Modeling Energy and Climate Mitigation Scenarios for Brazil

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PPE/COPPE/UFRJ

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- Overview
- The MSB300 IAM
- The MSB 8000 IAM
- Current research and the MS-Global IAM (COFFEE)

COPPE UFRJ Programa de Planejamento Energético

- **Overview**

- 1999: collaboration with UN-IAEA
- Since then fifteen versions of the MSG-Brazil model have been developed by our team
- As of November 2016 => the first full version of COFFEE (MSB-Global) is operational (land use and energy)
- But all of this has only been made possible given the large number of supporting studies done by our group: almost 100 papers recently published (associated with energy modelling + PhD thesis + Master Dissertation + technical reports)

COPPE UFRJ Programa de Planejamento Energético

The Center for Energy and Environmental Economics – CENERGIA (since 2003)

- Our team at CENERGIA

- Professors
  - Roberto Schaeffer
  - Alexandre Szklo
  - André F P Lucena

- Researchers
  - Ten M.Sc. students, ten D.Sc. students and four Pos-Docs (one third of the researchers are from abroad)

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The MSB300

Our "compact model" already translated to GAMS and translated to a full Brazilian Times Version (so-called "TIMBRA"

It helped also to build TIMES_CONE SUR (gas-power model – Southern Cone)

It is helping building TIMES-Peru

MESSAGE (MSG)

- MSG is a mixed integer programming model designed to formulate/evaluate alternative strategies to supply energy subject to:
  - Investment limits
  - Availability and price of fuels
  - Environmental regulations
  - Market penetration rates for new technologies
  - Etc

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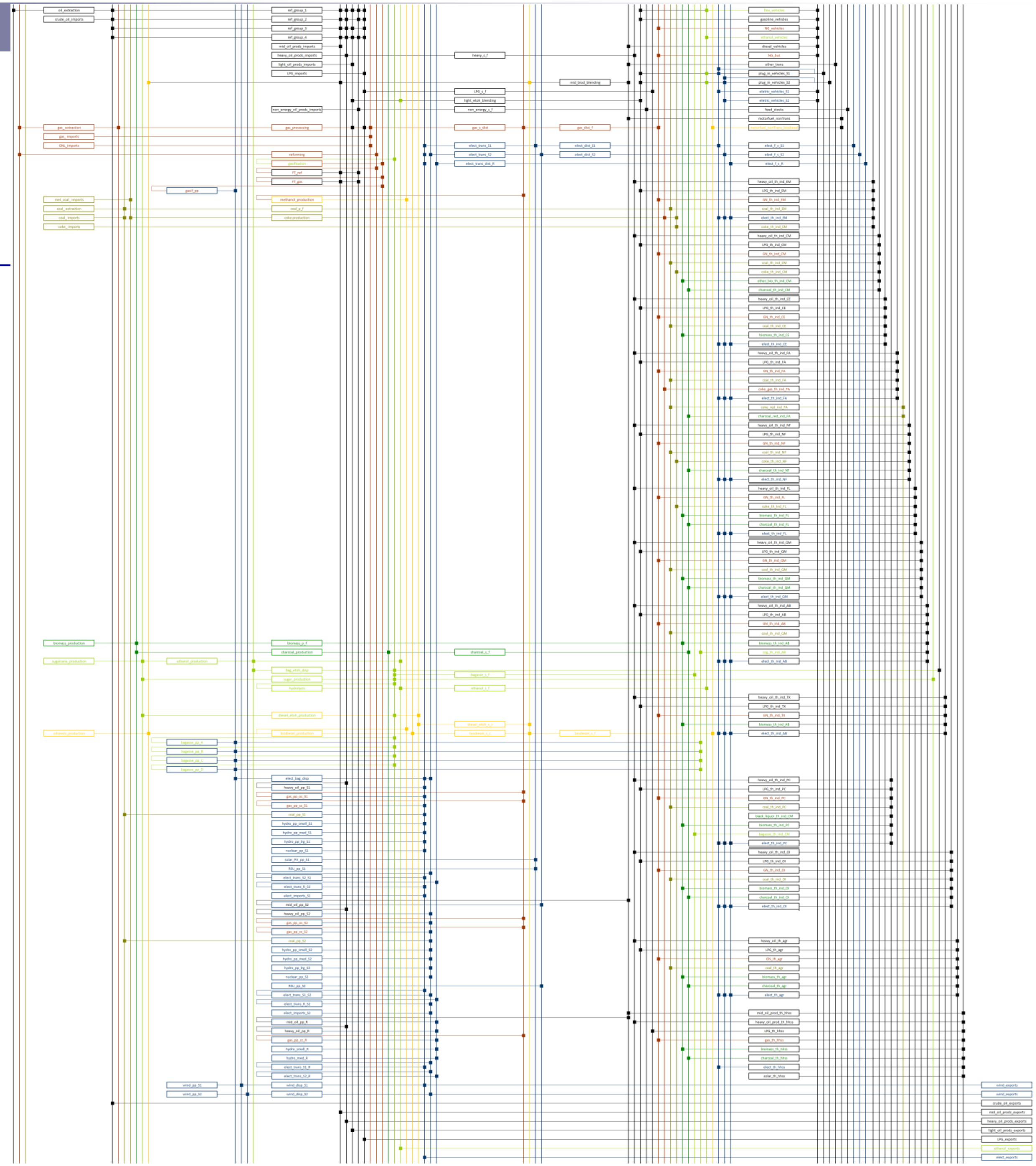
	TIMES-TiPS-B	MESSAGE-Brazil	Remix-Brazil NE
Methodology	Linear Programing	Linear Programing	Mixed Integer Linear Programming
Sectoral scope	Focus on power sector with simple residential sector representation	Integrated model that represents the entire energy system	Focus on power sector
CSP technology representation	CSP modelled with TES types and dispatch options	CSP-PT, 12hs HTS; CSP hybridization with biomass. Regional specific capacity factors	CSP module allowing configuration optimization (solar field, storage, back-up boiler)
Technology changes	Exogenous learning curves	Exogenous learning curves	Exogenous learning curves
Storages	Intra-day storage, endogenous storage optimization	Single option of TES for CSP	Multiple options for TES; hydro reservoir; batteries
Load management and energy efficiency	Limited (energy service demand for residential hot water endogenous)	Limited (energy service demand)	Not available (electricity demand)
Time resolution	432 time slices; 6 seasons; 3 typical days; 24 hours	4 seasons; 5 intra-day periods	Hourly resolution
Time horizon	2010-2050; 5 year steps	2010-2050; 5 year steps	One year, pre-defined
User-constraint/ policy options	Available, depends on scenario definition	Available, depends on scenario definition	Not available but implementable
Non-energy commodities	CO_2 only	CO_2; sugar production	None
Geographical coverage	5 regions (South-Central; Northwest, North; Southeast; external)	4 Regions (South-Southeast-Centre; Northeast; North; External)	2 Regions (Northeast; External)
Computational efficiency	Short running time	Short running time	Long running time
Power system operation	Energy and capacity balance, including dispatch on typical day basis	Energy balance only, based on intra-day energy production profiles	Electricity and capacity balance, including dispatch optimization
Unit commitment	No associated parameters available	No associated parameters available	Available

MSB-300



Last runs:

. Brazil´s Secretary of Strategic Affairs (SAE): role of unconventional gas in Brazil´s energy system + oil and gas production under a bottom-up analysis

. Latin American Modelling Project (LAMP)

. Technological Forecasting (UK Embassy)...

- **The MSB 8000 IAM**

Energy plus Land Use model: able to see food-energy competition)

- Partial equilibrium – the full energy system
- Emissions include fossil-fuel combustion from all sectors, industrial processes, waste treatment, and fugitive emissions
- Includes electricity transmission, O&G, petroleum products, CO_2 etc
- Includes land use model (math procedure from our global model): food demand

Upgrade (time resolution)

Base year: 2010	✓ Kept
Horizon: 2010-2050 each 5 years	✓ Kept
Seasonality: 4 seasons	**12 months**
Load curve: 5 sections	**24 hours**

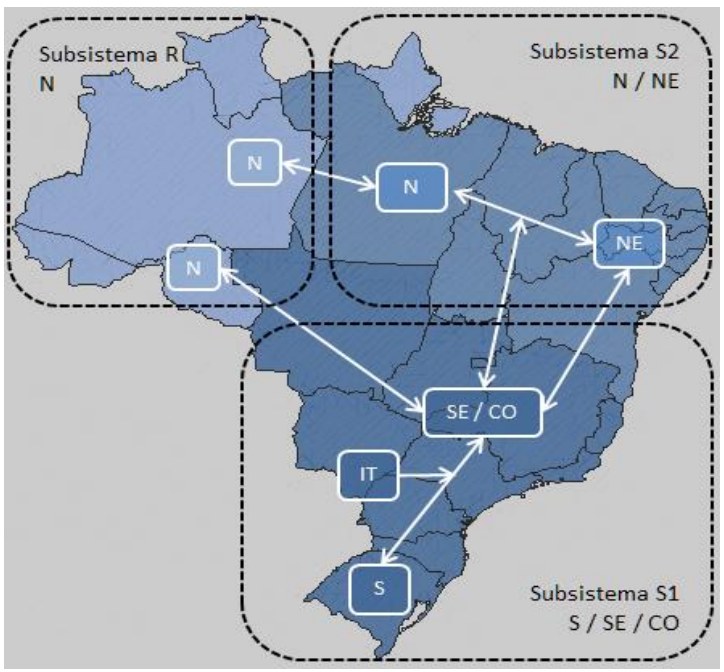
Upgrade (spatial resolution)

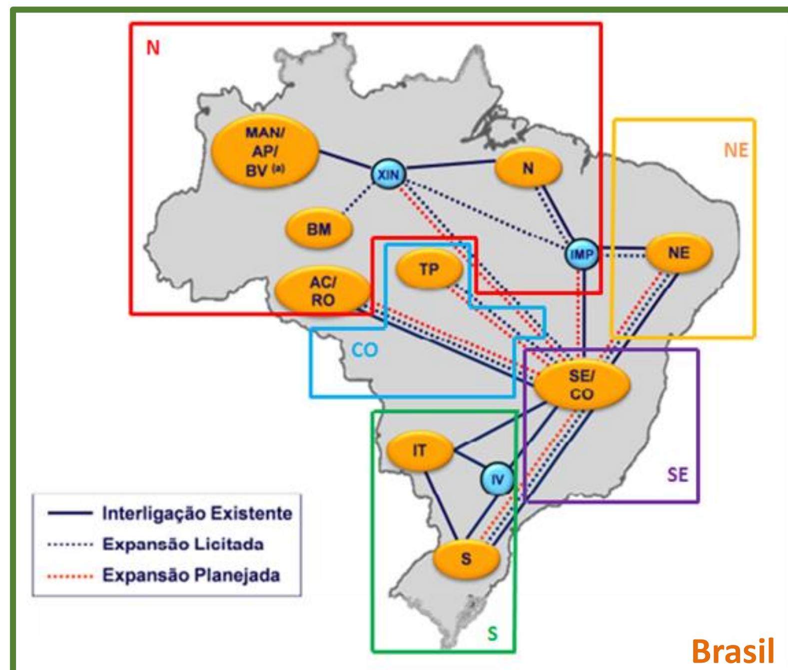
3 regions

(only electricity system)

6 regions

(electricity, gas, oil, oil products and CO_2)





