Climate change impacts on hydropower generation in Brazil: interactions between climate change mitigation and adaptation

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Introduction – Brazilian Energy System

• The Brazilian energy system is highly dependent on renewable energy, especially hydropower

• Renewables accounted for around 40% of primary energy supply in 2014
  – Hydropower was 80% of all electricity production in the country in average over the last ten years
  – 15% of fuel consumption in the transportation sector was ethanol in 2014
  – Wind energy is still low, but has increased sharply over the last few years (currently 4.8% of total installed capacity)

How is that impacted by future climate change?
Brazilian Interconnected Power System
National Interconnected System (SIN)
Previous Studies on Climate Change Impacts-Adaptation
What’s new?

• Project hired by Secretaria de Assuntos Estratégicos da Presidência da República – Colaboration COPPE-PSR
  – New scenarios – RCPs 8.5 and 4.5
    • Mitigation vs. Adaptation
  – New GCMs (HadGEM and MIROC)
  – Stochastic dispatch modeling

• Research questions:
  – What are the impacts of climate change on the Brazilian Interconnected System?
  – What would be the best alternatives to compensate hydropower loss?
    • What is the best way to adapt: operation vs. expansion?
  – To what extent mitigation policies may affect these best alternatives?
Methodology and Results
Methodology

- **(1) RCPs**

- **(2) GCMs**

- **(3) Downscaling**
  - Regional projections for temperature, precipitation, etc.

- **(4) Hydrological Modeling**
  - River-flow

- **(5) Energy Analysis**
Climate Change Data

- RCPs
  - 4.5
  - 8.5
- GCMs
  - HadGEM
  - MIROC
- Dowscaling
  - ETA: INPE (Chou et al., 2014)
- Hydrological Model
  - SMAP (water balance model): University of Ceará (Martins et al., 2014)
Projected Riverflow

Brazilian River Basins – Paraná
Projected Riverflow

Natural inflow to Itaipu hydropower plant – RCP 8.5

HadGEM

MIROC

Redução de 40%

Redução de 12%
Projected Riverflow

Brazilian River Basins – Tocantins Araguaia
Projected Riverflow

Natural inflow to **Tucuruí** hydropower plant – RCP 8.5

**HadGEM**

**MIROC**

Redução de 44%

Redução de 34%
Projected Riverflow

Brazilian River Basins – São Francisco
Projected Riverflow

Natural inflow to Sobradinho hydropower plant – RCP 8.5

HadGEM

MIROC
Energy Modeling Approach

Scenario Premisses (RCP 4.5 and 8.5)

Operation Model
SDDP (PSR)

Operation/Expansion

Expansion Model
MESSAGE-Brazil (COPPE)

Operation Impacts/adaptation

Operation

Adaptation through expansion

Hydro generation scenarios
Marginal cost of operation
Deficit probability

• Capacity expansion
• Investment costs
• Second order effects

GCM – Dowscaling – Hydrology Model
195 riverflow series
Energy Modeling Approach

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### Scenarios

<table>
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<tr>
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<th>Baseline</th>
<th>HadGEM</th>
<th>MIROC</th>
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<tbody>
<tr>
<td><strong>RCP 8.5</strong></td>
<td><strong>Scenario: Base 8.5</strong>&lt;br&gt;- RCP 8.5 energy system;&lt;br&gt;- NO IMPACTS</td>
<td><strong>Scenario: HadGEM 8.5</strong>&lt;br&gt;- RCP 8.5 energy system;&lt;br&gt;- HadGEM RCP 8.5 IMPACTS</td>
<td><strong>Scenario: MIROC 8.5</strong>&lt;br&gt;- RCP 8.5 energy system;&lt;br&gt;- MIROC RCP 8.5 IMPACTS</td>
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<tr>
<td><strong>RCP 4.5</strong></td>
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<td><strong>Scenario: HadGEM 4.5</strong>&lt;br&gt;- RCP 4.5 energy system;&lt;br&gt;- HadGEM RCP 4.5 IMPACTS</td>
<td><strong>Scenario: MIROC 4.5</strong>&lt;br&gt;- RCP 4.5 energy system;&lt;br&gt;- MIROC RCP 4.5 IMPACTS</td>
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Baseline Scenarios

Baseline scenarios: RCP comparison – Electricity

Premisses:

RCP 8.5
• BAU expansion – no explicit mitigation assumed

RCP 4.5
• Energy efficiency
• Lower fossil expansion
• $100/tCO2 Carbon tax after 2030 (ETP, 2015)
Energy Modeling Approach

Scenario Premisses (RCP 4.5 and 8.5)

Operation Model
- SDDP (PSR)

Operation/Expansion

Expansion Model
- MESSAGE-Brazil (COPPE)

Operation

Operation Impacts/adaptation

GCM – Dowscaling – Hydrology Model
- 195 riverflow series

Hydro generation scenarios
- Marginal cost of operation
- Deficit probability

Adaptation through expansion

- Capacity expansion
- Investment costs
- Second order effects
Results – Operation Costs

- **RCP 8.5**: Base < HadGEM < MIROC
- **RCP 4.5**: Base < MIROC < HadGEM
Energy Modeling Approach

GCM – Dowscaling – Hydrology Model
195 riverflow series

Scenario Premisses (RCP 4.5 and 8.5)

Operation Model
SDDP (PSR)

Operation
Impacts/adaptation

Operation/Expansion

Expansion Model
MESSAGE-Brazil (COPPE)

Operation through expansion

- Capacity expansion
- Investment costs
- Second order effects

- Hydro generation scenarios
- Marginal cost of operation
- Deficit probability
Results – Adaptation
RCP 8.5
Results – Adaptation Costs

• Accumulated investment costs up to 2040:
  – HadGEM
    • RCP 4.5: USD 79 billion
    • RCP 8.5: USD 280 billion
  – MIROC
    • RCP 4.5: USD 3 billion
    • RCP 8.5: USD 158 billion
Discussion

• Operational impacts can be severe and costly if there is no adaptation

• Mitigation policies do impact optimal adaptation strategies.
  – Electricity generation in Brazil can become more carbon intensive in a BaU scenario
  – Adapting to a reduced hydropower availability may further increase Brazil’s emissions if no other actions are taken
  – Adaptation can be achieved by combination of energy efficiency, renewable energy, etc.

• Impacts on other renewable sources?
Thank you
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