Climate change impacts on hydropower generation in Brazil

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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?

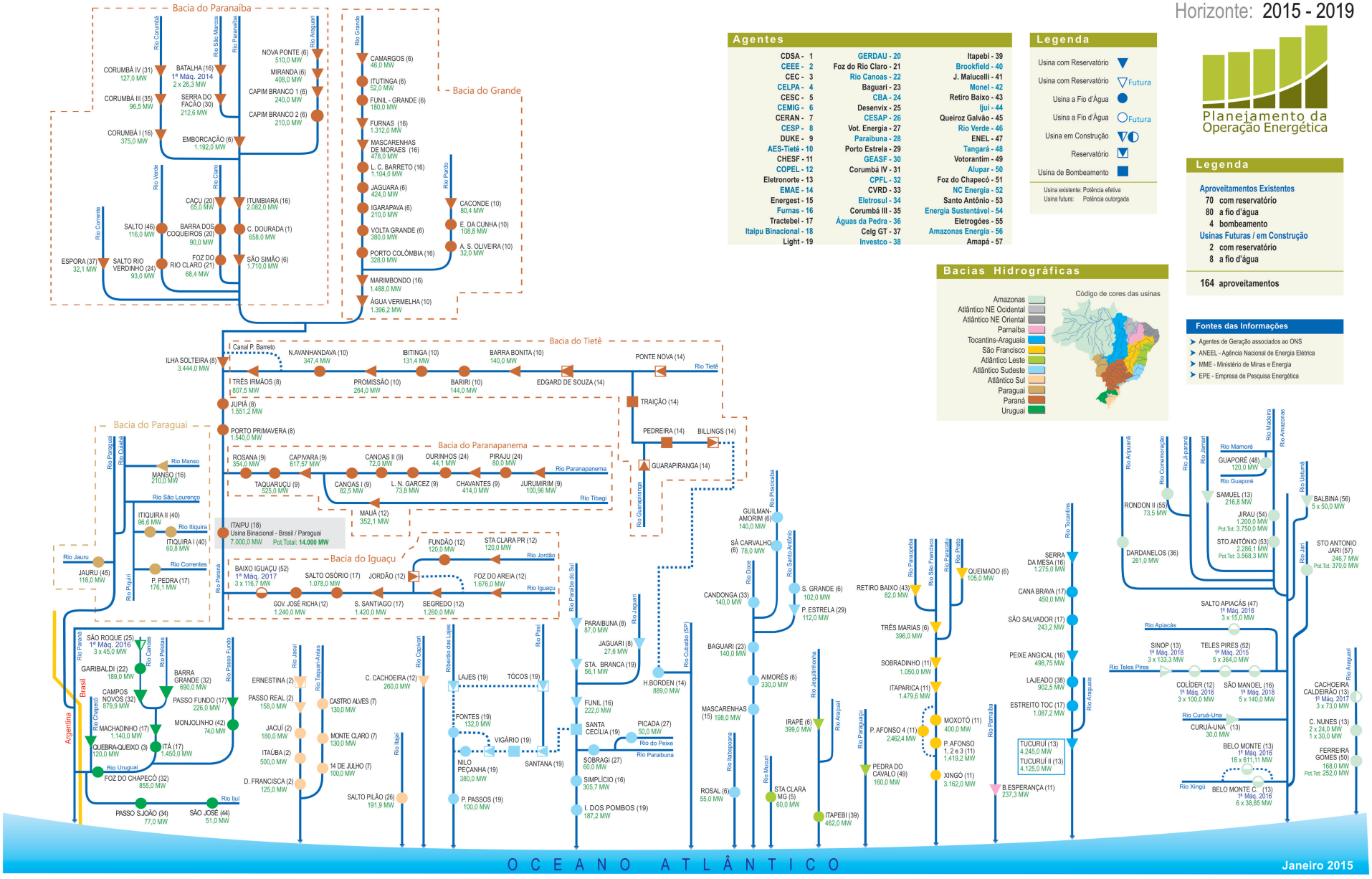
Diagrama Esquemático das Usinas Hidroelétricas do SIN

Usinas Hidroelétricas Despachadas pelo ONS na Otimização da Operação Eletroenergética do Sistema Interligado Nacional

Horizonte: 2015 - 2019

Operador Nacional do Sistema Elétrico

Planejamento da Operação Energética



Agentes

CDSA - 1	GERDAU - 20	Itapebi - 39
CEEE - 2	Foz do Rio Claro - 21	Brookfield - 40
CEC - 3	Rio Canoas - 22	J. Malucelli - 41
CELPA - 4	Baguari - 23	Monel - 42
CESC - 5	CBA - 24	Retiro Baixo - 43
CEMIG - 6	Desenvix - 25	Ijuí - 44
CERAN - 7	CESAP - 26	Queiroz Galvão - 45
CESP - 8	Vot. Energia - 27	Rio Verde - 46
DUKE - 9	Paraibuna - 28	ENEL - 47
AES-Tietê - 10	Porto Estrela - 29	Tangará - 48
CHESF - 11	GEASF - 30	Votorantim - 49
COPEL - 12	Corumbá IV - 31	Alupar - 50
Eletronorte - 13	CPFL - 32	Foz do Chapecó - 51
EMAE - 14	CVRD - 33	NC Energia - 52
Energest - 15	Eletrosul - 34	Santo Antônio - 53
Furnas - 16	Corumbá III - 35	Energia Sustentável - 54
Tractebel - 17	Águas da Pedra - 36	Eletrogóes - 55
Itaipu Binacional - 18	Celg GT - 37	Amazonas Energia - 56
Light - 19	Investco - 38	Amapá - 57

Legenda

- Usina com Reservatório
- Usina com Reservatório Futura
- Usina a Fio d'Água
- Usina a Fio d'Água Futura
- Usina em Construção
- Reservatório
- Usina de Bombeamento

Usina existente: Potência efetiva
Usina futura: Potência outorgada

Bacias Hidrográficas

Código de cores das usinas

- Amazonas
- Atlântico NE Ocidental
- Atlântico NE Oriental
- Parnaíba
- Tocantins-Araguaia
- São Francisco
- Atlântico Leste
- Atlântico Sudeste
- Atlântico Sul
- Paraguai
- Paraná
- Uruguai

