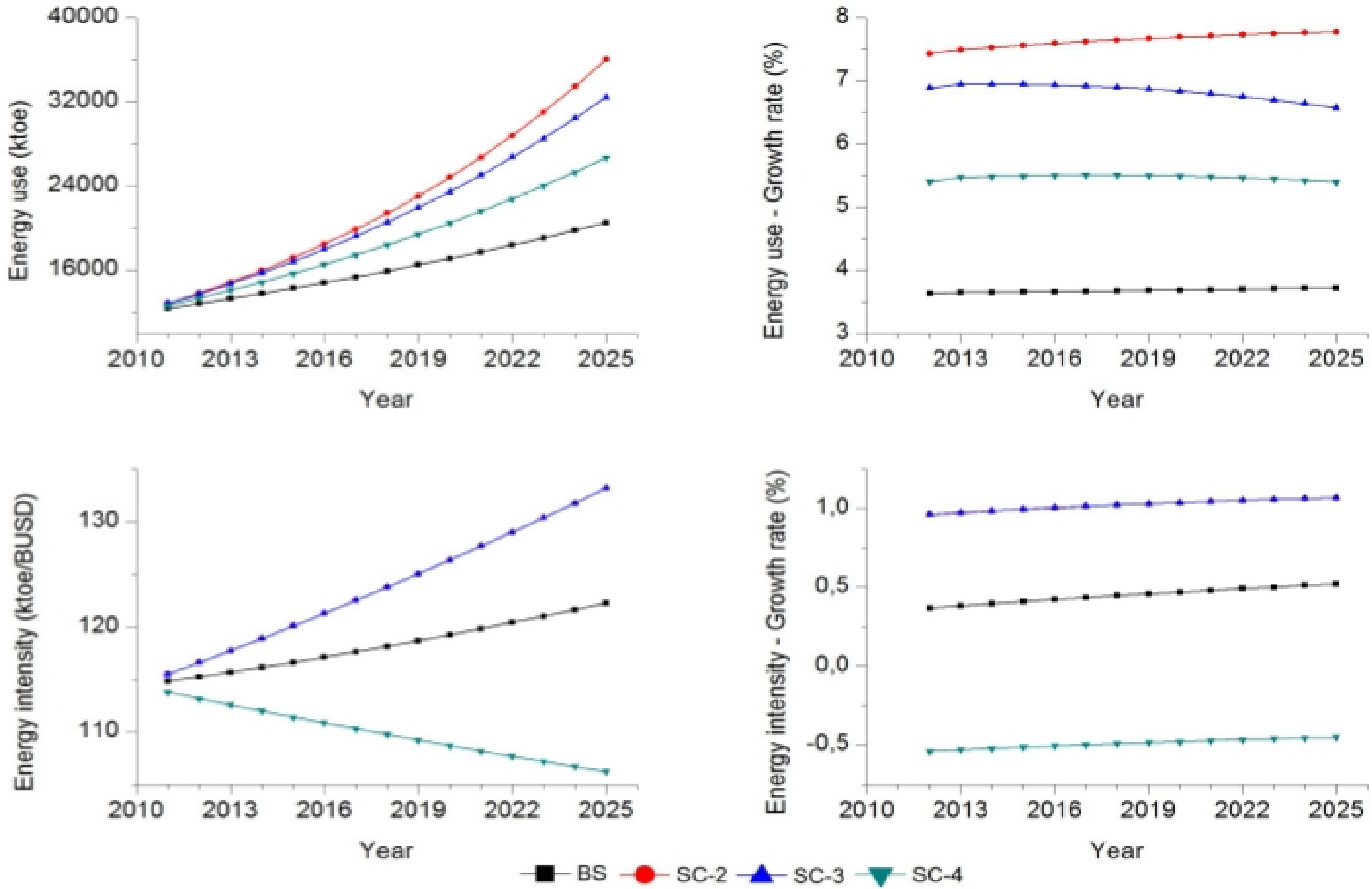
Estimations: Energy



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