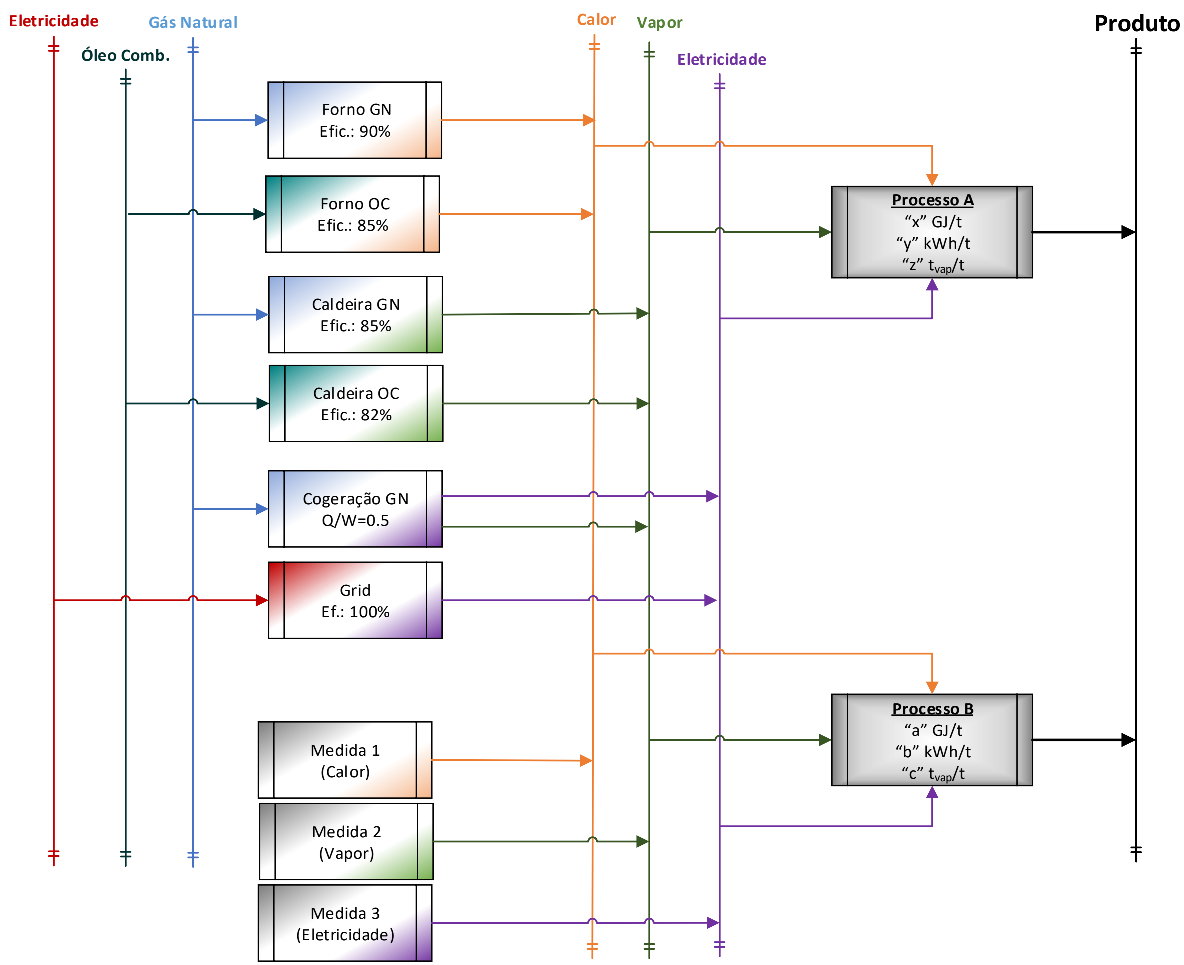
Upgrade (technologies)

Around 300 technologies

→

Around 8,000 Technologies (by macrorregions)

Example: simplified energy service demand structure



Ministry Of Science and Technology/ PNUMA/ GEF Project "Mitigation Options of Greenhouse Gas (GHG) Emissions in Key Sectors in Brazil“

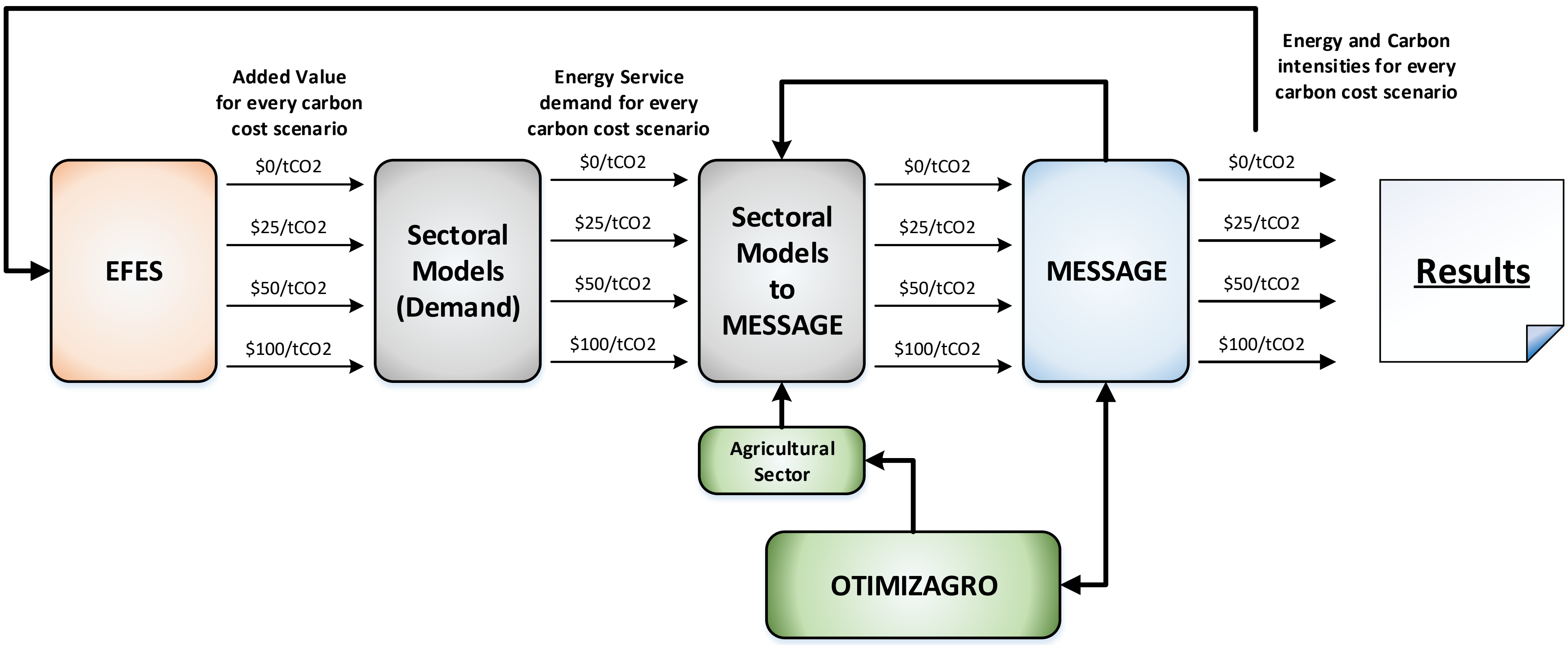
A full hybrid integrated model to support Brazil´s NDC

Consistency (Energy-Economy-Land Use)

All simulations and iterative procedures done!

Model Integration

Iterative modeling procedure considered in the project



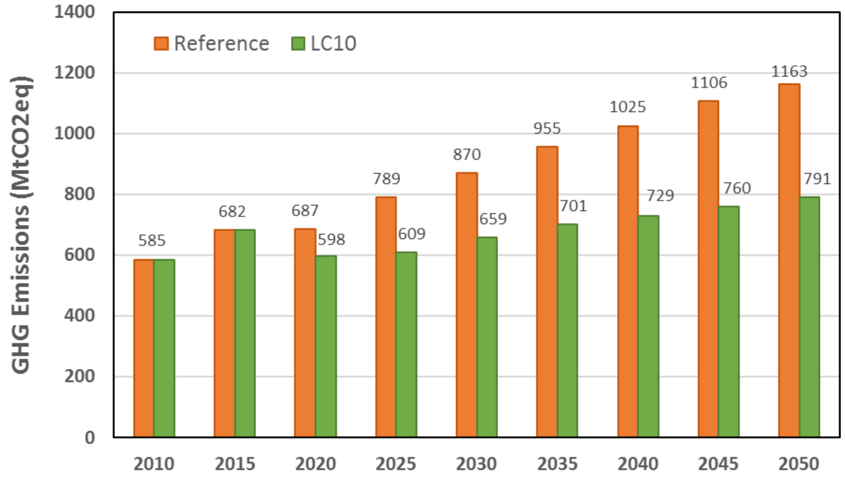
Few and not so fresh results presented in Morocco(Nov 2016):

Results: consistent, integrated, detailed by useful energy or industrial process.. As you wish

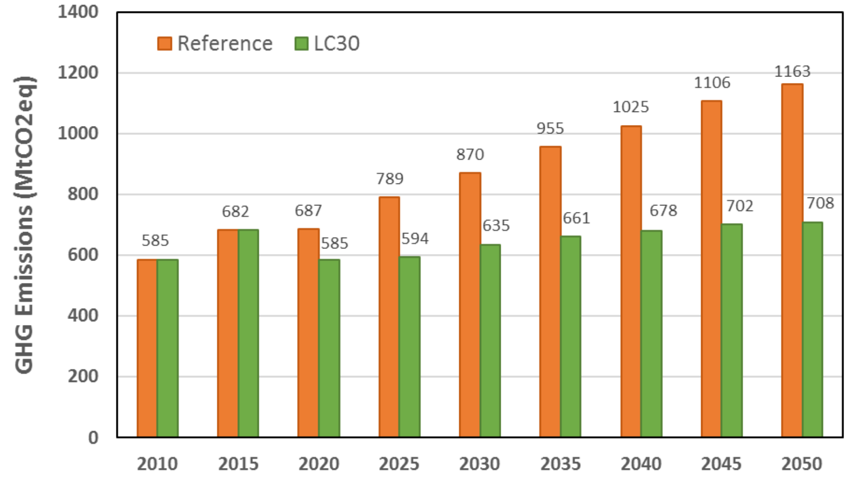
(for more details, please see: http://www.mct.gov.br/upd_blob/0240/240525.pdf)