Legenda

Aproveitamentos Existentes
70 com reservatório
80 a fio d'água
4 bombeamento

Usinas Futuras / em Construção
2 com reservatório
8 a fio d'água

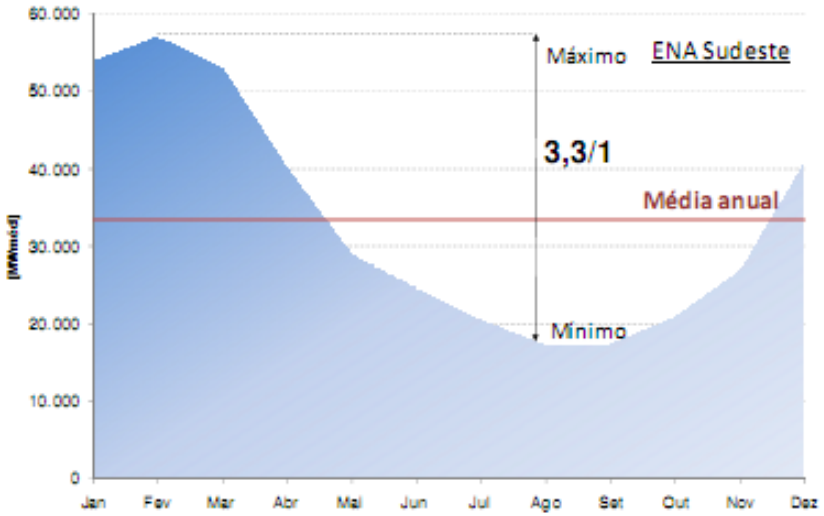
164 aproveitamentos

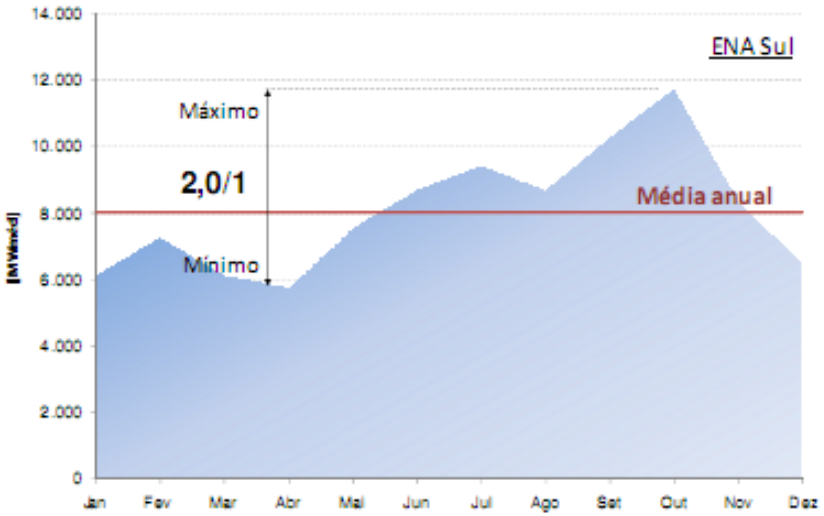
Fontes das Informações

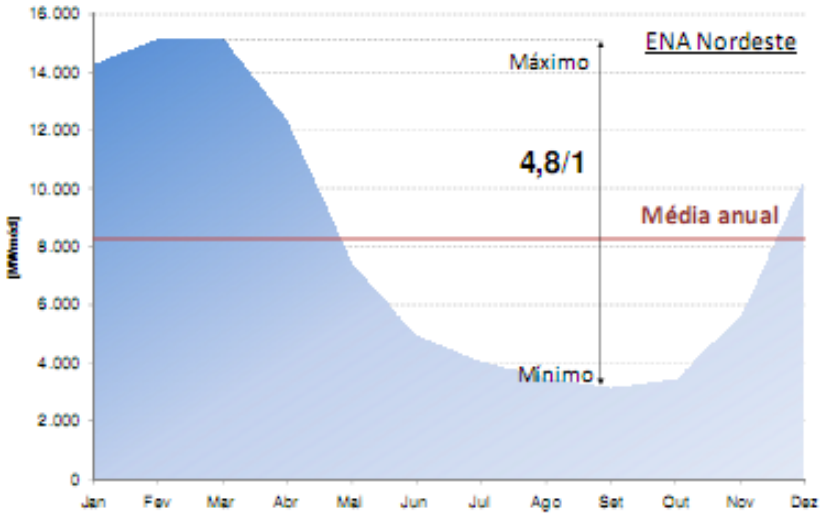
- Agentes de Geração associados ao ONS