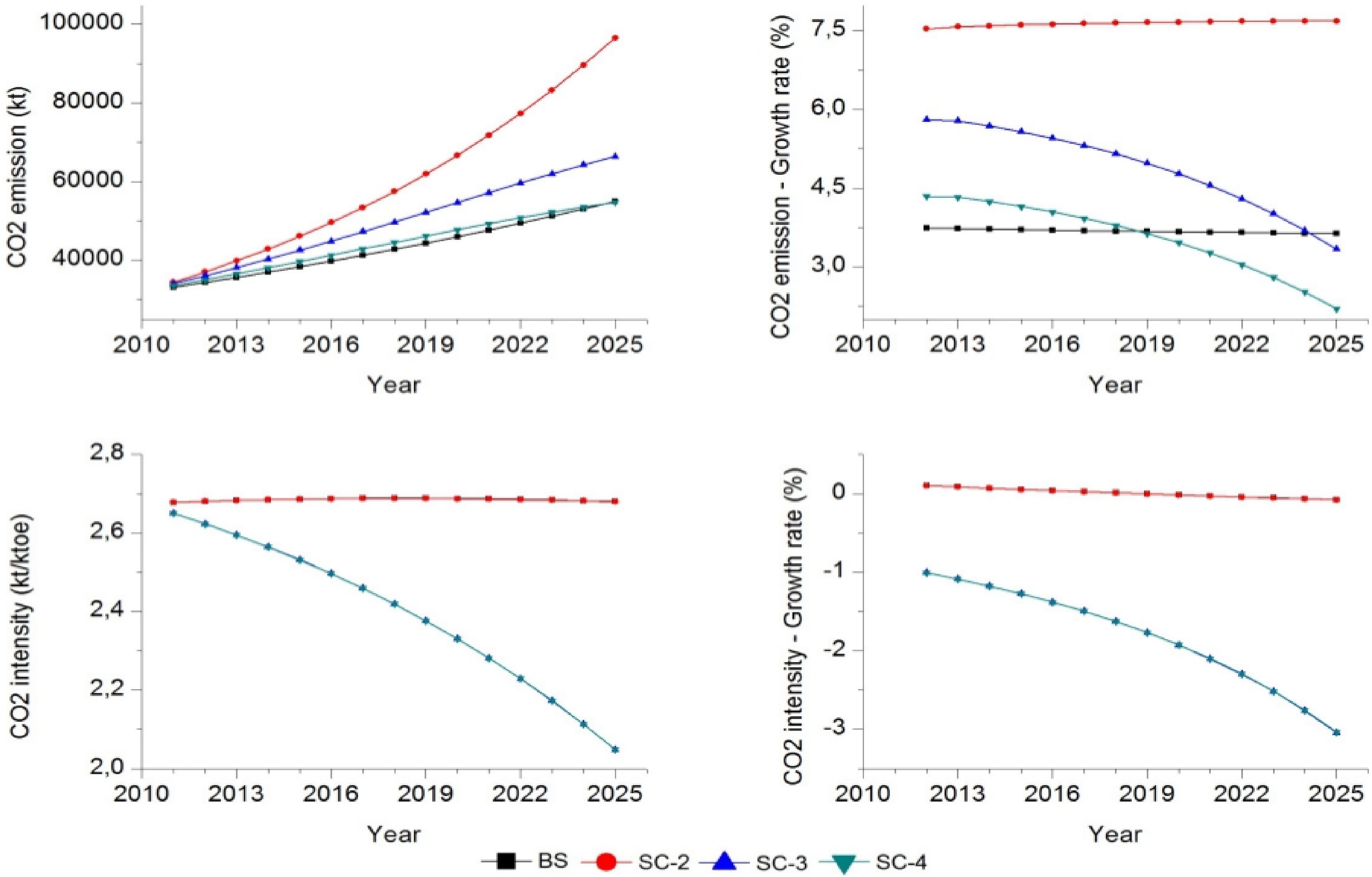
Estimations: emissions



