Crecimiento económico, energía renovable y emisiones de CO2: 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.
5. (The Environmental Kuznets Curve).
6. Conclusions.
Uncertainties in future emissions

From IPCC 5th Assessment Report: Climate Change 2013

The Kaya identity
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.
CO\textsubscript{2} and GDP

CO\textsubscript{2} Emissions & Wealth

CO\textsubscript{2} Emissions per Capita (log)

Gross Domestic Product - Purchasing Power Parity per Capita (log)

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

Kaya identity

\[
\text{CO}_2 = \text{Population} \times \text{PIB}\_pc \times \text{Energy}\_\text{intensity} \times \text{CO}_2\_\text{intensity}
\]

\[
\text{CO}_2 = \text{Population} \times \frac{\text{PIB}}{\text{Population}} \times \frac{\text{Energy}}{\text{PIB}} \times \frac{\text{CO}_2}{\text{Energy}}
\]
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

http://data.worldbank.org/

http://www.iea.org/

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

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

- **GDP**
- **Energy intensity**
- **Energy matrix**
- **Emission factors**
- **Sectors**

i labels sector
j labels kind of fuel

General structure of this analysis

From A. Robalino PhD Thesis

Hodrick-Prescott filter and validation

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

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MAPE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>2.2</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>3.3</td>
</tr>
<tr>
<td>Energy intensity</td>
<td>3.2</td>
</tr>
<tr>
<td>CO$_2$ intensity</td>
<td>16</td>
</tr>
<tr>
<td>CO$_2$ emission</td>
<td>17</td>
</tr>
</tbody>
</table>

From A. Robalino PhD Thesis

Economic submodel

- Consumption (C)
- Investment (I)
- Government Spending (G)
- Trade Balance (TB)

From A. Robalino PhD Thesis

Economic submodel

From A. Robalino PhD Thesis

Economic submodel

\[
GDP = C + I + G + X - M,
\]


\[
Q = a_1 \cdot I + a_2 \cdot TB + a_3 \cdot C + a_4 \cdot Eimp + a_5 \cdot RN + \epsilon_1
\]
\[
I = b_1 \cdot RN + b_2 \cdot C + \epsilon_2,
\]
\[
TB = c_1 \cdot Eimp + c_2 \cdot RN + \epsilon_3,
\]
\[
Eimp = d_1 \cdot RN + \epsilon_4,
\]
\[
C = f_1 \cdot Eimp + f_2 \cdot TB + \epsilon_5,
\]


### Economic submodel

<table>
<thead>
<tr>
<th>Variable</th>
<th>GDP $^b$</th>
<th>I</th>
<th>TB</th>
<th>C</th>
<th>Eimp</th>
</tr>
</thead>
<tbody>
<tr>
<td>I $^c$</td>
<td>1.16***</td>
<td></td>
<td></td>
<td>-6.07***</td>
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<tr>
<td></td>
<td>(5.11)</td>
<td></td>
<td></td>
<td>(-41.44)</td>
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<tr>
<td>TB $^d$</td>
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<td></td>
<td>(3.46)</td>
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<tr>
<td>C $^e$</td>
<td>1.21***</td>
<td>0.50***</td>
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<td></td>
<td>(7.70)</td>
<td>(100.40)</td>
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<td></td>
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<tr>
<td>$E_{imp}^f$</td>
<td>0.05***</td>
<td>0.01***</td>
<td>-0.27***</td>
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<tr>
<td></td>
<td>(2.66)</td>
<td>(4.14)</td>
<td>(-100.17)</td>
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<tr>
<td>RN $^g$</td>
<td>-0.50***</td>
<td>-0.84***</td>
<td>0.04</td>
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<td>-36.79***</td>
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<tr>
<td></td>
<td>(-4.44)</td>
<td>(-5.40)</td>
<td>(0.28)</td>
<td></td>
<td>(-5.47)</td>
</tr>
</tbody>
</table>

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


$^b$ GDP in $10^{10}$ USD.  
$^c$ I in $10^{10}$ USD.  
$^d$ TB in $10^{10}$ USD.  
$^e$ C in $10^{10}$ USD.  
$^f$ $E_{imp}$ in $10^6$ toe.  
$^g$ RN in $10^6$ toe.

---

Model equations

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

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-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

From A. Robalino PhD Thesis

Estimations: GDP

From A. Robalino PhD Thesis

Estimations: Energy

From A. Robalino PhD Thesis

Estimations: emissions

From A. Robalino PhD Thesis

A step further: the environmental Kuznets curve
EKC: evolution of Ecuador

Stage I: Environmental degradation

Stage II: Environmental stabilization

Stage III: Environmental optimization

\[ LCO2_t = \mu_0 + \mu_1 LGDP_t + \epsilon_t \]

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

EKC: evolution of Ecuador

CO2 per capita (kg of CO2)

GDP per capita (USD)

1980  2010  2025

BS  SC-2  SC-3  SC-4  Data

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


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

Scenarios: Sectors

From A. Robalino PhD Thesis