LC_x Results – GHG Emissions

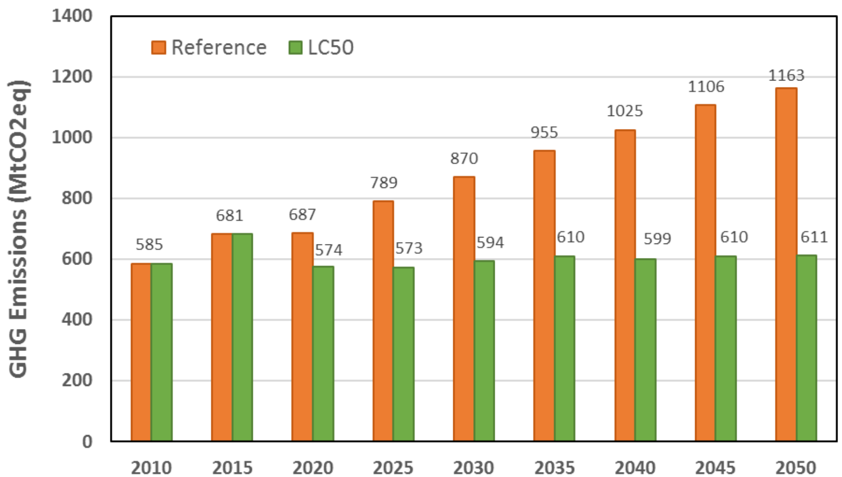
LC_{10}



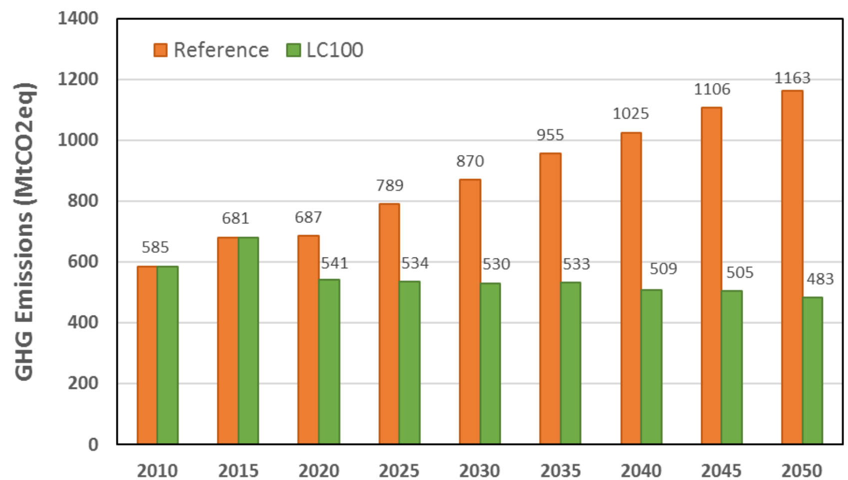
LC_{25}



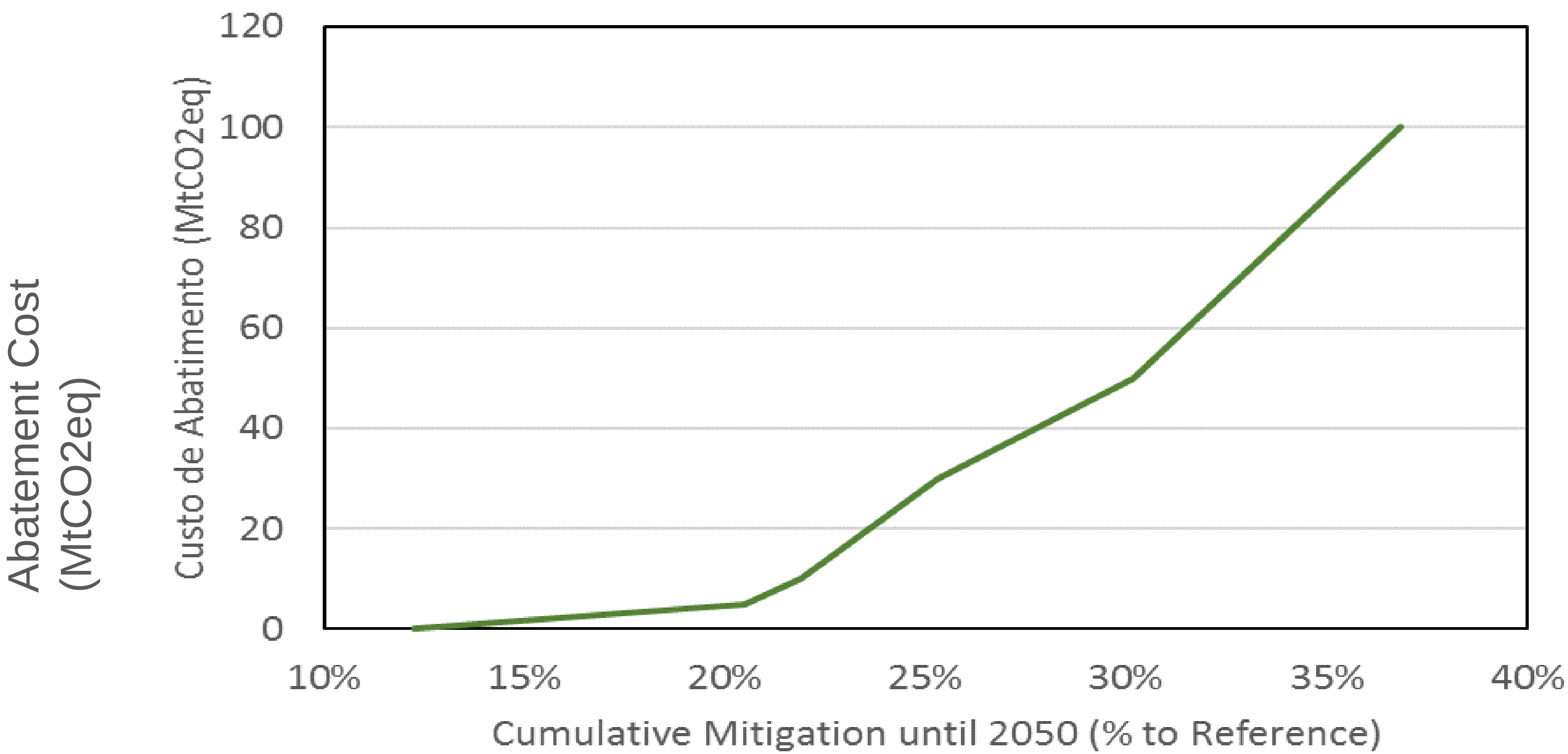
LC_{50}



LC_{100}

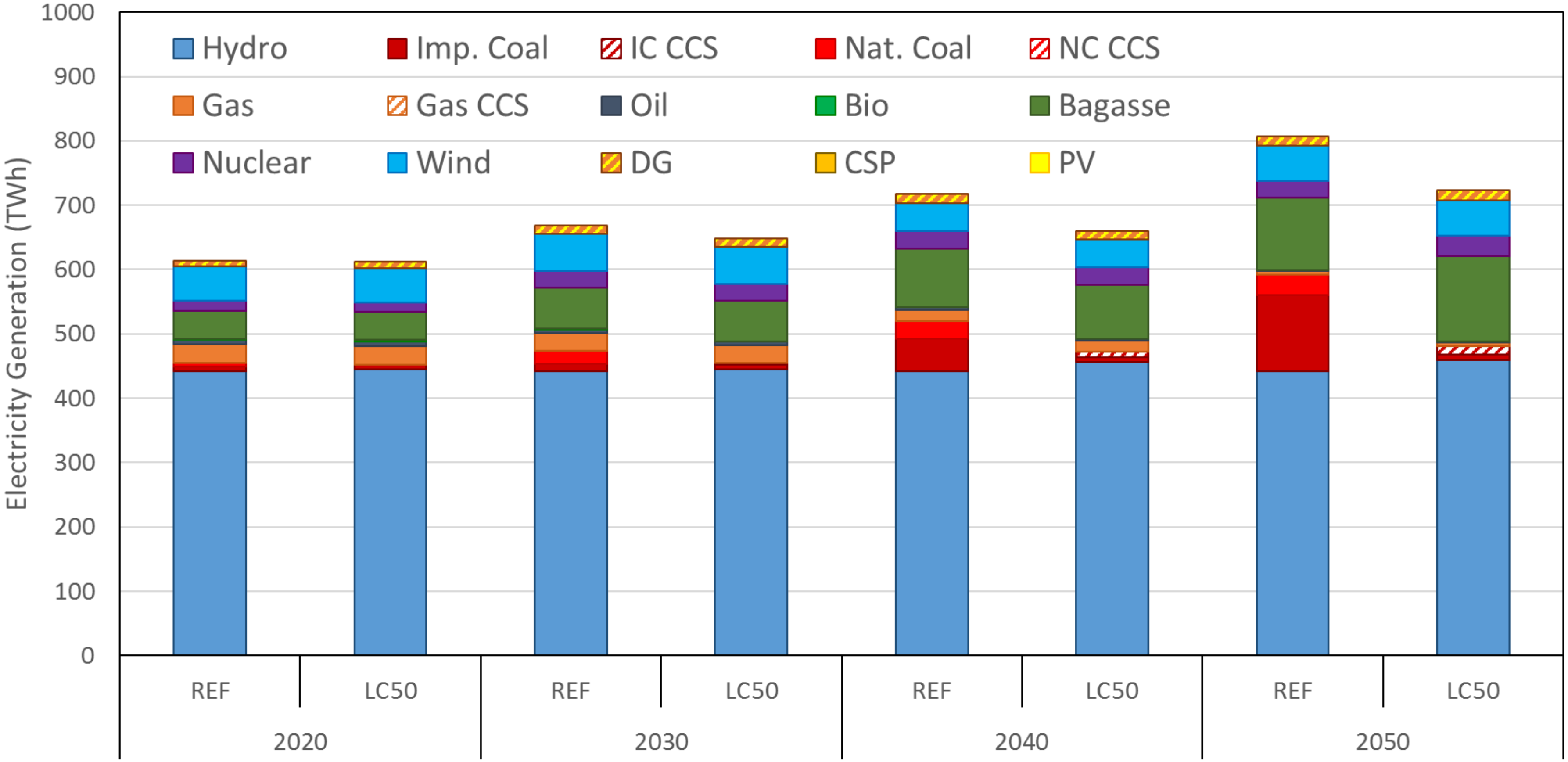


LC_x Results up to 2050



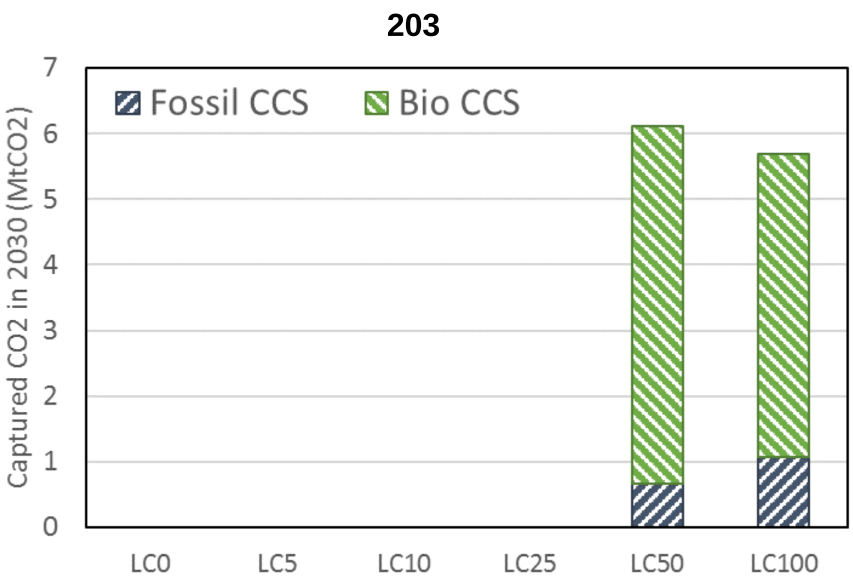
LC_{50} Results

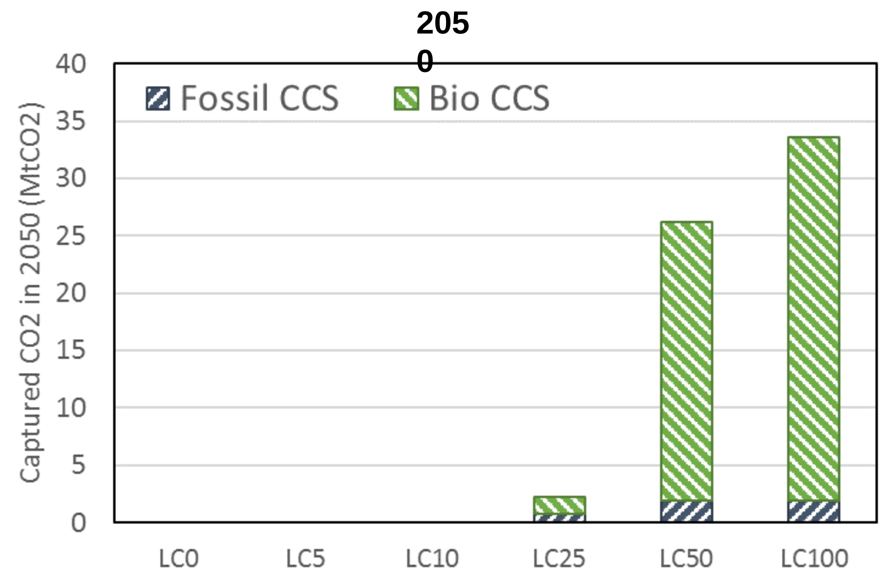
/// Electricity Generation: CCS starts at 40 US$/$tCO_2$