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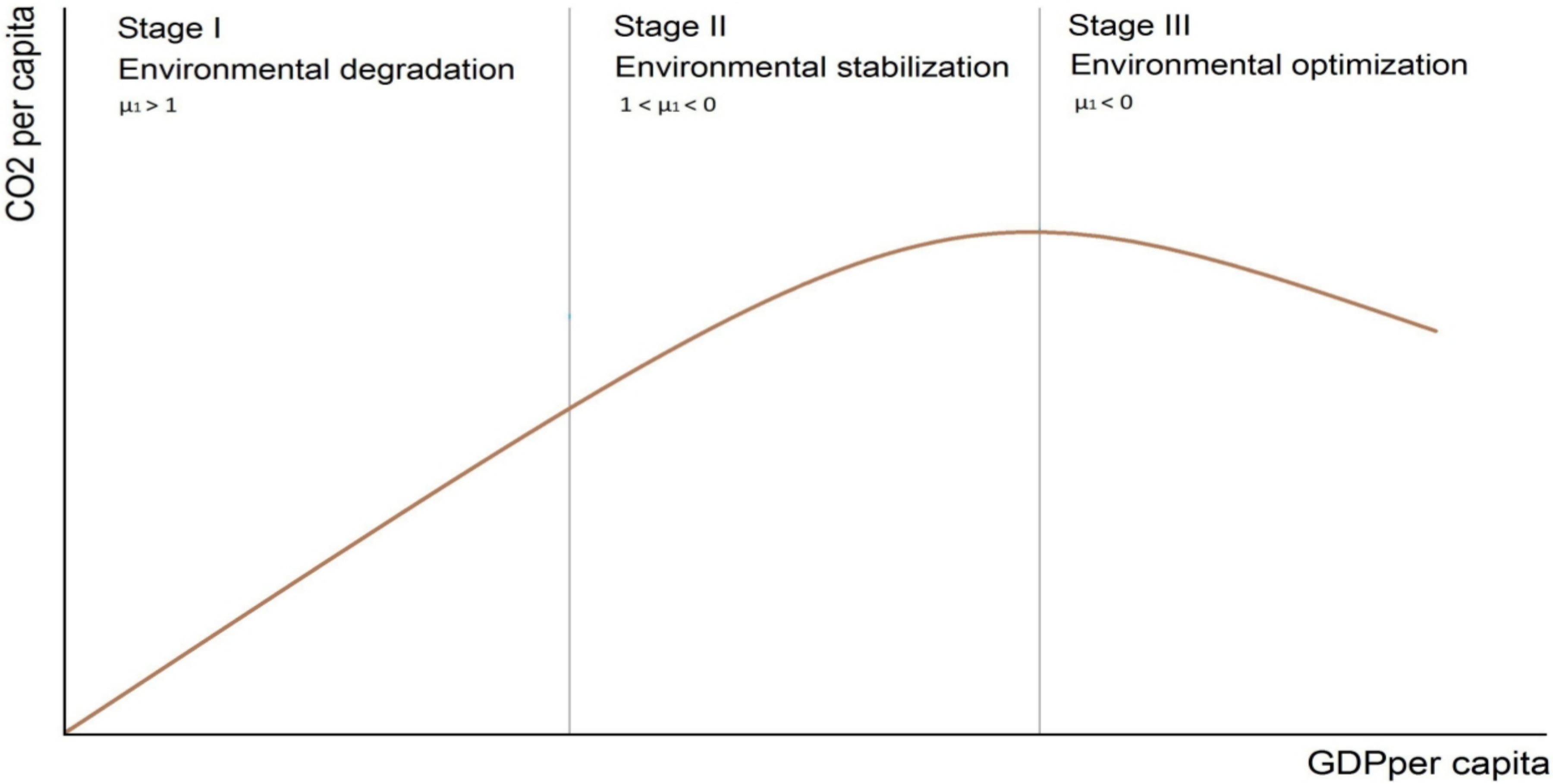