- ANEEL - Agência Nacional de Energia Elétrica
- MME - Ministério de Minas e Energia
- EPE - Empresa de Pesquisa Energética

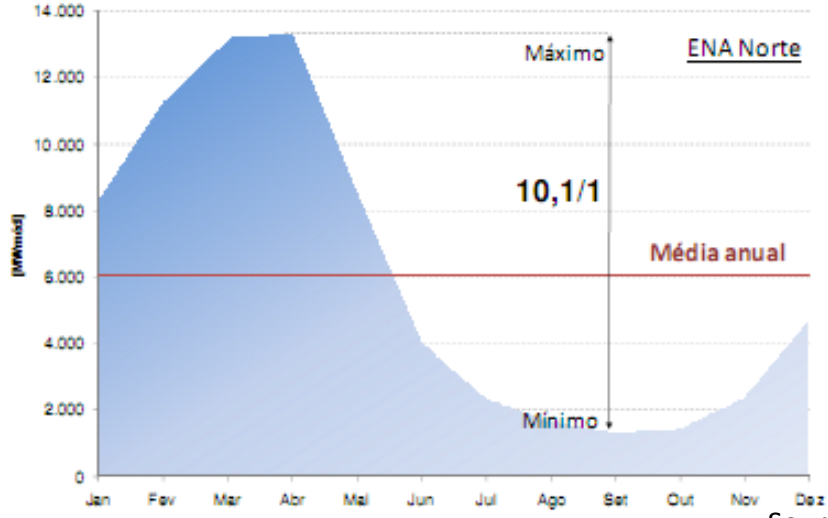
Janeiro 2015

Hydrological Seasonality in Brazil (Historical data 1931 – 2009)



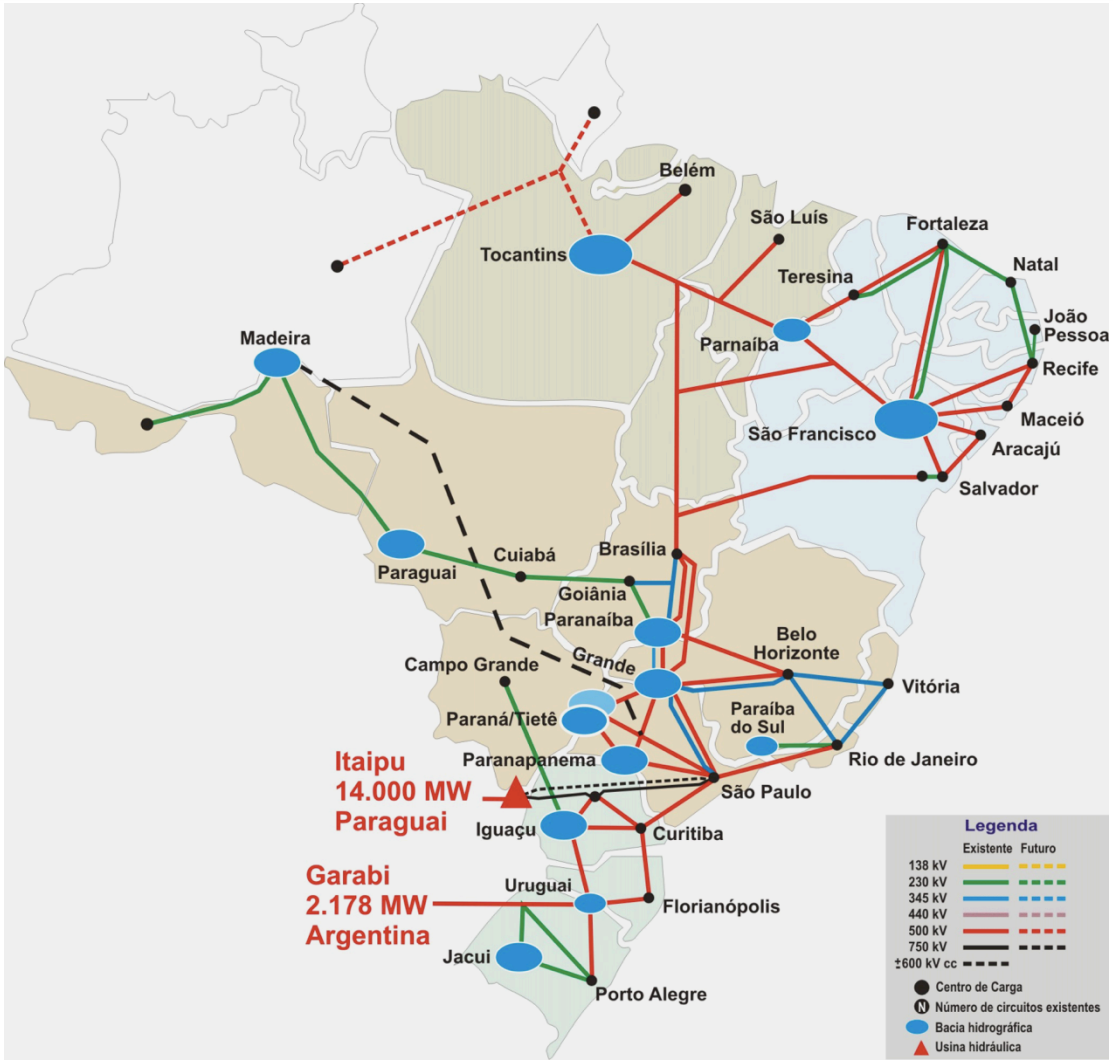






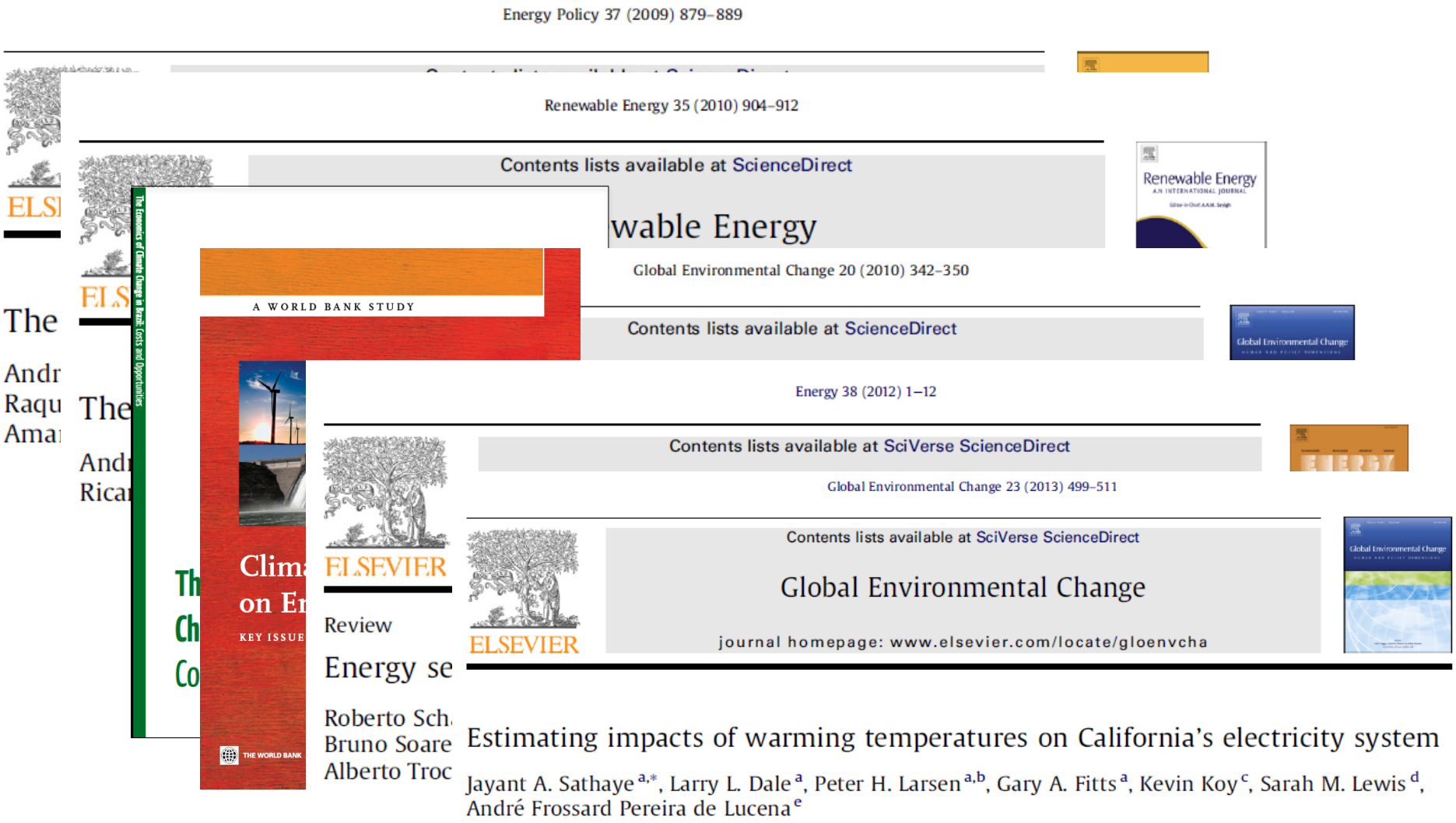
Source: Silva (2012)