LC_X Results – Bio CCS

- The importance of BECCS



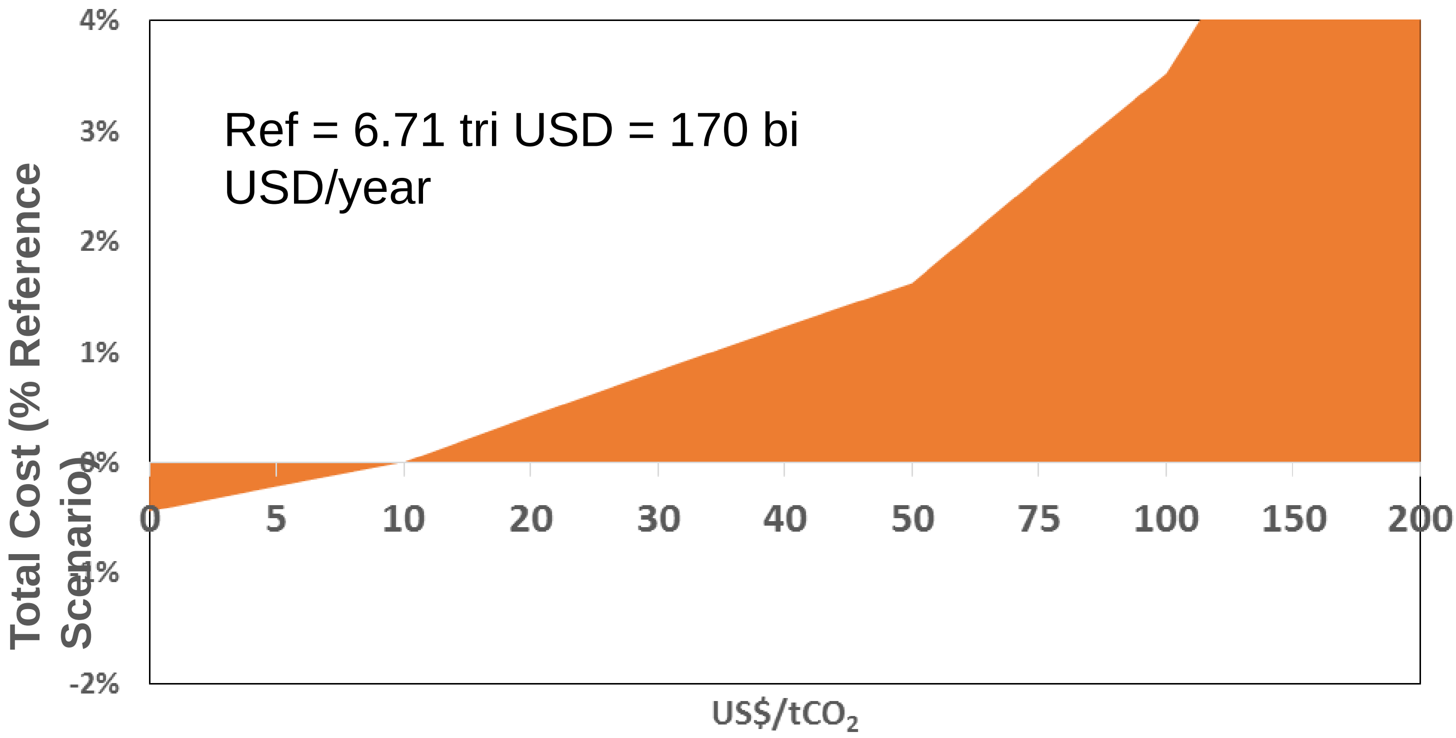


Will Brazil have the CO_2 transport capacity needed in 2030?

Commercial scale + regulatory aspects + transaction costs

Implementation costs

- Energy system incremental total costs (supply and demand) – 2010 to 2050



Our Global IAM

- Global energy model, with a detailed representation of Brazil
  - Most compreensive effort of this kind outside Europe, Japan and the US
  - First development of a full integrated assessment model (IAM) for climate mitigation outside Europe, Japan and the US

- To assess the role of Brazil, the BRICS countries, or any other country in climate stabilization scenarios

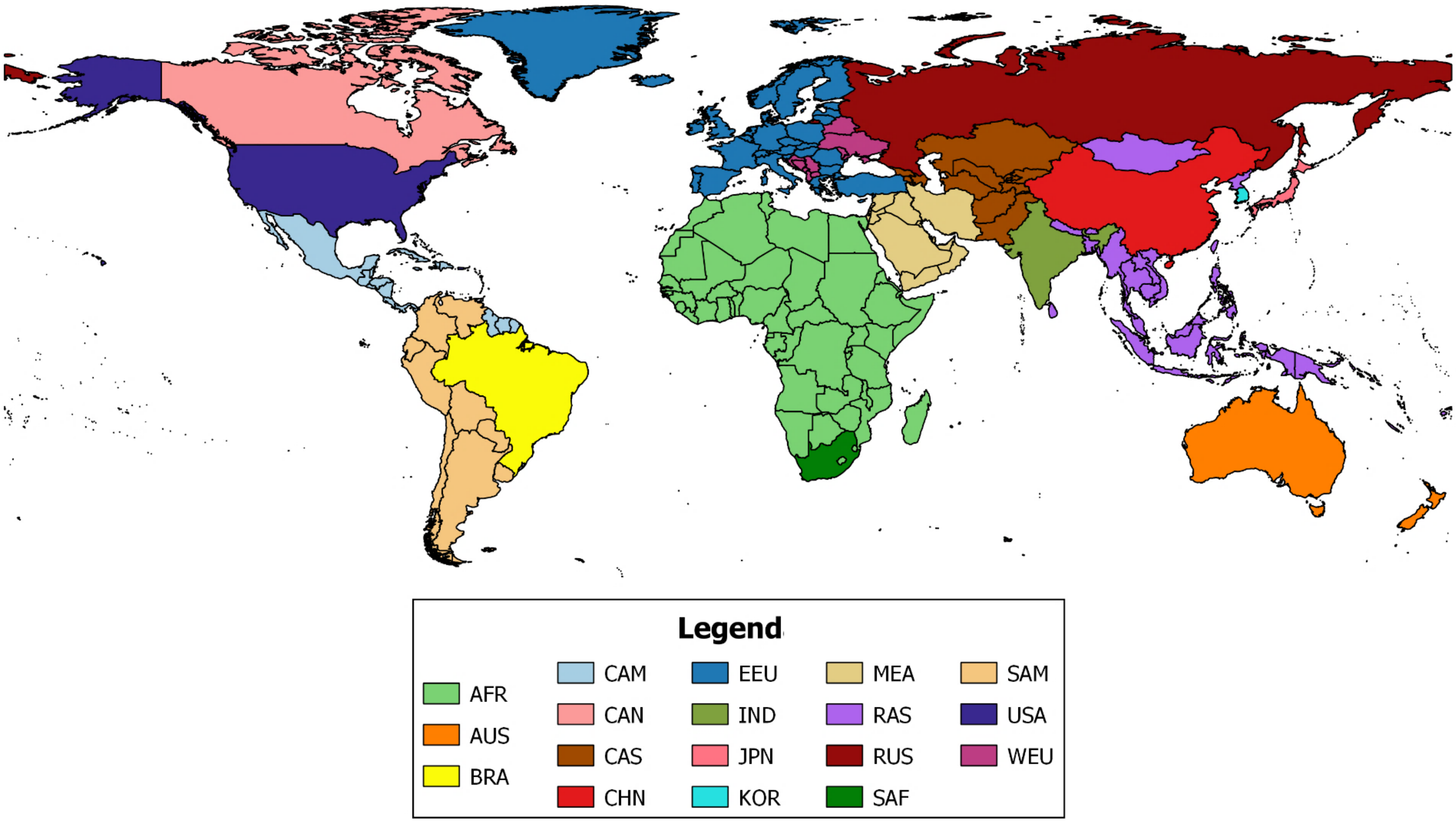
COFFEE (COppe´s integrated assessment Framework For Energy, land and the Environment)

A GLOBAL INTEGRATED MODEL

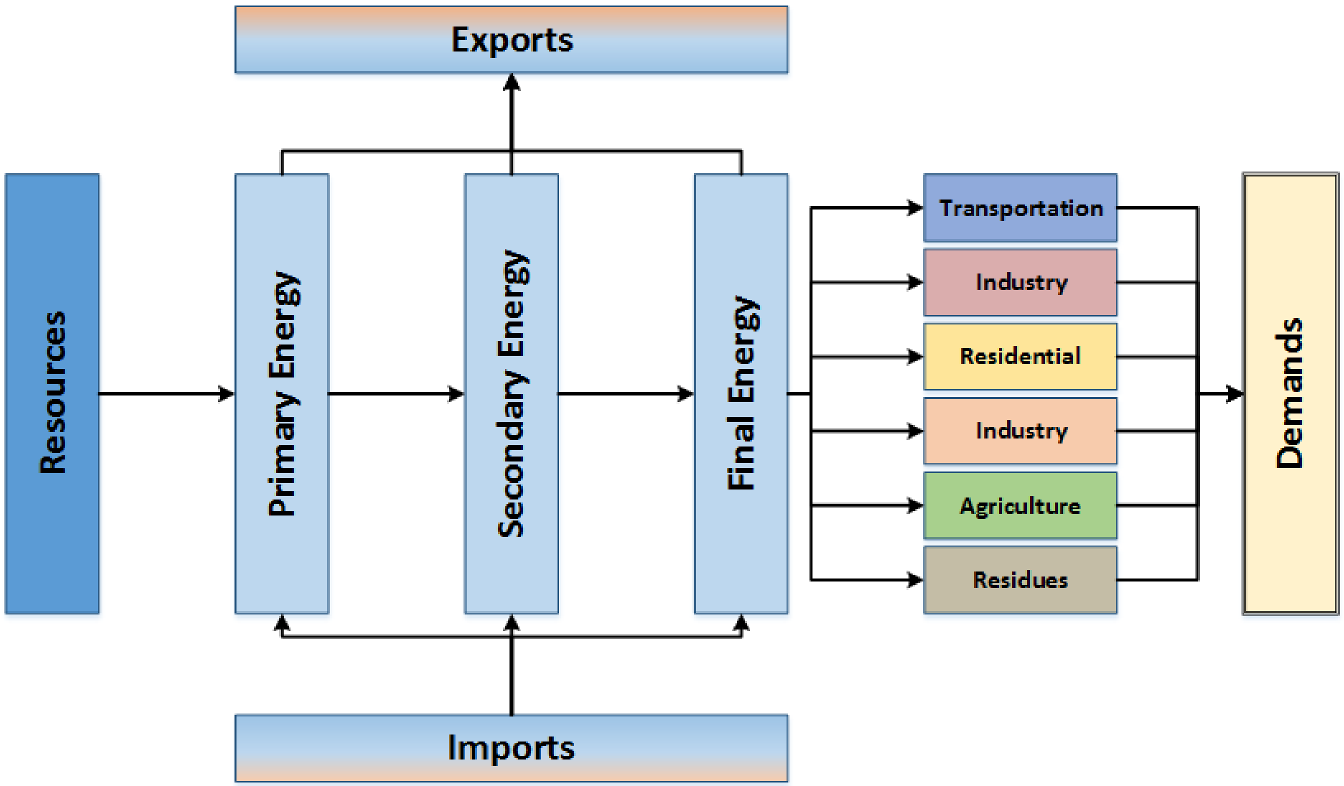
Alexandre Szklo and Roberto Schaeffer

With sincere thanks to Pedro Rochedo, the lead developer of this model, and from whom we have adapted these slides, borrowed from his doctoral dissertation defense