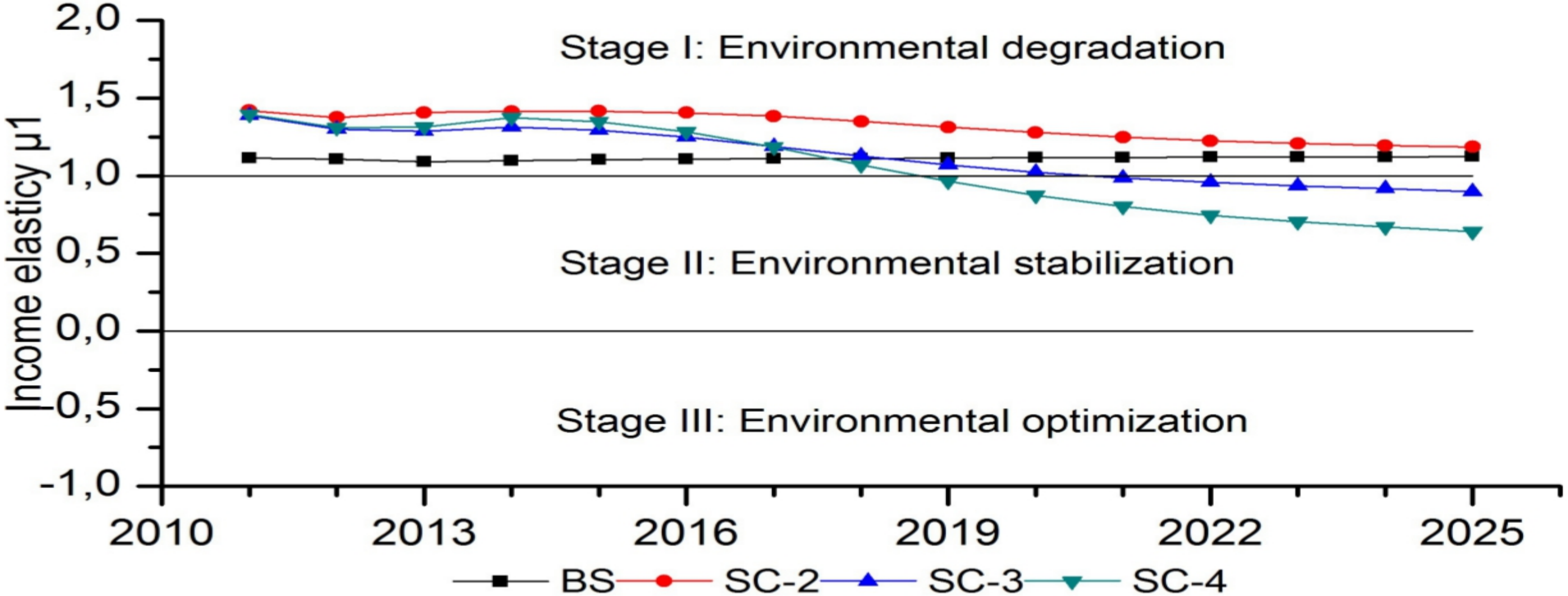
A step further:
the environmental Kuznets curve