National Interconnected System (SIN)



http://www.ons.org.br/

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?

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Methodology and Results

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 at., 2014)

Projected Riverflow

Brazilian River Basins

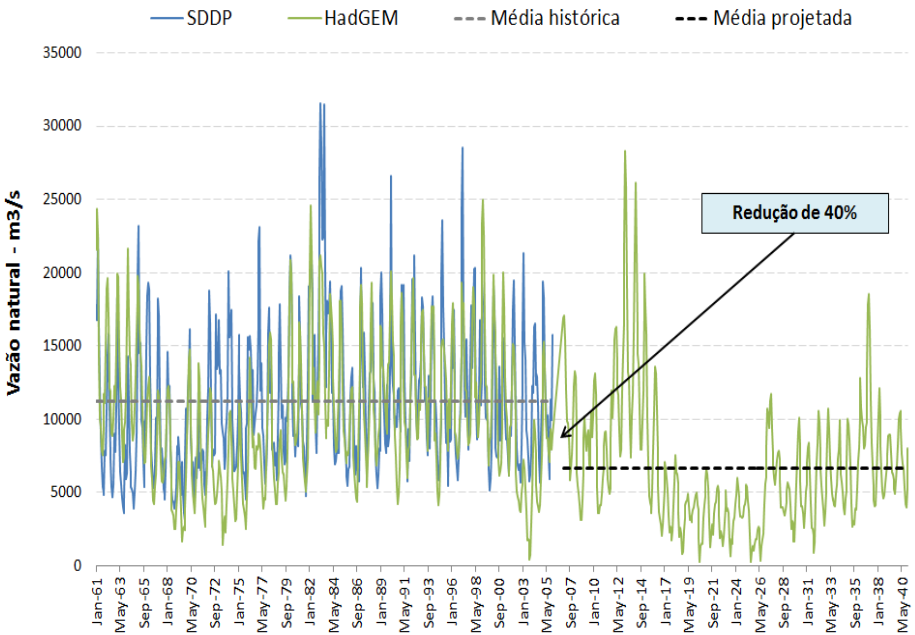
Projected Riverflow

Brazilian River Basins – Paraná

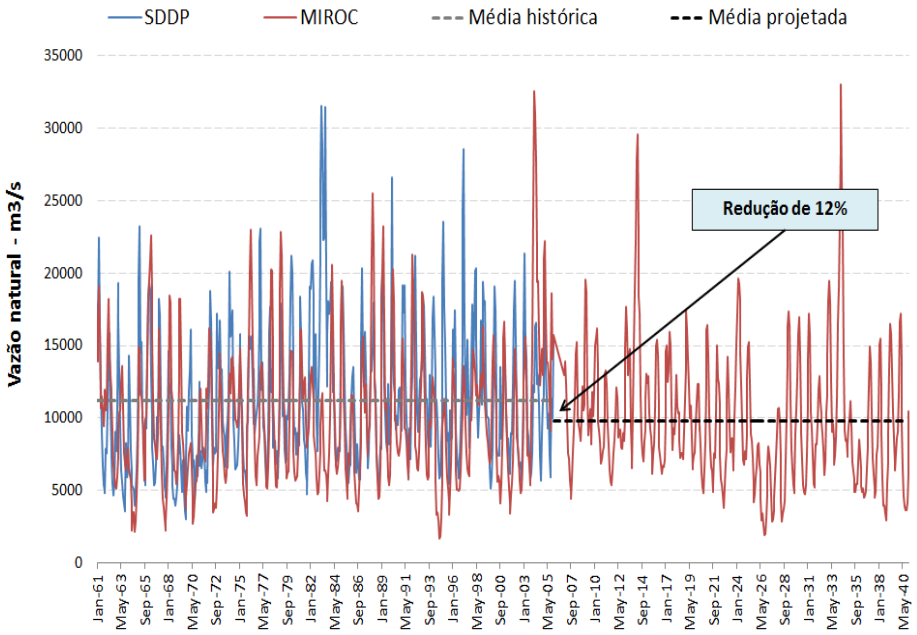
Projected Riverflow

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

HadGEM



MIROC



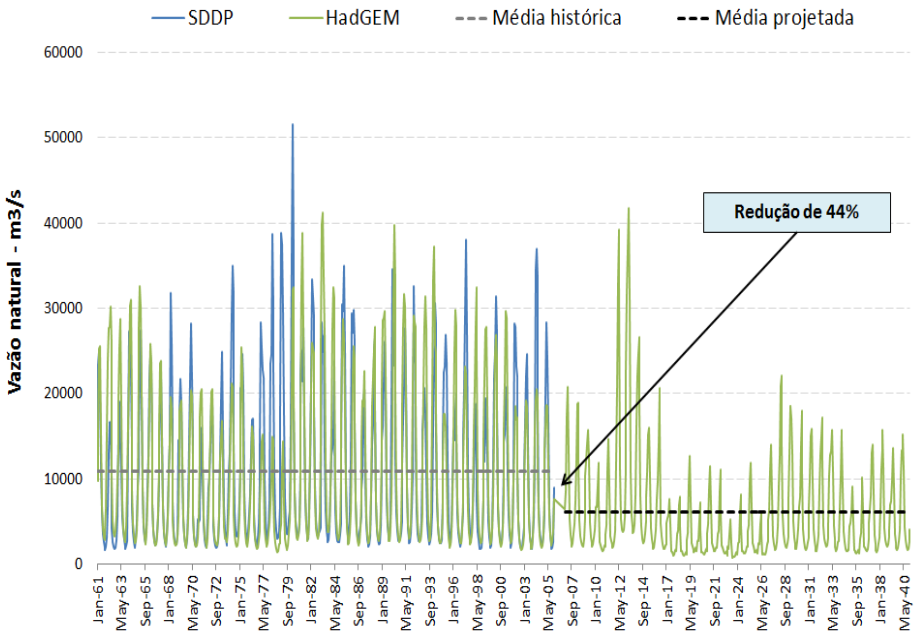
Projected Riverflow

Brazilian River Basins – Tocantins Araguaia