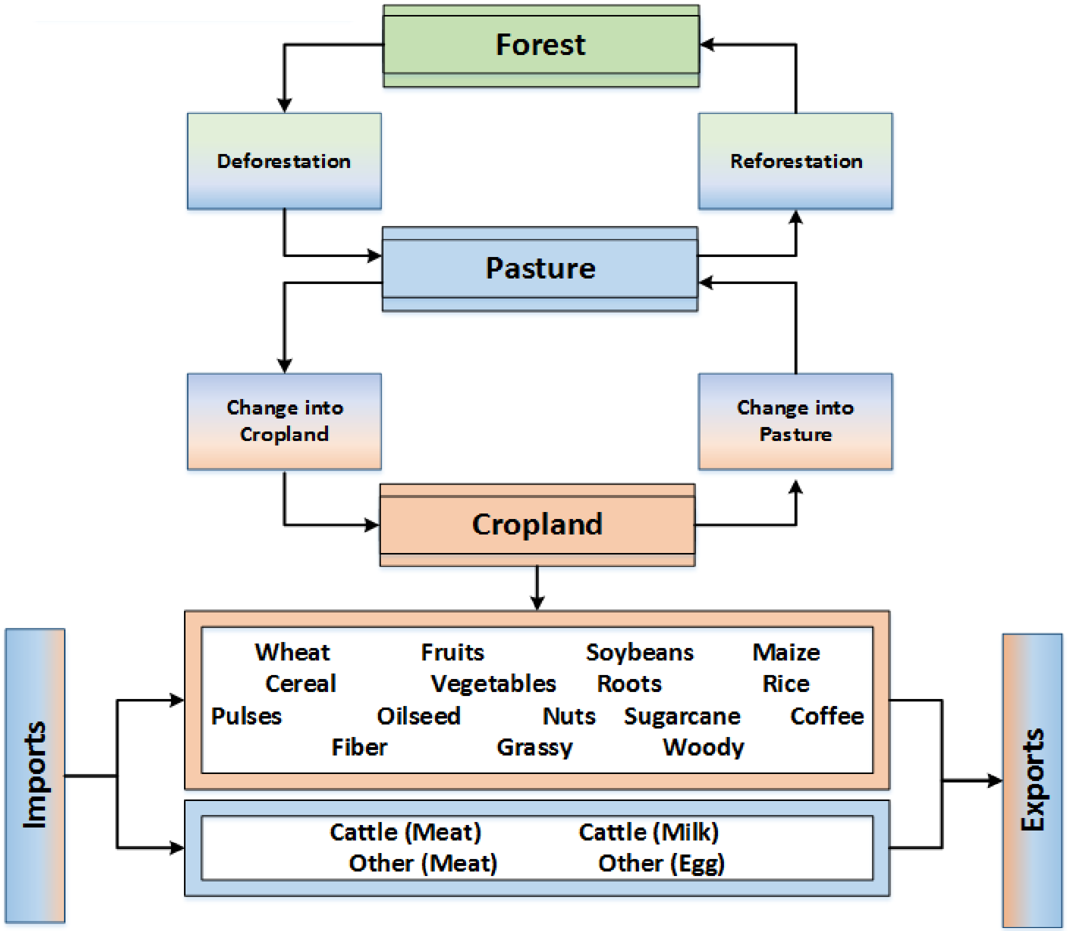
Full version originally presente in EPE, November 9th 2016


Legend
AFR
AUS
BRA
CAM
CAN
CAS
CHN
EEU
IND
JPN
KOR
MEA
RAS
RUS
SAF
SAM
USA
WEU

- Model structure: energy system
  - Supply (production and distribution) and demand

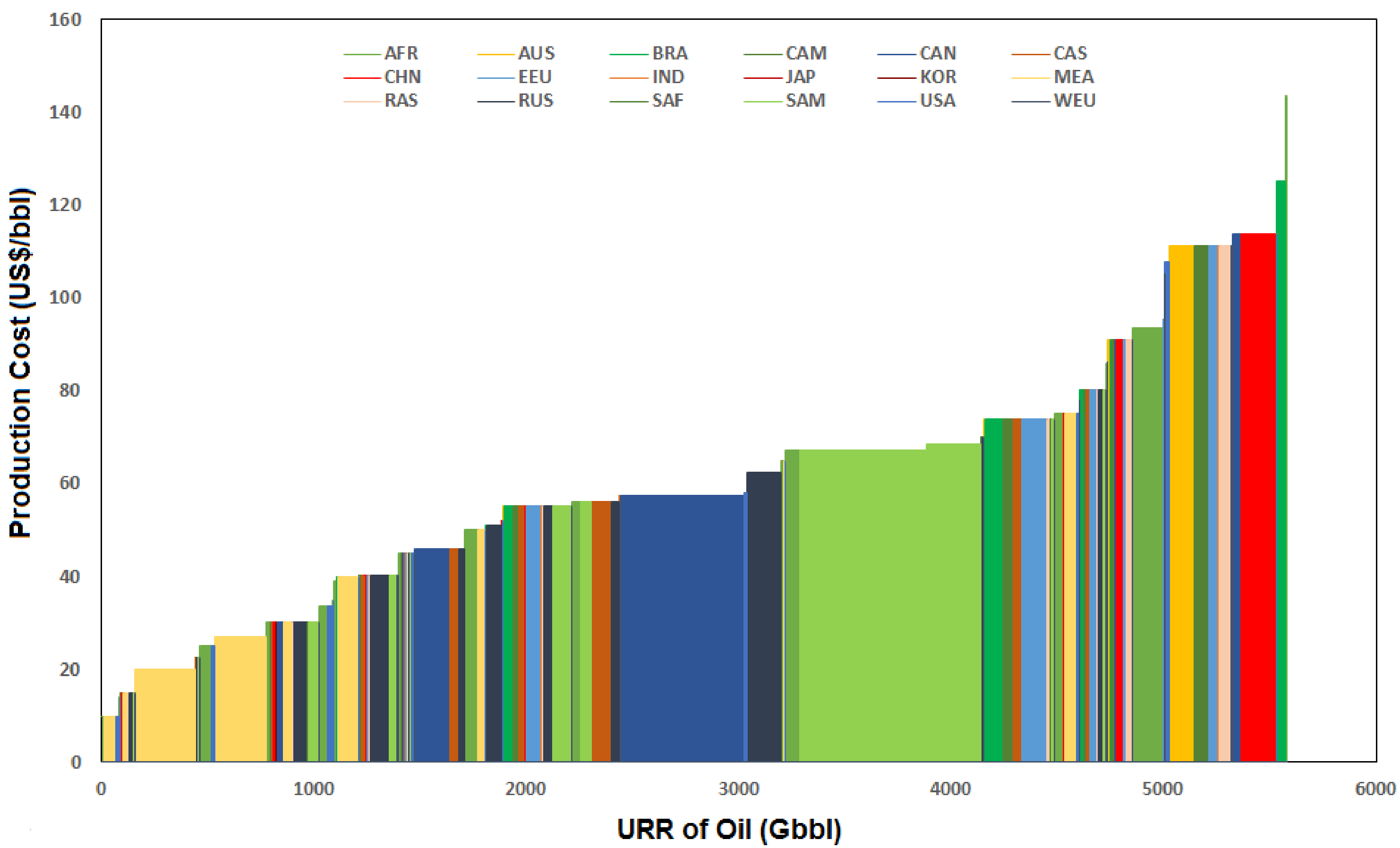


- Model structure: land system



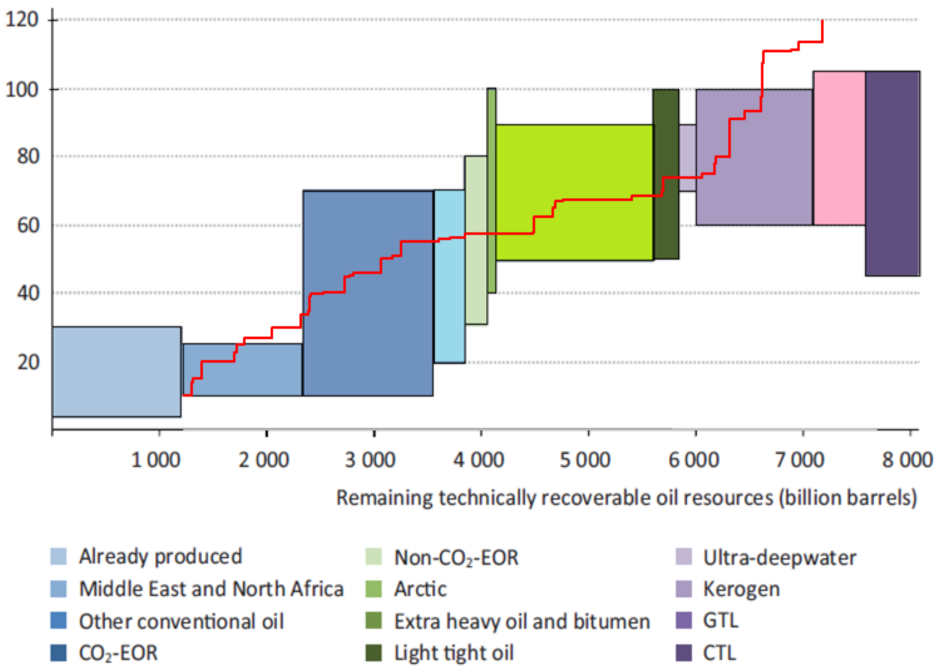
Energy resources

- Oil
  - Detailed representation of resources, discovered and to be discovered
    - Split by category and type (on/offshore)
  - 18 categories per region
    - 324 resources with associated gas
- Natural gas
  - Additional detail on non-associated gas
    - Including shale gas (non-conventional)
  - 14 categories per region
    - 252 resources, most of them including estimates on liquids (LNG)
- Coal
  - 3 types (betuminous, sub-betuminous and lignite)
  - 19 categories per region
    - 342 resources, with estimates for open and underground mining, including coal-bed methane

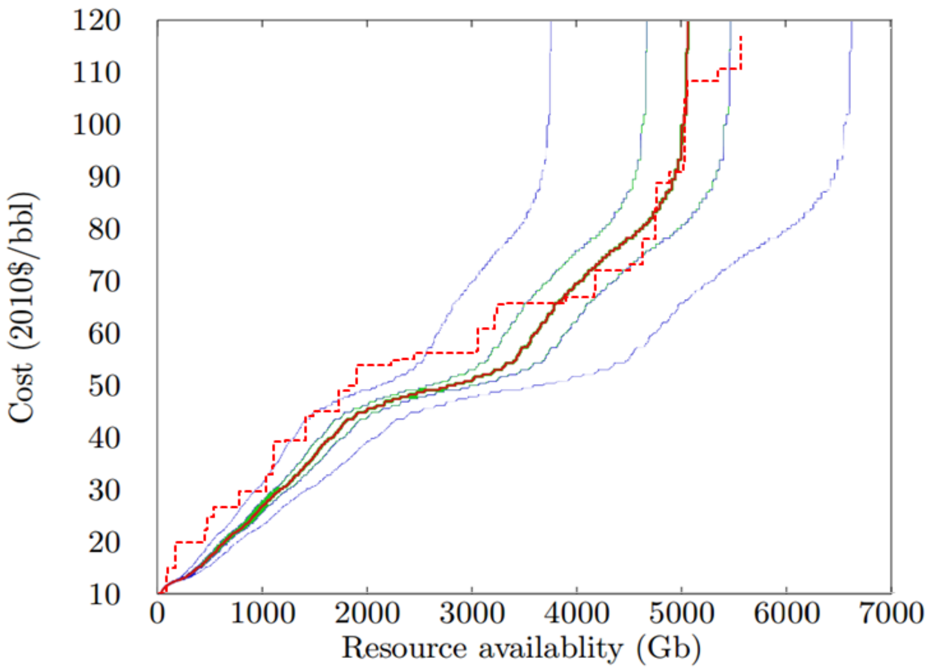


Production Cost (US$/bbl)
160
140
120
100
80
60
40
20
0
AFR
AUS
BRA
CAM
CAN
CAS
CHN
EEU
IND
JAP
KOR
MEA
RAS
RUS
SAF
SAM
USA
WEU
0
1000
2000
3000
4000
5000
6000
URR of Oil (Gbbl)