EKC: evolution of Ecuador



$$LCO2_t = \mu_0 + \mu_1 LGDP_t + \epsilon_t$$

$$LCO2_t = \mu_0 + \mu_1 LGDP_t + \sum_{j=-q}^{q} \mu_j \Delta LGDP_{t-j} + \epsilon_j$$

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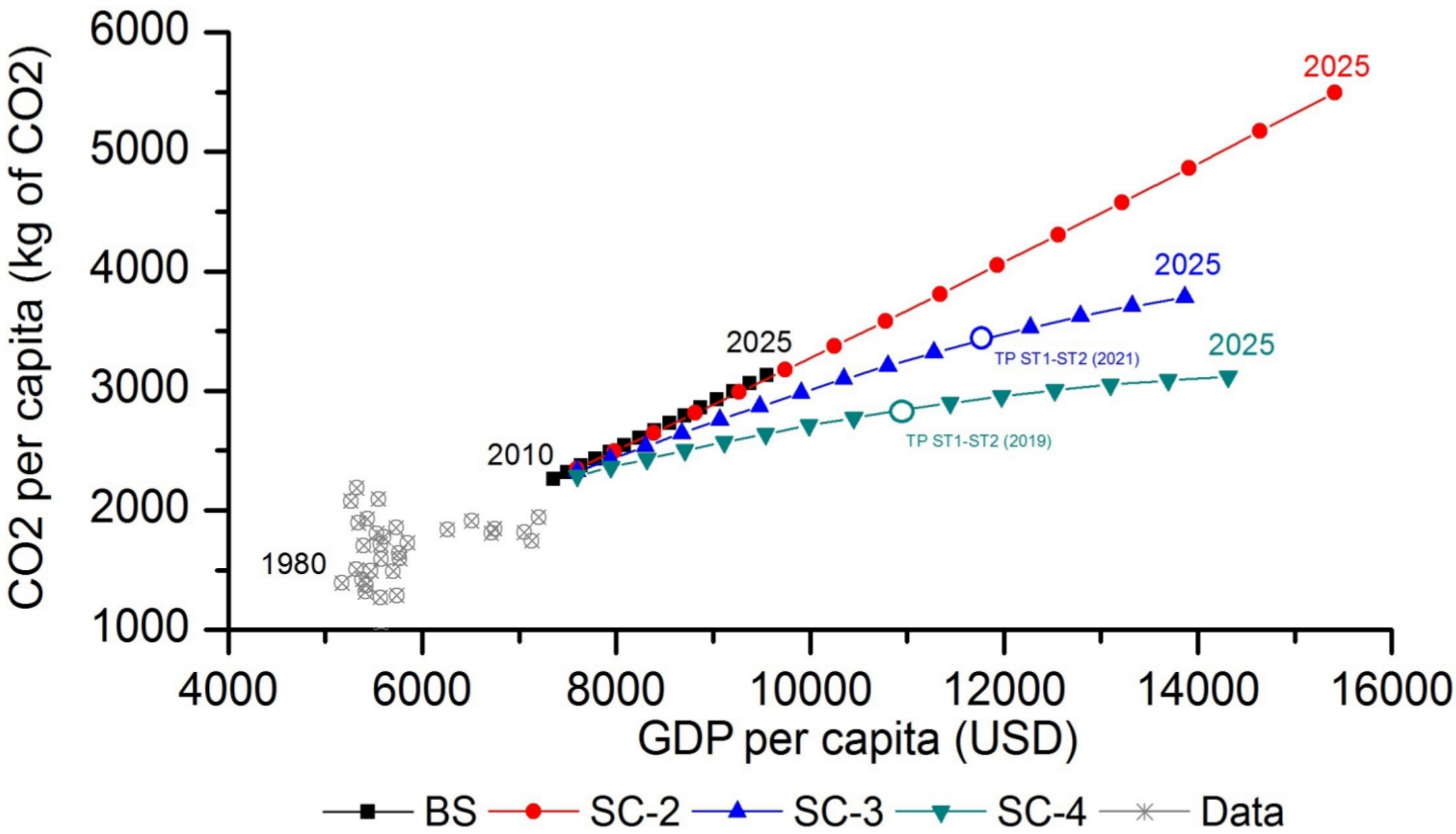
EKC: evolution of Ecuador



Conclusions

- It is possible to moderate CO_2 emissions even under an scenario of rapid GDP growth.
- The use or renewable energies is a key ingredient to reduce CO_2 emissions.
- The improvement of energy intensity is a equally valid way to reduce CO_2 emissions than the use of renewable energies.
- Next step: apply the model of the countries of Anexe I of IPCC.

References

- A. Robalino-López, JEGR, A.A. Golpe y A. Mena-Nieto, “System dynamics modelling and the Environmental Kuznets Curve in Ecuador (1980-2025)”, **Energy Policy** 67, 923-931 (2014).
- A. Robalino-Lopez, A. Mena-Nieto y JEGR, “System dynamics modeling for renewable energy and CO2 emissions: A case study of Ecuador”, **Energy for Sustainable Development** 20, 11-20 (2014).
- A. Robalino-López, A. Mena-Nieto, JEGR y A.A. Golpe, “Studying the relationship between economic growth, CO2 emissions, and the environmental Kuznets curve in Venezuela (1980-2025)”, **Renewable and Sustainable Energy Reviews** 41, 602-614 (2015).
- PhD Thesis, Andrés Robalino López, “Carbon emissions, energy consumption and sustainable development in Ecuador (1980-2025) : system dynamics modelling, decomposition analysis and the Environmental Kuznets Curve”, Universidad de Huelva (July 2014).