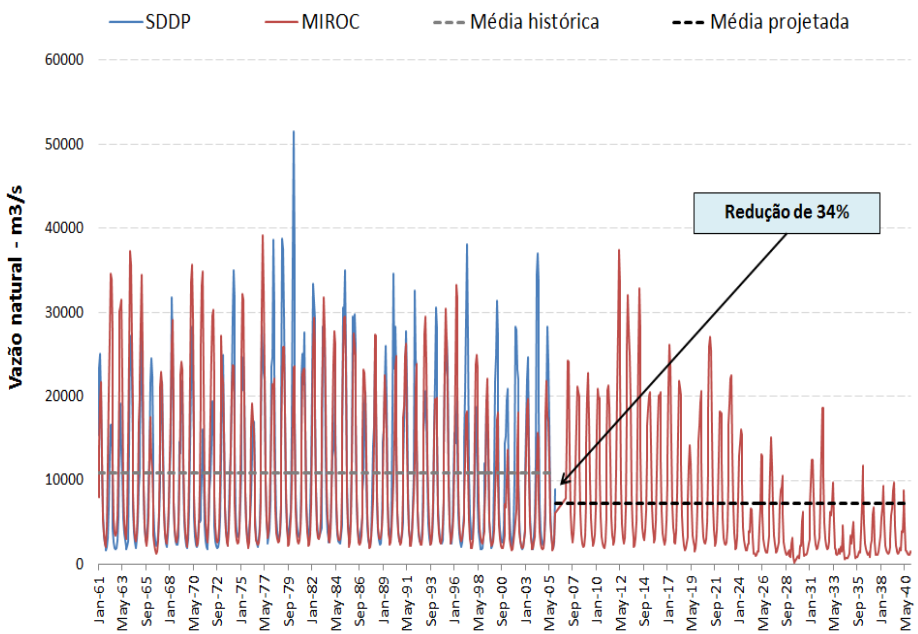
Projected Riverflow

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

HadGEM



MIROC



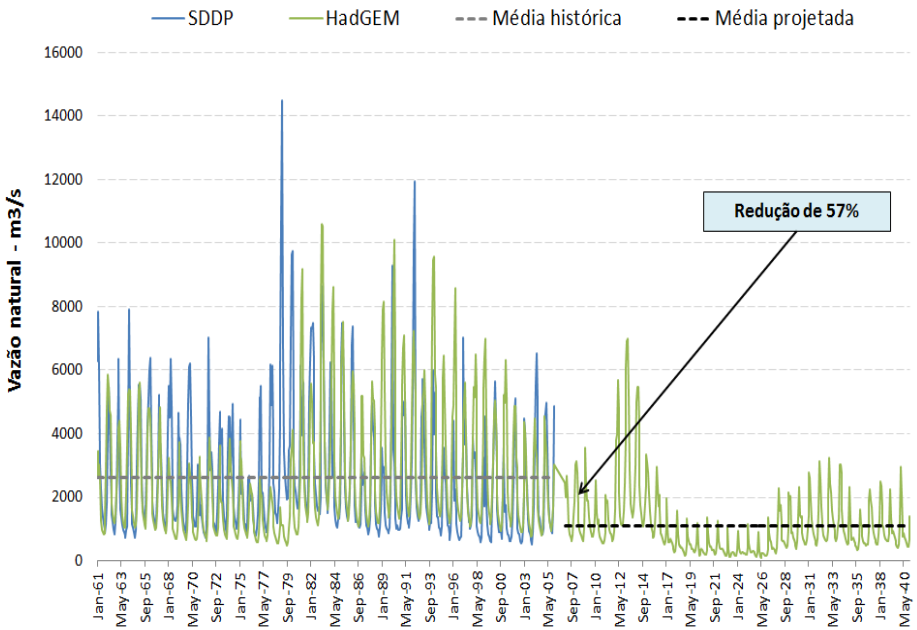
Projected Riverflow

Brazilian River Basins – São Francisco

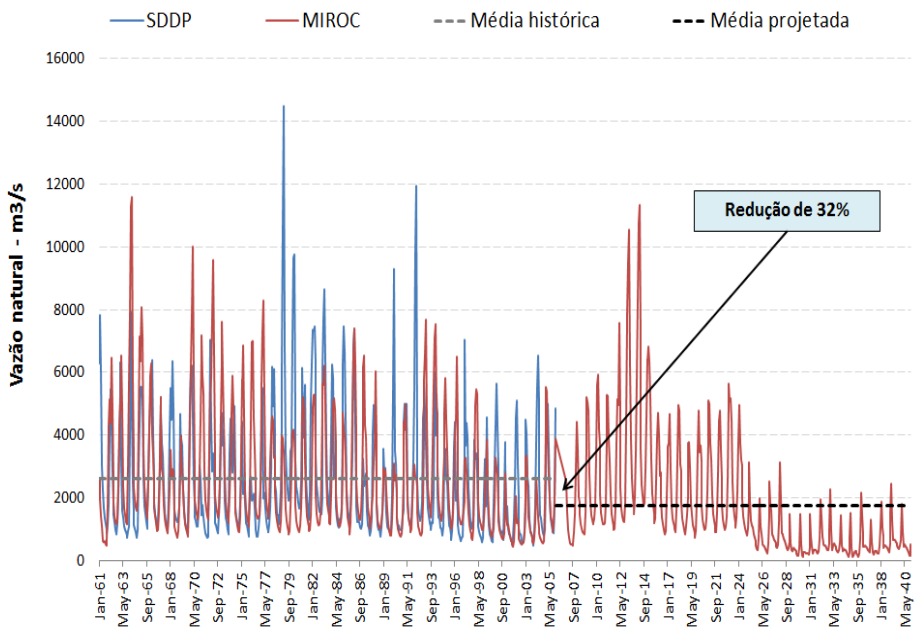
Projected Riverflow

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

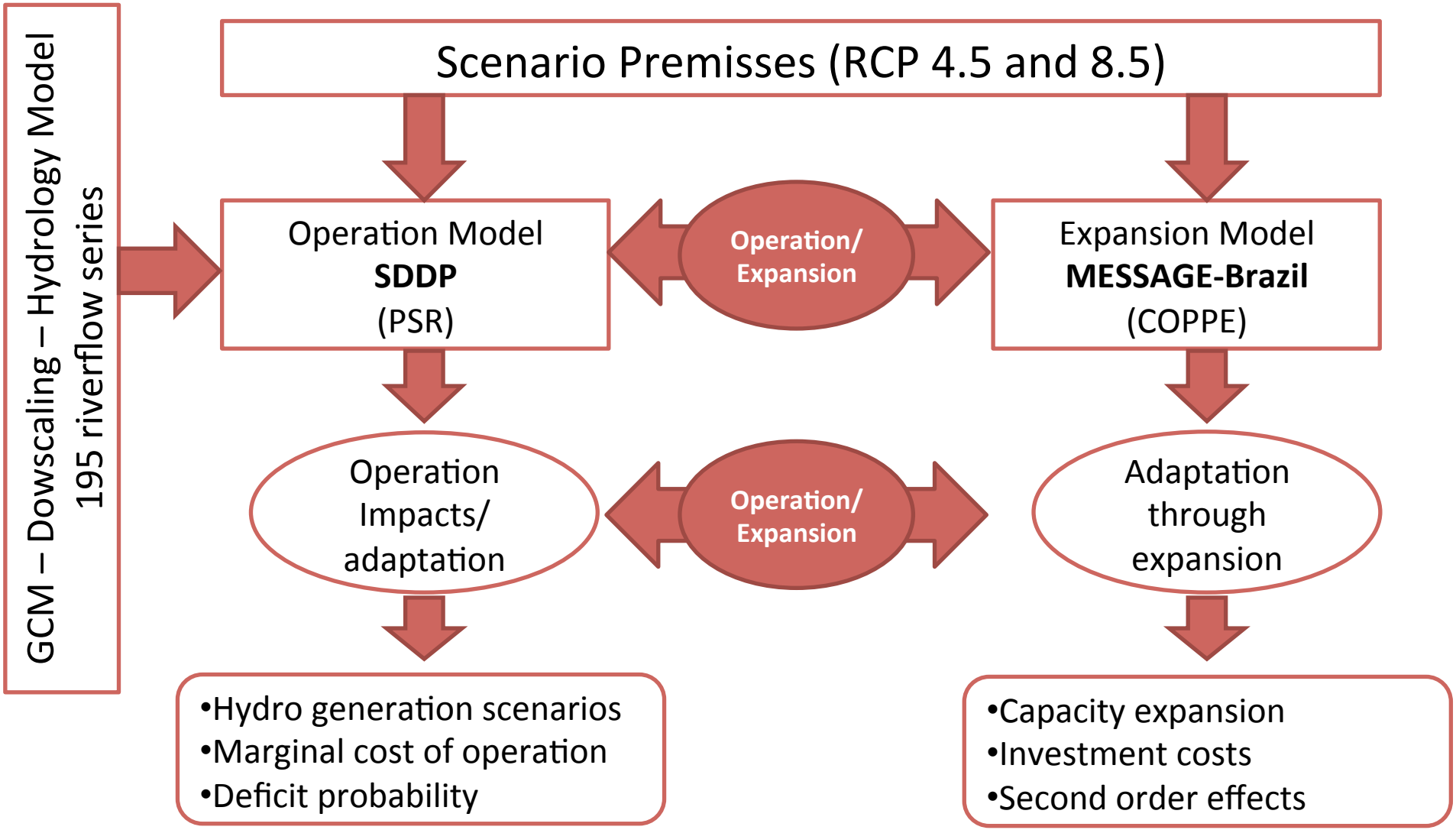
HadGEM



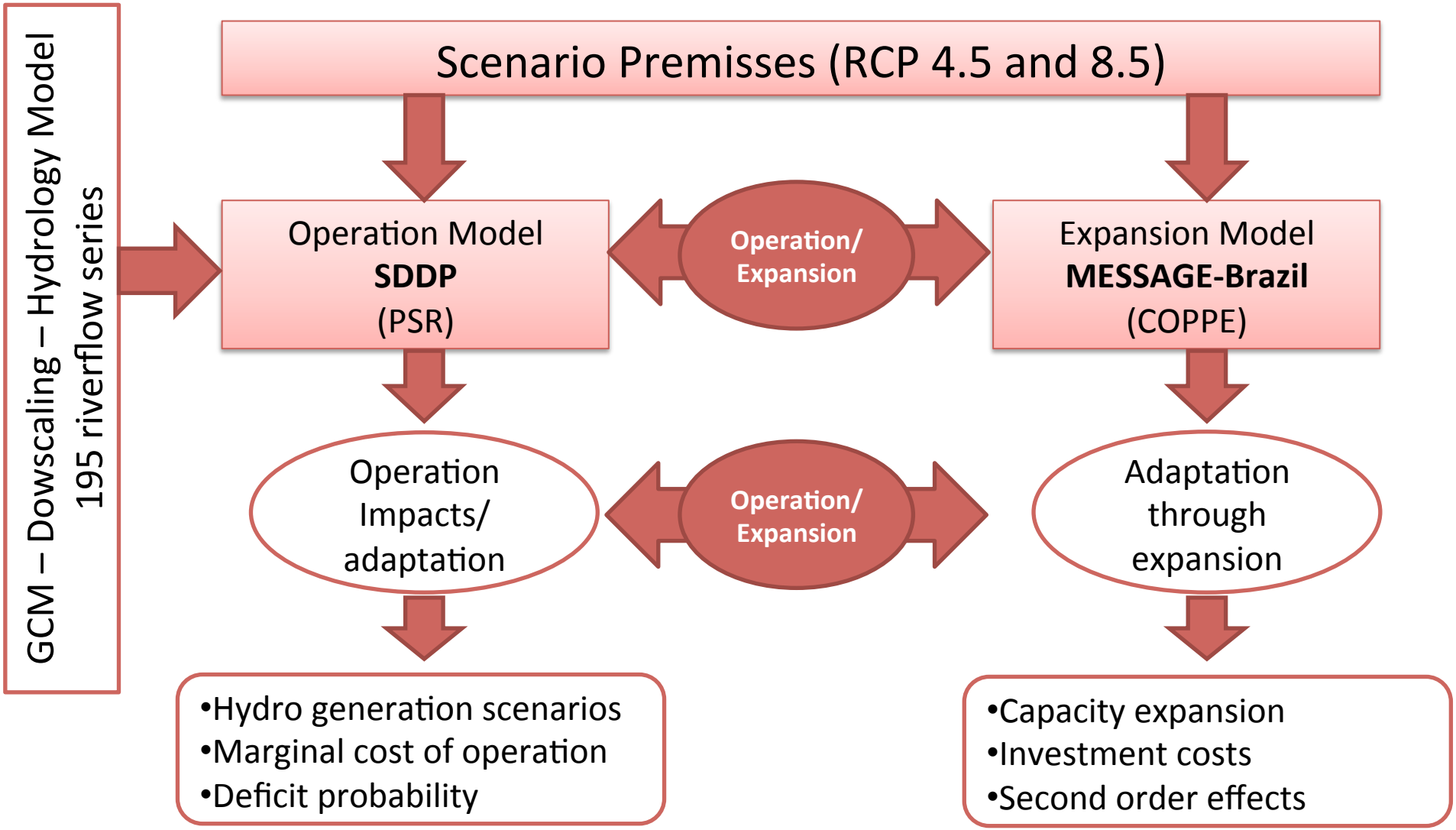
MIROC



Energy Modeling Approach

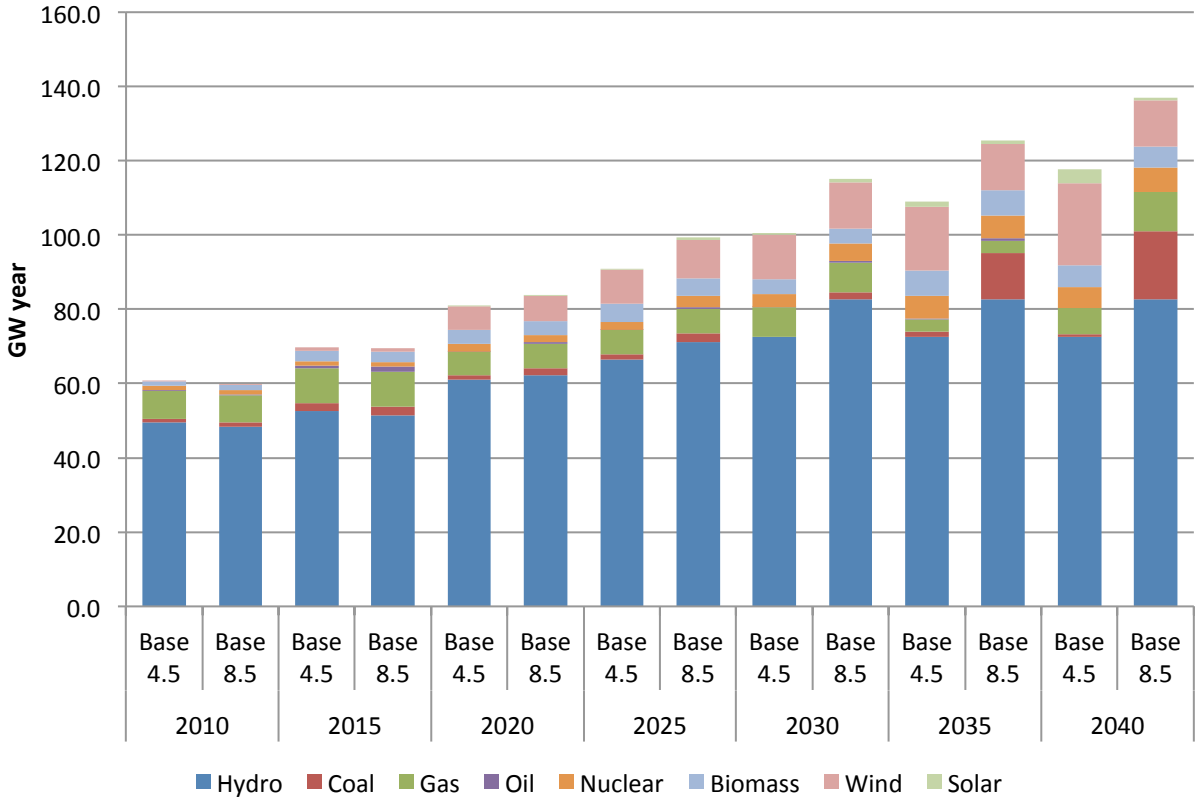


Energy Modeling Approach



Baseline Scenarios

Baseline scenarios: RCP comparison – Electricity



Premisses:

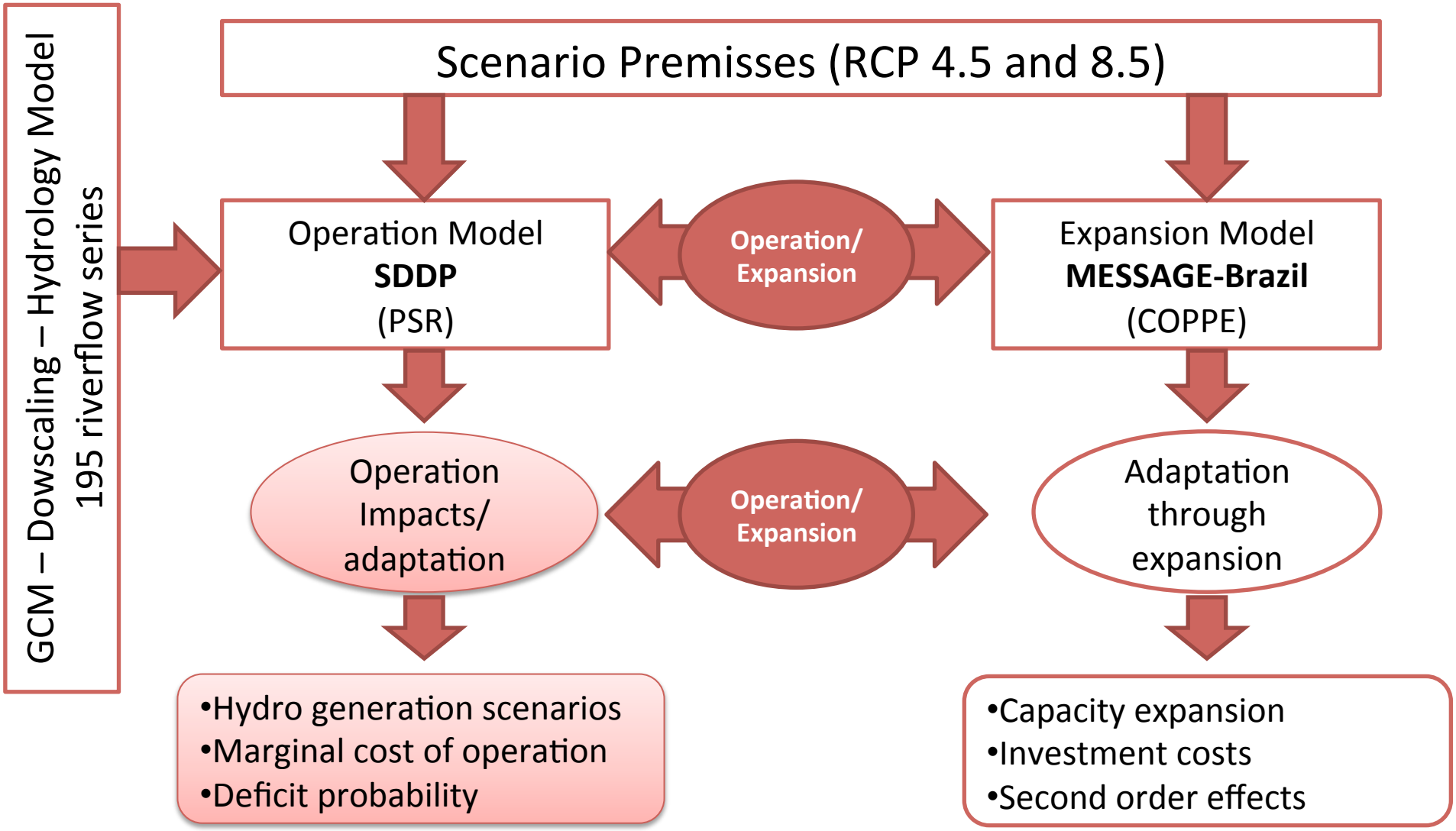
RCP 8.5

- BAU expansion – no explicit mitigation assumed

RCP 4.5

- Energy efficiency
- Lower fossil expansion
- 100$/tCO2 Carbon tax after 2030 (ETP, 2015)

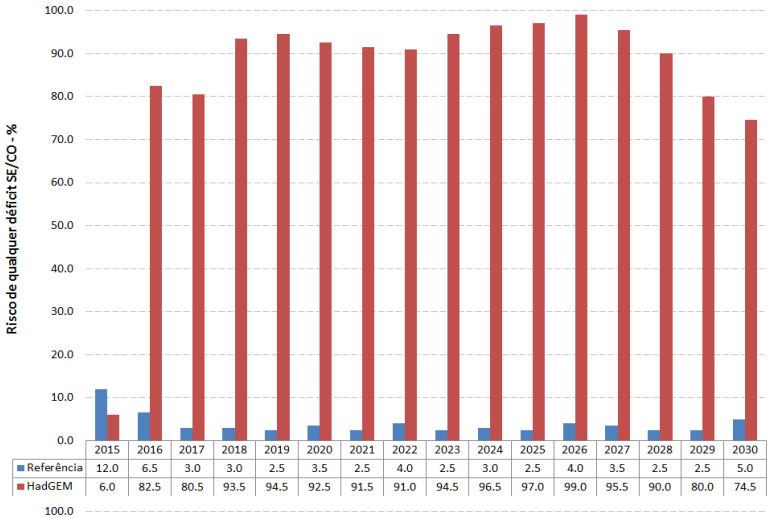
Energy Modeling Approach



Results Operation: Risk of shortage

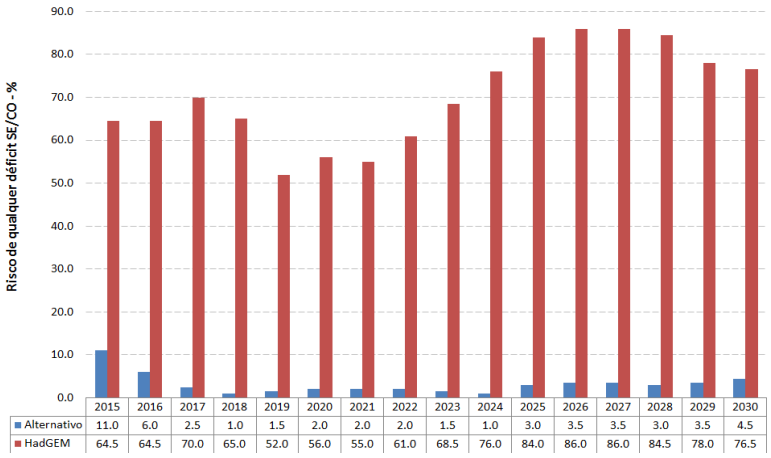
HadGEM

RCP 8.5



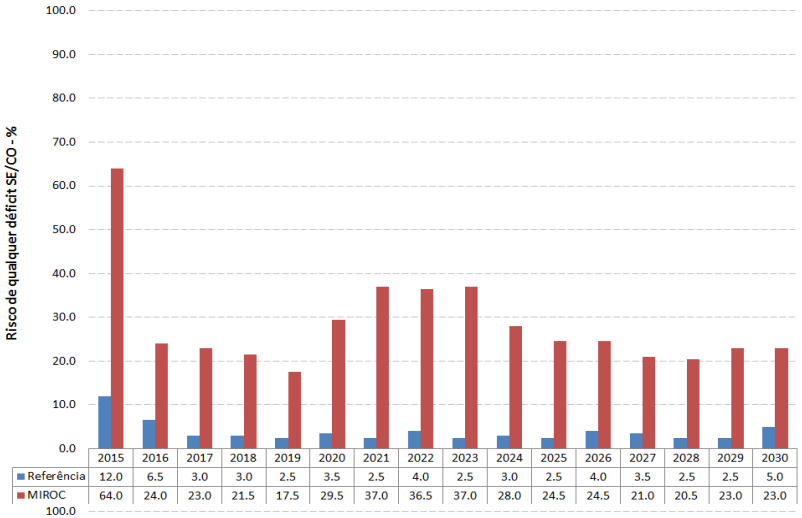
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Referência	12.0	6.5	3.0	3.0	2.5	3.5	2.5	4.0	2.5	3.0	2.5	4.0	3.5	2.5	2.5	5.0
HadGEM	6.0	82.5	80.5	93.5	94.5	92.5	91.5	91.0	94.5	96.5	97.0	99.0	95.5	90.0	80.0	74.5

RCP 4.5

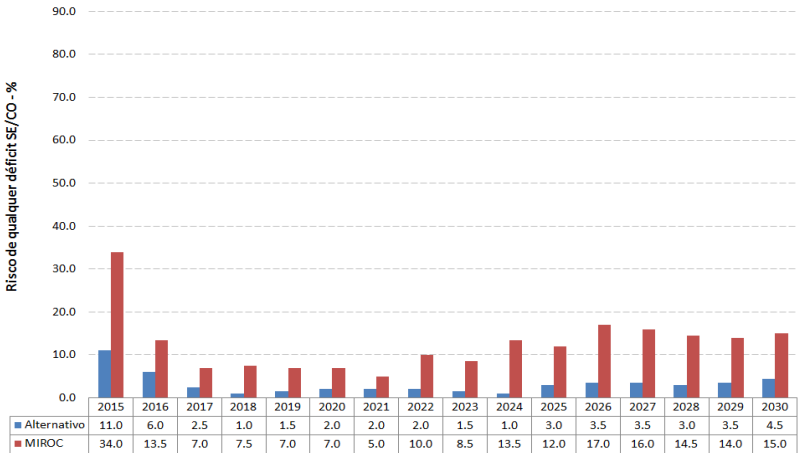


	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Alternativo	11.0	6.0	2.5	1.0	1.5	2.0	2.0	2.0	1.5	1.0	3.0	3.5	3.5	3.0	3.5	4.5
HadGEM	64.5	64.5	70.0	65.0	52.0	56.0	55.0	61.0	68.5	76.0	84.0	86.0	86.0	84.5	78.0	76.5

MIROC

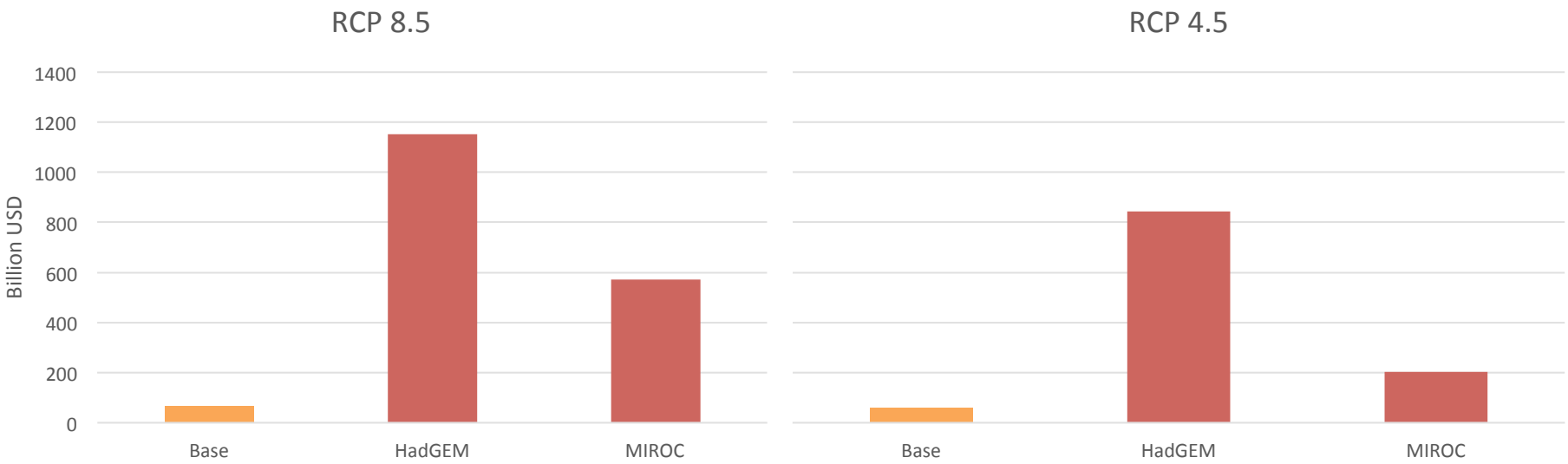


	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Referência	12.0	6.5	3.0	3.0	2.5	3.5	2.5	4.0	2.5	3.0	2.5	4.0	3.5	2.5	2.5	5.0
MIROC	64.0	24.0	23.0	21.5	17.5	29.5	37.0	36.5	37.0	28.0	24.5	24.5	21.0	20.5	23.0	23.0