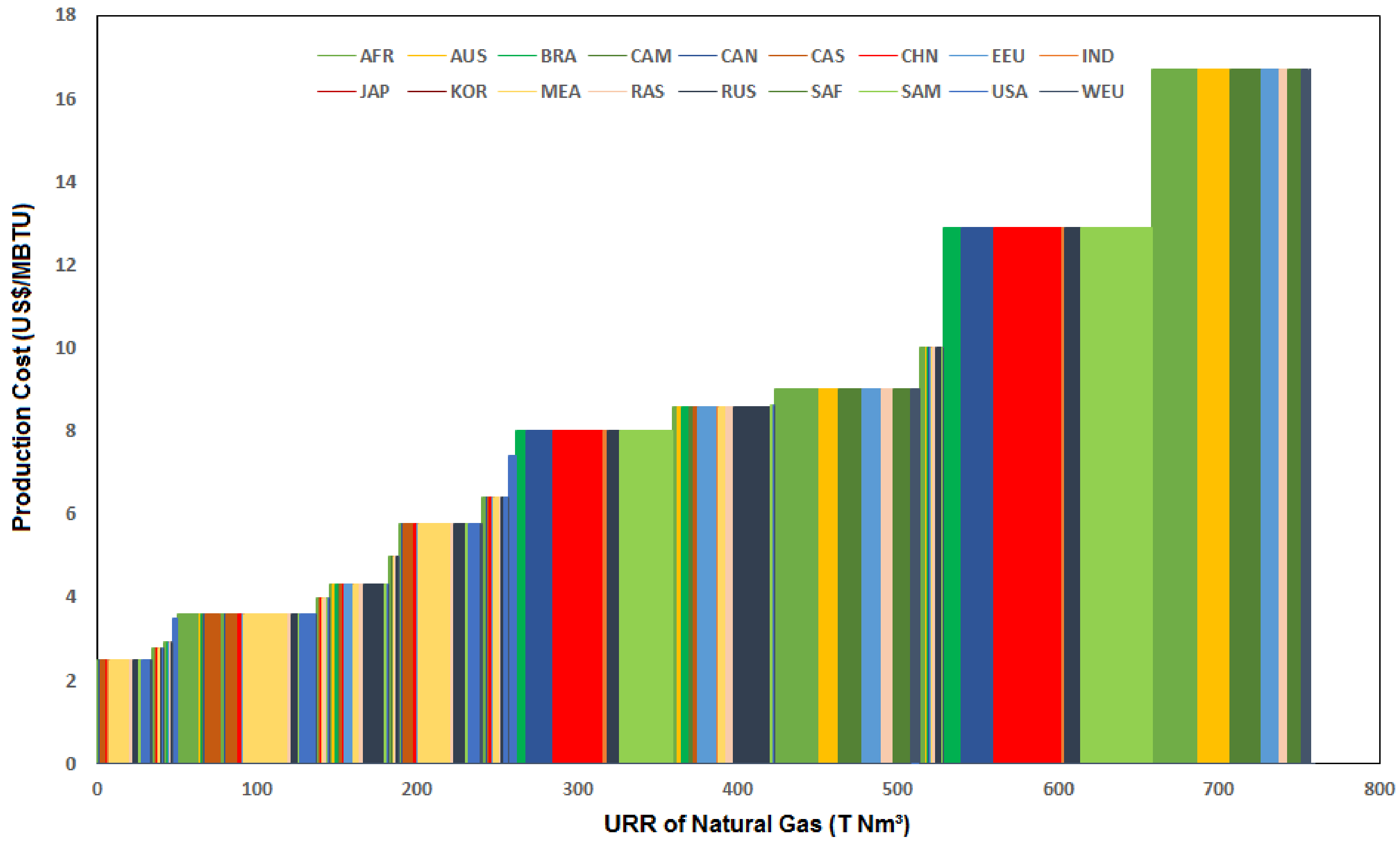
- Oil: comparison with the available literature



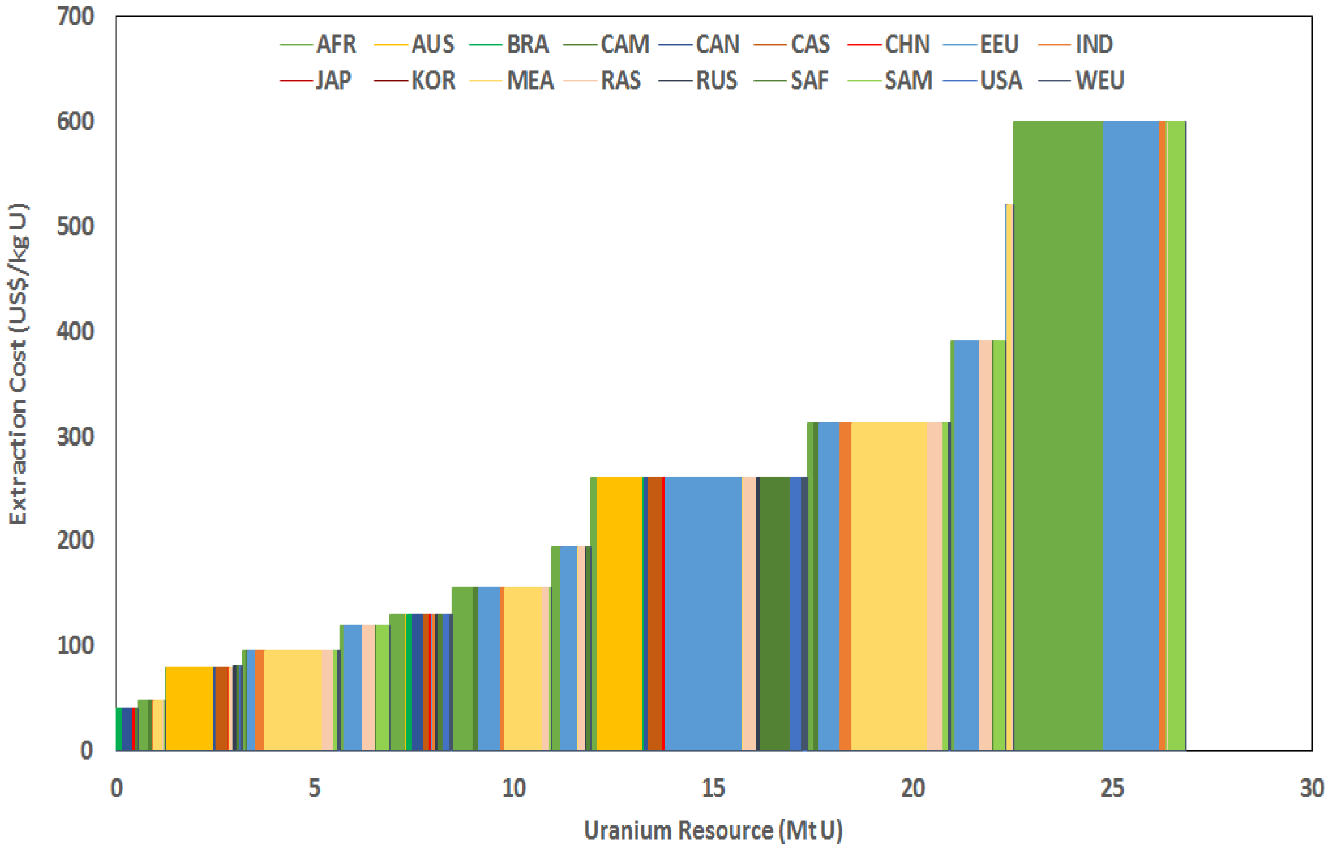
Source: IEA, 2014



Source: MCGLADE, 2013

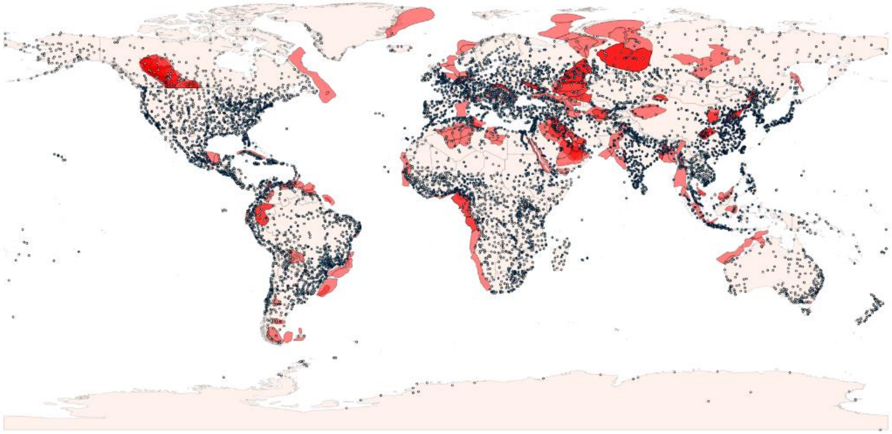


Production Cost (US$/MBTU)
URR of Natural Gas (T Nm³)
AFR
AUS
BRA
CAM
CAN
CAS
CHN
EEU
IND
JAP
KOR
MEA
RAS
RUS
SAF
SAM
USA
WEU
0
2
4
6
8
10
12
14
16
18
0
100
200
300
400
500
600
700
800