Energy and productive sectoral structure submodel

CO2 intensity

$$CO2_{int} = \frac{\sum_{ij} C_{ij}}{\sum_{ij} E_{ij}}$$

Energy intensity

$$M_j = \frac{\sum_{i} E_{ij}}{\sum_{ij} E_{ij}}$$

$$M_1 + M_2 + M_3 + M_4 + M_5 = 100\%$$

1: natural gas, 2: coal, 3: petroleum, 4: renewable, 5: alternative

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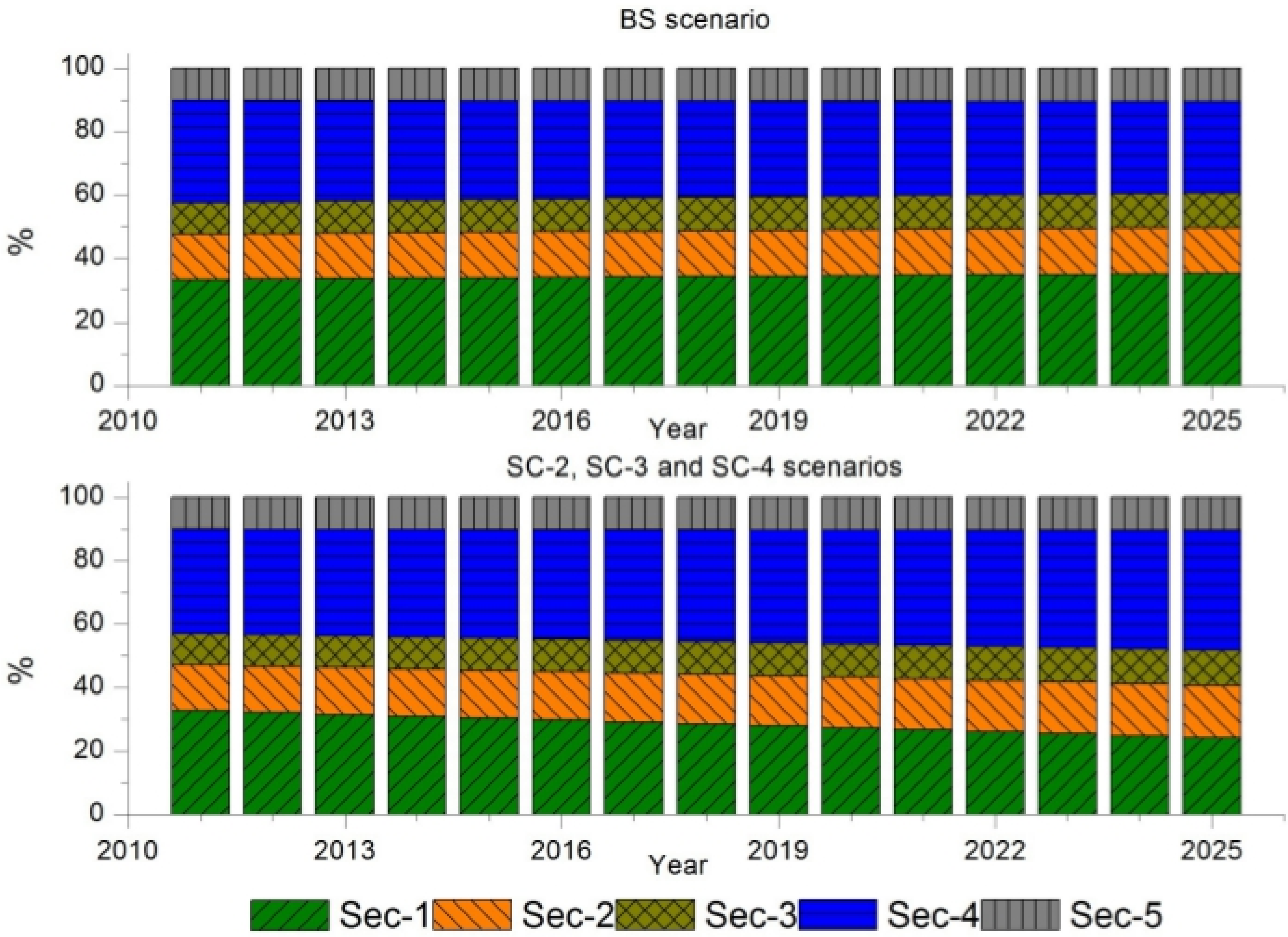
Scenarios: Sectors



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