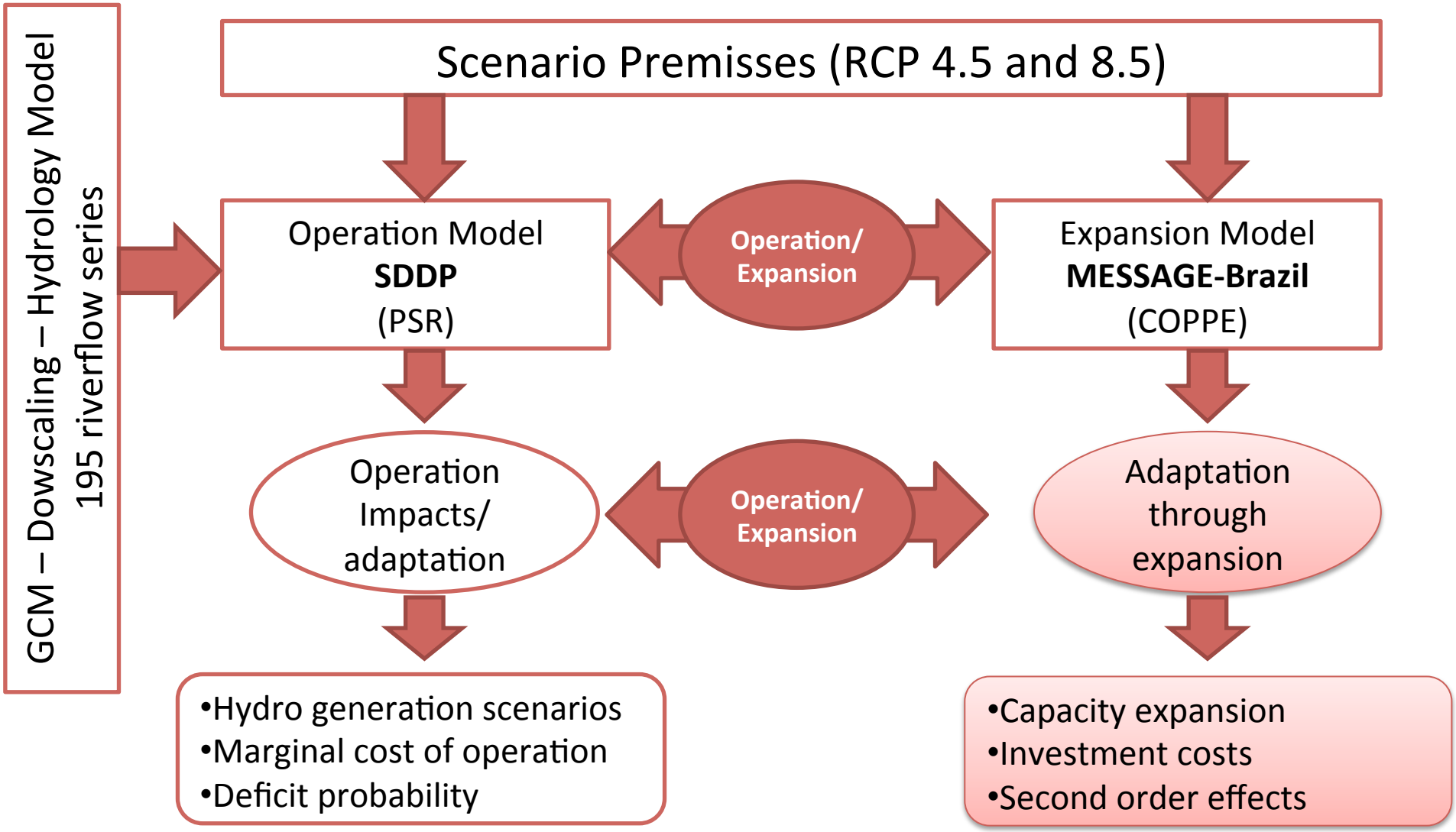


	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Alternativo	11.0	6.0	2.5	1.0	1.5	2.0	2.0	2.0	1.5	1.0	3.0	3.5	3.5	3.0	3.5	4.5
MIROC	34.0	13.5	7.0	7.5	7.0	7.0	5.0	10.0	8.5	13.5	12.0	17.0	16.0	14.5	14.0	15.0