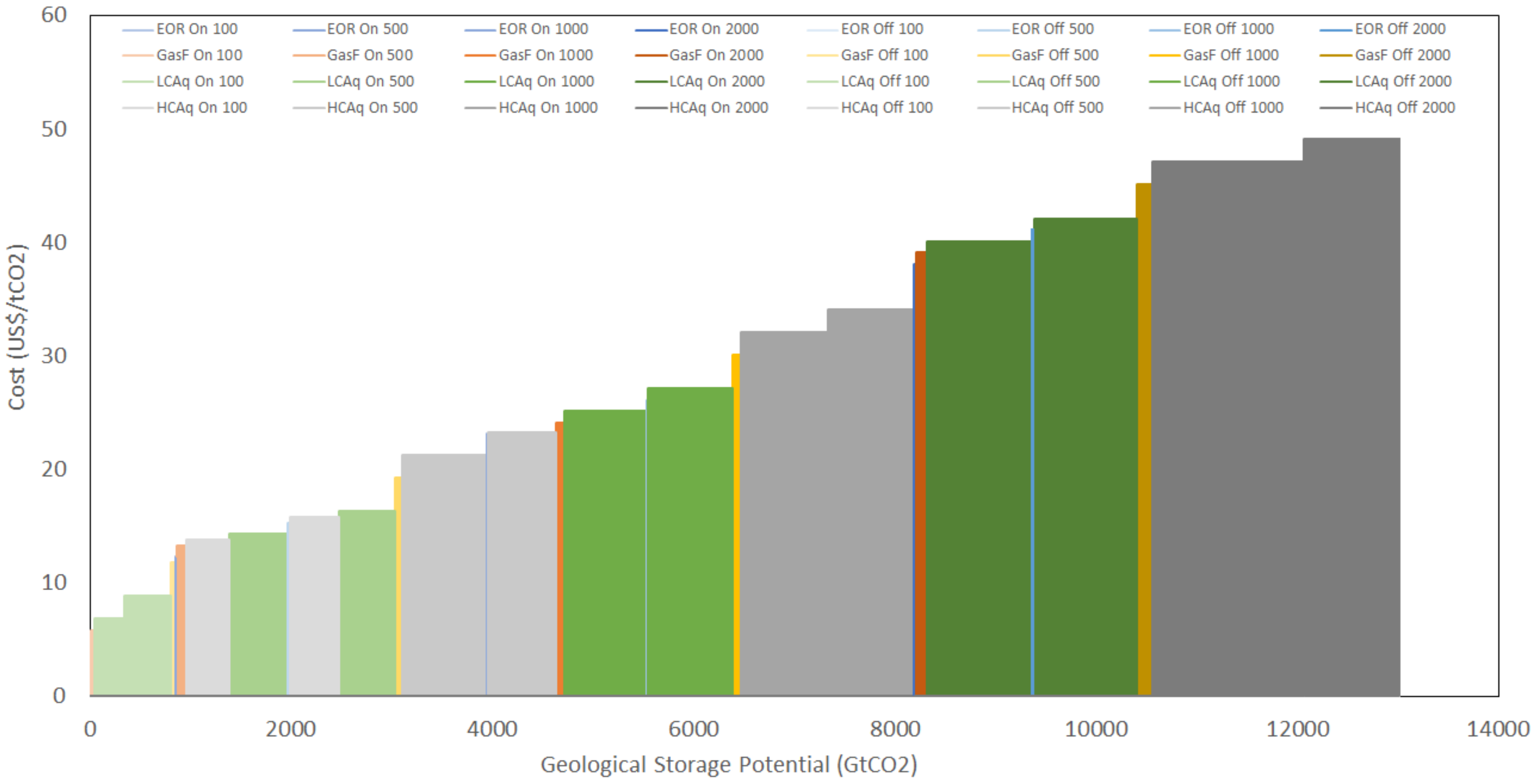


AFR
AUS
BRA
CAM
CAN
CAS
CHN
EEU
IND
JAP
KOR
MEA
RAS
RUS
SAF
SAM
USA
WEU
Extraction Cost (US$/kg U)
Uranium Resource (Mt U)
0
100
200
300
400
500
600
700
0
5
10
15
20
25
30

- Carbon transport and storage (really new)
  - Original approach for an IAM
  - Storage potential by region, with a differentiation by:
    - Type of reservoir: oil fields (EOR), gas fields and aquifers (2 types)
      - Injection costs
    - Distance
      - Transport costs
  - Literature revision for factors and potential estimates
  - Assessment with the use of GIS tools



- Carbon transport and storage



: Oil refining

– Existing capacity: yields and energy consumption given by the CAESAR model

Parameter		AFR			AUS			BRA			CAM			CAN			CAS		
Type of Run		Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene
Output (%)	RefGas	0.9	0.9	0.9	1.9	1.8	1.7	1.9	1.9	1.9	2.1	2.1	2.1	1.7	1.7	1.6	1.4	1.4	1.4
	LPG	1.4	1.2	1.4	3.8	3.7	3.7	5.4	5.2	5.4	3.7	3.7	3.7	3.0	2.9	2.9	2.5	2.3	2.5
	Naphtha	18.7	16.9	14.8	26.2	24.3	23.0	30.9	29.1	27.0	26.6	24.4	22.7	25.1	22.9	21.6	20.3	18.5	16.4
	Gasoil	44.0	48.5	48.5	50.9	55.4	52.8	42.8	47.3	47.3	43.9	48.4	48.4	54.5	59.0	59.0	43.5	48.0	48.0
	Coke	0.5	0.5	0.5	0.7	0.7	0.7	2.5	2.5	2.5	3.0	3.0	3.0	1.2	1.2	1.2	2.1	2.1	2.1
	Heavy	30.6	30.6	30.6	16.1	16.1	16.1	25.6	25.6	25.6	36.1	36.1	36.1	14.3	14.3	14.3	26.3	26.3	26.3
Utilities (%)	H2	1.3	1.3	1.4	4.9	4.9	5.1	0.6	0.6	0.7	1.3	1.3	1.5	6.7	6.7	7.1	1.1	1.1	1.5
	Steam	0.5	0.5	0.5	0.6	0.6	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.7	0.7	0.7	0.4	0.4	0.4
	Heat	4.3	4.3	4.3	6.7	6.4	6.3	4.6	4.6	4.7	5.7	5.7	5.8	6.4	6.4	6.3	4.8	4.8	5.0
	FCC Coke	0.2	0.2	0.2	1.2	1.2	1.2	1.7	1.7	1.7	1.1	1.1	1.1	0.8	0.8	0.8	0.5	0.5	0.5
	Elect	0.2	0.2	0.2	0.4	0.4	0.4	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.2	0.2	0.2

Parameter		CHN			EEU			IND			JPN			KOR			MEA		
Type of Run		Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene
Output (%)	RefGas	0.9	0.9	0.9	1.7	1.7	1.7	1.1	1.1	1.1	2.1	2.1	2.0	0.9	0.9	0.9	0.8	0.8	0.8
	LPG	2.5	2.3	2.5	3.3	3.3	3.3	2.6	2.6	2.6	4.2	4.2	4.2	2.1	1.9	2.1	1.8	1.6	1.8
	Naphtha	23.0	21.2	19.1	26.5	24.3	22.6	26.3	24.1	22.5	27.7	25.4	24.1	23.9	21.9	20.0	21.2	19.4	17.3
	Gasoil	46.8	51.2	51.2	55.0	59.5	59.5	45.1	49.5	49.6	50.5	58.6	54.1	53.6	58.1	58.1	50.0	54.5	54.5
	Coke	0.9	0.9	0.9	1.2	1.2	1.2	1.5	1.5	1.5	1.5	1.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5
	Heavy	22.2	22.2	22.2	21.2	21.2	21.2	21.2	21.2	21.2	16.1	16.1	16.1	17.7	17.7	17.7	22.6	22.6	22.6
Utilities (%)	H2	2.2	2.2	2.4	6.3	6.3	6.7	2.1	2.1	2.1	6.6	6.6	7.6	6.7	6.7	7.4	4.8	4.8	5.0
	Steam	0.6	0.6	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.6	0.6	0.7
	Heat	3.7	3.7	3.8	6.3	6.3	6.5	3.6	3.6	3.7	7.4	7.4	7.8	4.9	4.9	5.2	4.2	4.2	4.4
	FCC Coke	0.6	0.6	0.6	1.0	1.0	1.0	0.8	0.8	0.8	1.3	1.3	1.3	0.5	0.5	0.5	0.3	0.3	0.3
	Elect	0.2	0.2	0.2	0.4	0.4	0.4	0.2	0.2	0.2	0.5	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.2

Parameter		RAS			RUS			SAF			SAM			USA			WEU		
Type of Run		Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene
Output (%)	RefGas	1.1	1.1	1.1	1.0	1.0	1.0	2.2	2.2	2.2	1.9	1.9	1.9	2.9	2.9	2.8	1.4	1.4	1.3
	LPG	2.3	2.1	2.3	2.1	1.9	2.1	4.5	4.4	4.5	4.0	4.0	4.0	5.0	4.9	4.9	2.8	2.6	2.8
	Naphtha	22.3	20.5	18.4	19.0	17.2	15.1	28.4	26.2	24.6	29.1	26.8	25.2	30.0	28.1	26.8	20.6	18.8	16.8
	Gasoil	50.9	55.3	55.3	43.0	47.5	47.5	45.3	49.8	49.8	45.8	50.3	50.3	48.8	53.2	53.3	44.6	49.1	49.1
	Coke	0.7	0.7	0.7	0.6	0.6	0.6	2.2	2.2	2.2	2.9	2.9	2.9	4.2	4.2	4.2	0.9	0.9	0.9
	Heavy	20.2	20.2	20.2	36.5	36.5	36.5	26.3	26.3	26.3	25.8	25.8	25.8	19.4	19.4	19.4	25.7	25.7	25.7
Utilities (%)	H2	4.6	4.6	4.8	0.8	0.8	1.9	2.1	2.1	2.5	2.0	2.0	2.0	4.2	4.2	4.3	1.7	1.7	2.6
	Steam	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
	Heat	4.8	4.8	4.9	4.4	4.4	4.9	6.2	6.2	6.4	5.2	5.2	5.2	7.1	7.0	6.7	5.0	5.0	5.4
	FCC Coke	0.5	0.5	0.5	0.4	0.4	0.4	1.4	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.4	0.6	0.6	0.6
	Elect	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.2	0.2	0.3

• Energy sector: Power sector

		AFR	AUS	BRA	CAM	CAN	CAS	CHN	EEU	IND	JPN	KOR	MEA	RAS	RUS	SAF	SAM	USA	WEU
Betuminous Coal	Sub-critical ST	8.0	25.1	4.9	4.9	27.1	17.8	50.3	134.1	260.4	6.3	28.0	4.8	45.5	10.4	46.6	7.1	246.1	24.6
Betuminous Coal	Super-critical ST	0.0	1.6	0.0	0.0	0.0	0.0	78.2	10.9	22.1	31.2	0.0	0.0	7.7	0.0	0.0	0.0	0.6	0.0
Betuminous Coal	Super-critical ST 2	0.0	1.7	0.0	0.0	0.0	0.0	73.0	6.2	18.5	4.8	0.0	0.0	0.0	1.3	0.0	0.0	5.1	0.0
Betuminous Coal	CHP Steam Turbine	0.0	0.0	0.0	0.0	0.0	0.0	3.9	16.5	0.0	0.0	0.0	0.0	0.6	21.1	0.0	0.0	0.2	1.8
Coal Syngas	IGCC	0.0	0.9	0.0	0.0	0.0	0.0	0.7	4.1	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.0	4.2	0.0
Sub-bituminous Coal	Sub-critical ST	0.0	2.5	0.0	0.0	7.2	0.0	0.0	8.3	5.1	0.0	0.0	0.0	24.8	2.2	0.0	1.2	148.7	1.4
Sub-bituminous Coal	Super-critical ST	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	2.3	0.0	0.0	0.0	0.0	2.7
Sub-bituminous Coal	Super-critical ST 2	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0
Sub-bituminous Coal	CHP Steam Turbine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.1	0.0
Lignite	Sub-critical ST	0.0	8.2	0.0	0.0	1.9	0.0	1.0	77.4	12.3	0.0	0.0	0.0	7.4	3.1	0.0	0.0	19.7	7.7
Lignite	Super-critical ST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Lignite	CHP Steam Turbine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	0.0
Diesel	Sub-critical ST	0.0	0.8	0.1	0.1	1.2	0.0	0.0	2.5	0.0	18.4	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.4
Diesel	Oil Engine	0.2	0.2	0.4	0.2	2.7	0.0	0.3	1.6	4.4	4.1	0.3	11.3	0.8	0.0	0.0	0.0	27.0	0.0
Diesel	CHP Steam Turbine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fuel Oil	Sub-critical ST	8.2	0.2	2.1	0.5	8.0	9.3	0.0	18.6	0.0	26.0	3.4	21.3	3.0	0.0	0.0	1.2	0.9	0.9
Fuel Oil	Oil Engine	5.7	0.2	0.2	14.9	1.1	3.4	0.0	6.0	1.2	16.0	1.3	18.7	4.2	0.0	0.0	0.1	51.3	0.0
Fuel Oil	CHP Steam Turbine	0.0	0.0	0.2	0.0	0.0	0.1	0.0	1.4	0.0	0.0	0.0	3.8	0.0	0.9	0.0	0.0	0.0	0.2
Petroleum Coke	Sub-critical ST	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0
Petroleum Coke	Gasification	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4	0.0	0.0	0.2	0.0	0.0	0.0	3.5	0.0
Natural Gas	OCGT	21.1	11.7	1.9	0.6	7.3	2.0	1.4	12.9	2.3	0.8	1.5	31.2	8.5	4.0	3.5	10.2	110.0	0.1
Natural Gas	CCGT	49.8	3.5	9.0	22.5	13.9	9.6	34.7	211.9	49.0	77.8	31.8	87.8	92.0	5.1	0.0	25.6	324.1	0.7
Natural Gas	Sub-critical ST	20.9	1.8	0.0	0.0	0.3	15.5	0.0	12.2	0.0	15.8	0.5	2.3	9.6	10.1	0.0	8.3	0.7	4.2
Natural Gas	CHP Gas Turbine	0.0	0.6	0.3	0.0	1.1	0.0	0.0	0.7	0.2	0.8	0.0	2.9	0.7	0.0	0.0	2.7	0.0	0.0
Natural Gas	CHP CCGT	0.0	0.1	2.2	0.0	3.8	0.0	1.2	21.0	0.2	22.2	1.0	12.9	2.7	13.6	0.0	0.0	2.9	1.3
Natural Gas	CHP Steam Turbine	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	51.3	0.0	0.0	0.0	4.6
Biomass	Sub-critical ST	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0
Biomass	CHP Steam Turbine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biomass	Gasification	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bagasse	Sub-critical ST	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bagasse	CHP Steam Turbine	0.0	0.0	6.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BioGas	OCGT	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0
Black Liquor	Sub-critical ST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0
Nuclear	All Tech.	0.0	0.0	2.0	1.4	45.6	1.8	35.7	146.9	9.1	24.5	21.3	1.0	0.0	10.0	3.8	1.4	3.2	27.7
Hydro	All Tech.	31.5	17.8	84.0	14.6	98.5	28.4	48.3	140.1	77.7	32.4	7.6	18.0	30.0	91.9	2.6	51.7	155.3	17.0
Wind	All Tech.	1.6	2.7	0.9	0.4	3.2	0.0	0.0	8.3	0.5	0.0	0.3	0.0	0.2	0.0	0.0	0.4	10.1	0.0
Geothermal	All Tech.	0.2	0.8	0.0	2.2	0.0	0.0	0.0	5.2	0.0	1.0	0.0	0.0	3.2	0.0	0.0	0.0	2.8	0.0
Solar	All Tech.	0.1	0.0	0.0	0.0	0.2	0.0	0.0	3.0	0.2	0.0	0.0	0.2	0.0	0.0	0.1	0.0	4.1	0.0