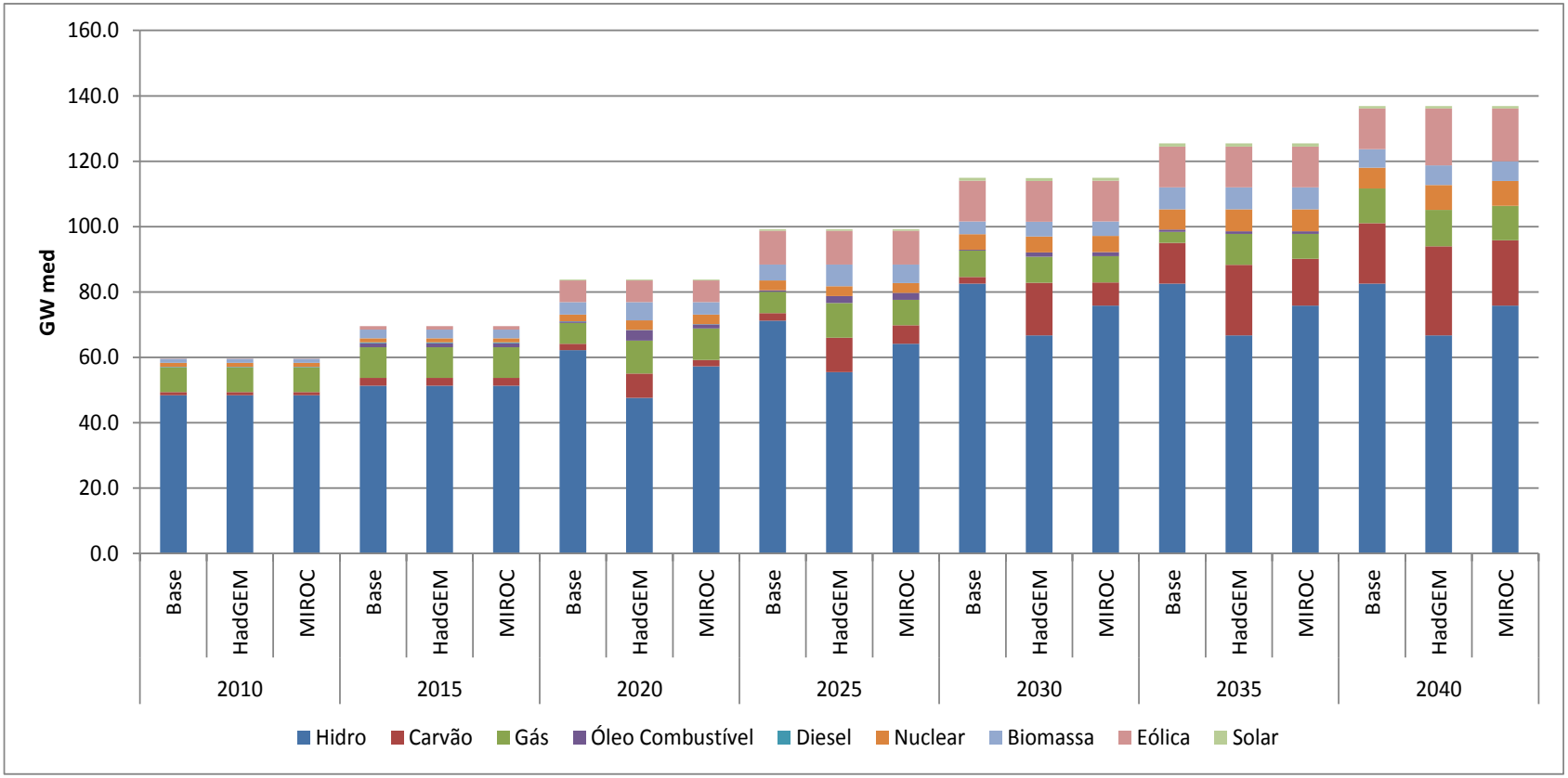
Results – Operation Costs



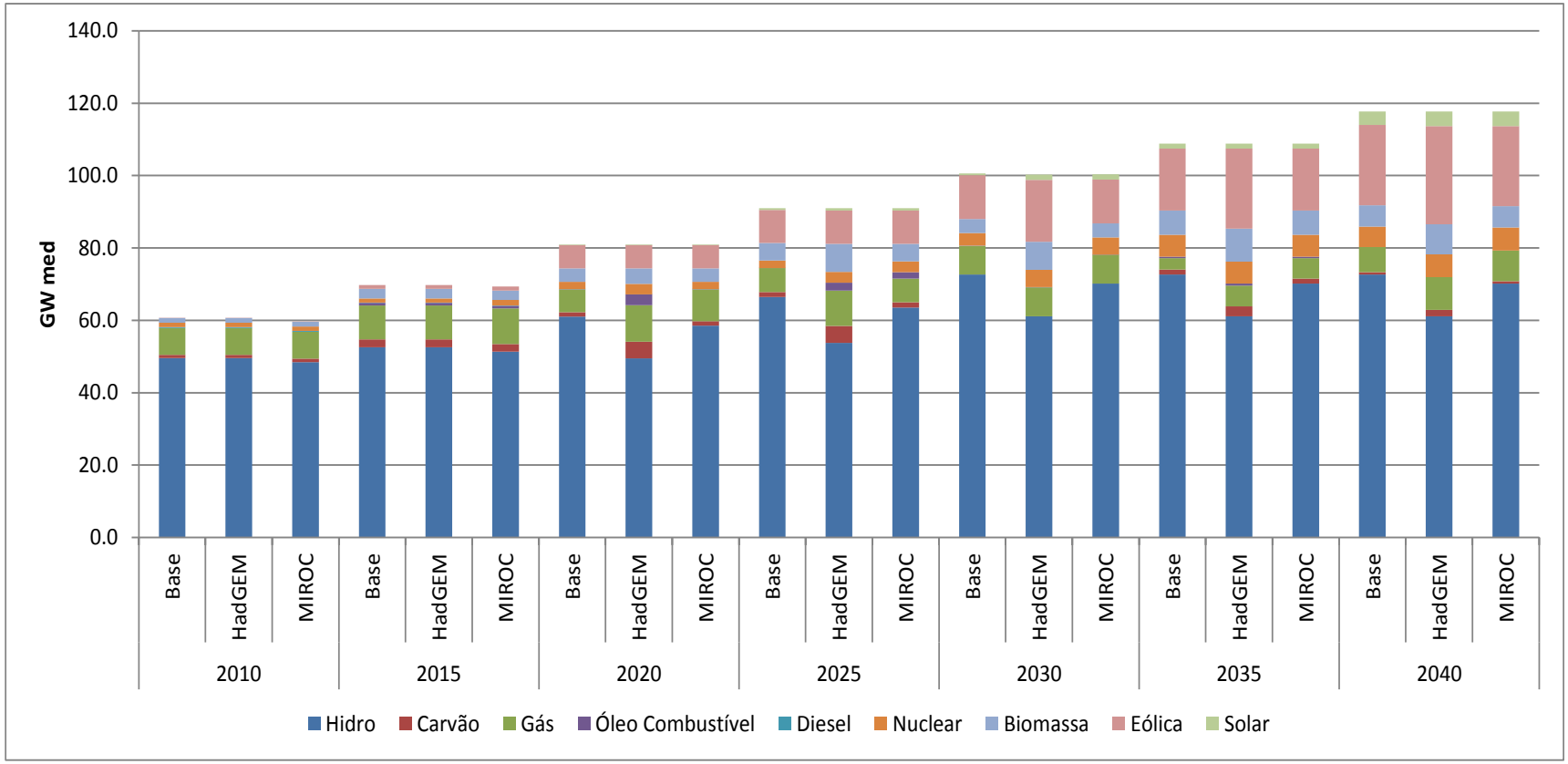
Energy Modeling Approach



Results – Adaptation
RCP 8.5



Results – Adaptation
RCP 4.5



Results – Adaptation Costs

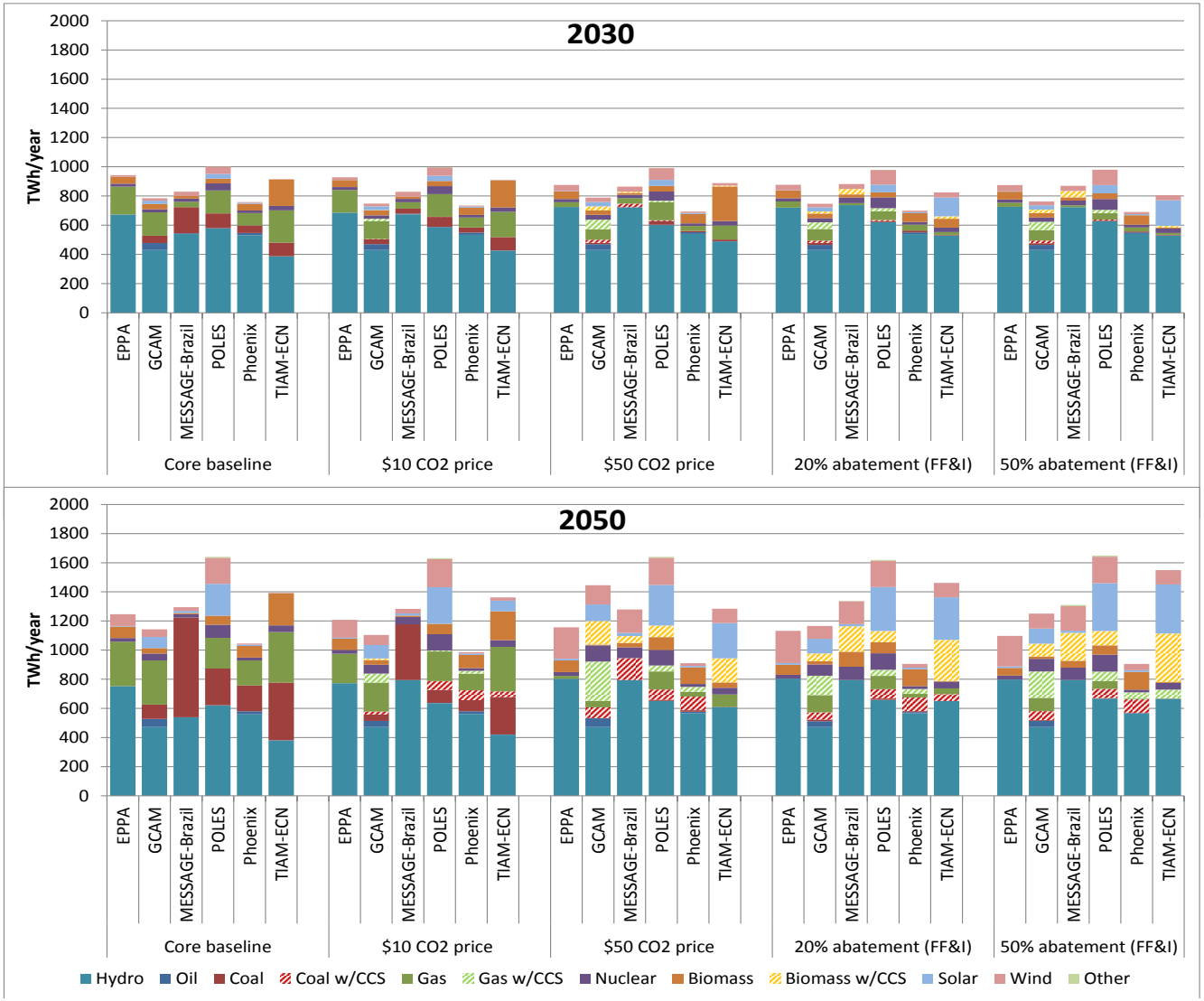
- Accumulated investiment costs up to 2040:
  - HadGEM
    - RCP 4.5: USD 79 billion
    - RCP 8.5: USD 280 billion
  - MIROC
    - RCP 4.5: USD 3 billion
    - RCP 8.5: USD 158 billion

Discussion

- Detailed dispatch modeling requires detailed hydrological modeling
- Operational impacts can be severe and costly if there is no adaptation through system expansion

- Mitigation policies do impact optimal adaptation strategies
  - Adapting to a reduced hydropower availability may further increase Brazil's emissions if no other actions are taken
  - Adaptation can be achieved by fossil fuels or by a combination of energy efficiency, renewable energy, etc.

LAMP Climate Policy Scenarios
Electricity Generation



Next Steps

- Second stage of LAMP – impacts/adaptation
  - To what extent a more detailed dispatch analysis is relevant for adaptation-mitigation assessment?
  - What are the uncertainties related to the mitigation-adaptation interactions?
    - What is the role of Brazil in a given climate goal?
    - How will adaptation take place in such circumstances?
- JGCRI – impact analysis
- Several IAMs looking at mitigation-adaptation
  - GCAM, TIAM-ECN, IMAGE, EPPA, MESSAGE-Brazil

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Thank you

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