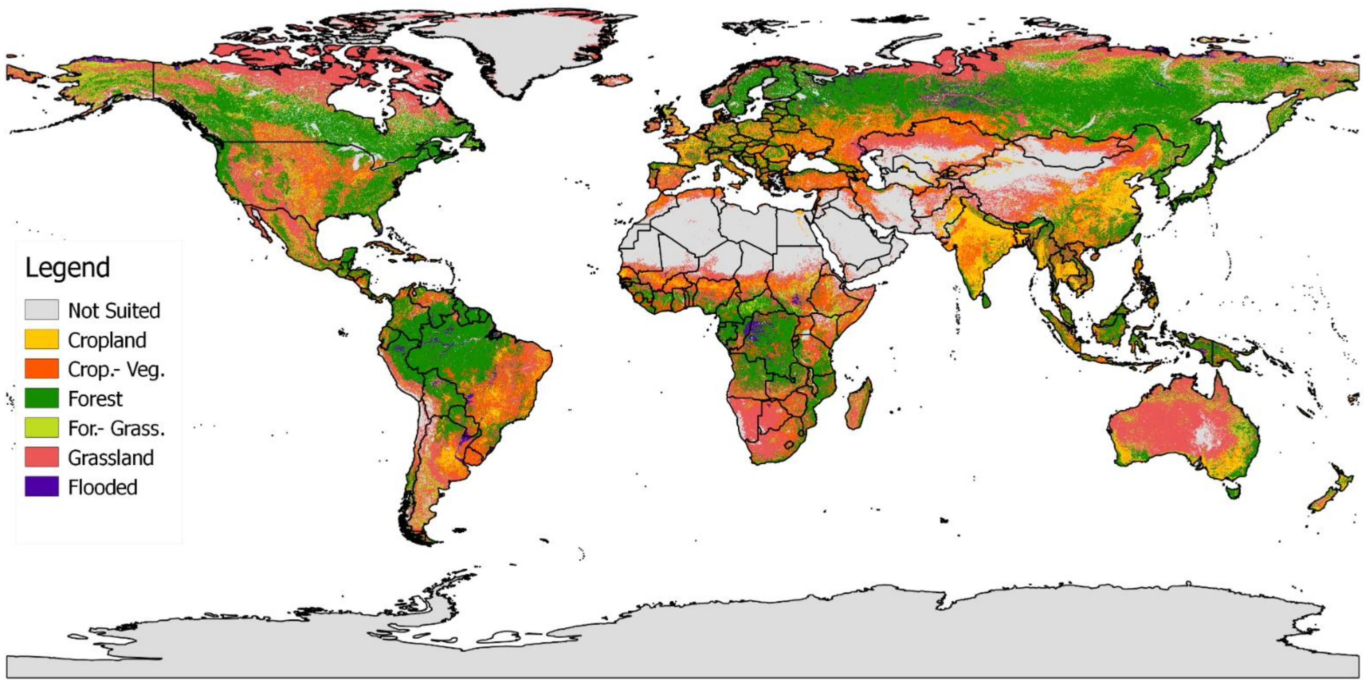
- Energy sector: Other fuels
  - Nuclear fuels
    - 8 types of fuels (reators) with different kinds/levels of enrichement
  - Hydrogen
    - Steam reform, CTH, BTH, electrolysis
  - Synthetic liquids (Fischer Tropsch)
    - Coal and biomass, with and without CCS
  - Biofuels (to be detailed later today)

- **End-use sectors**
  - Transport
  - Industry
  - Residential
  - Services (excluding Transport)
  - Residues
  - Agriculture

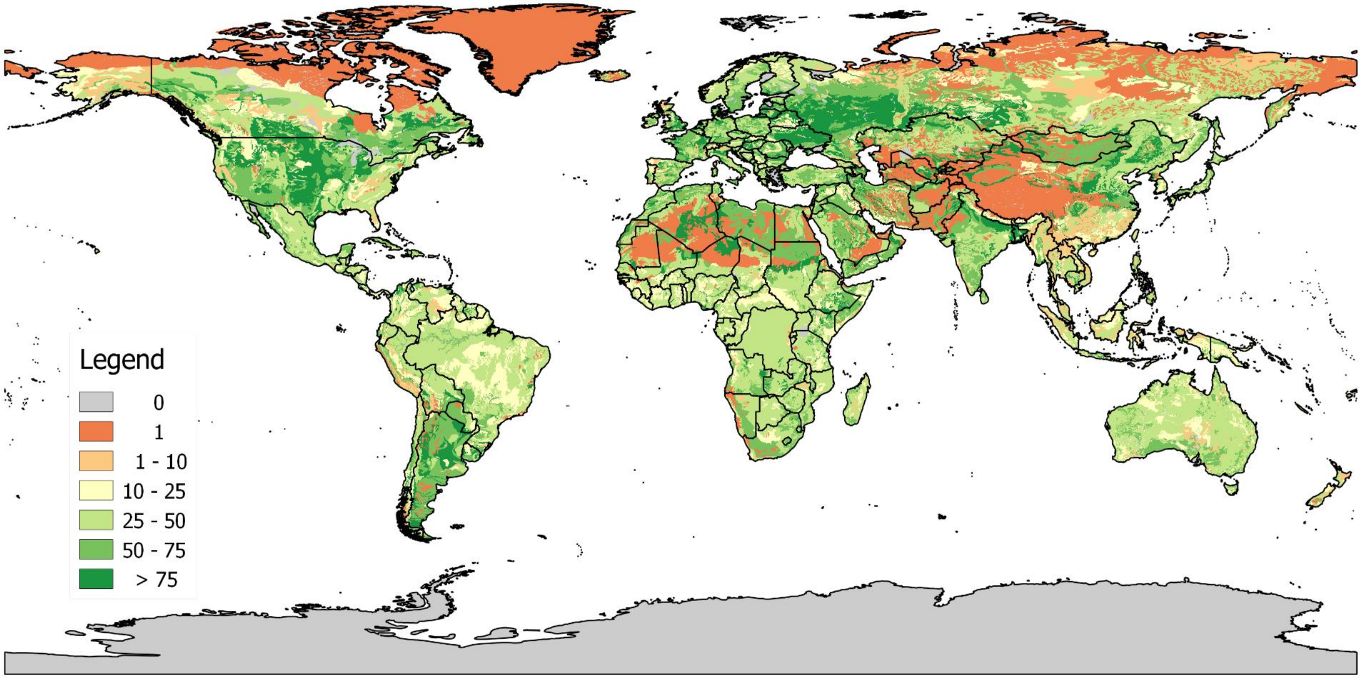
Land-use and Agriculture

Fonte: NATURE, 2016

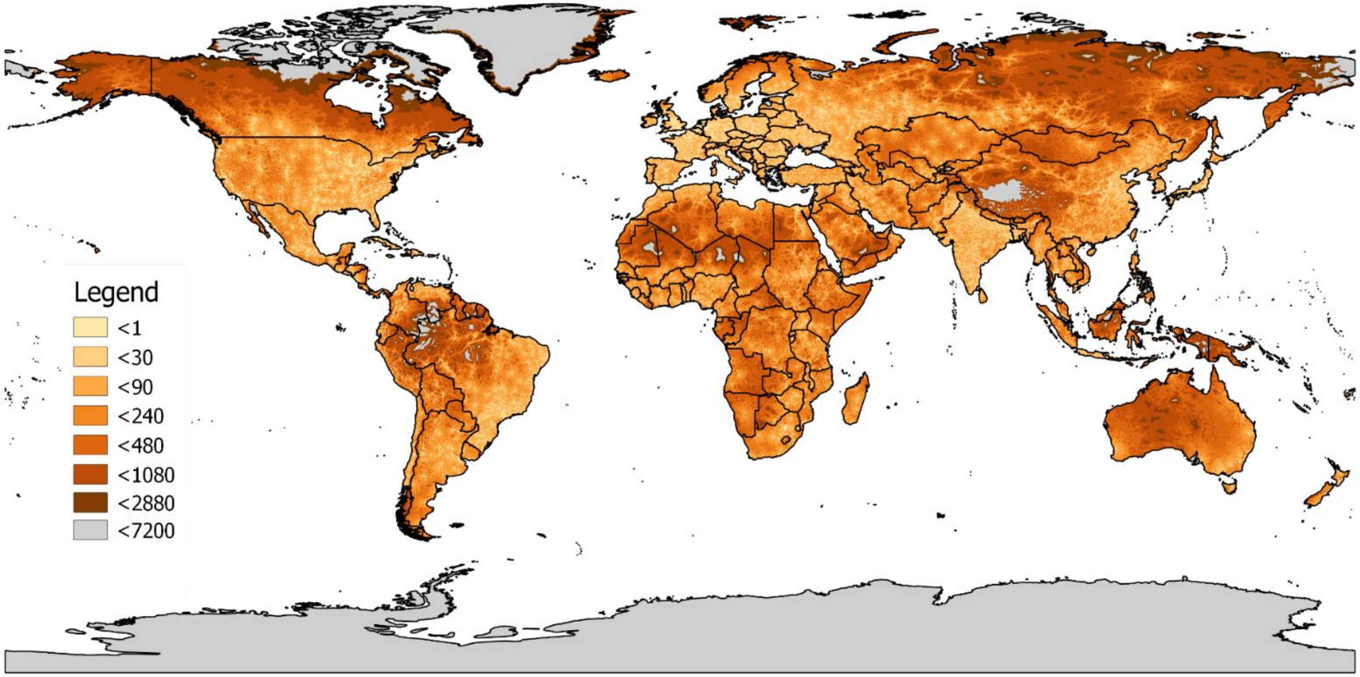
- Land cover
  - Biophysical surface cover
  - Deployment of 7 distinct categories
    - 2 non-suited: “Not Suited” and “Flooded”



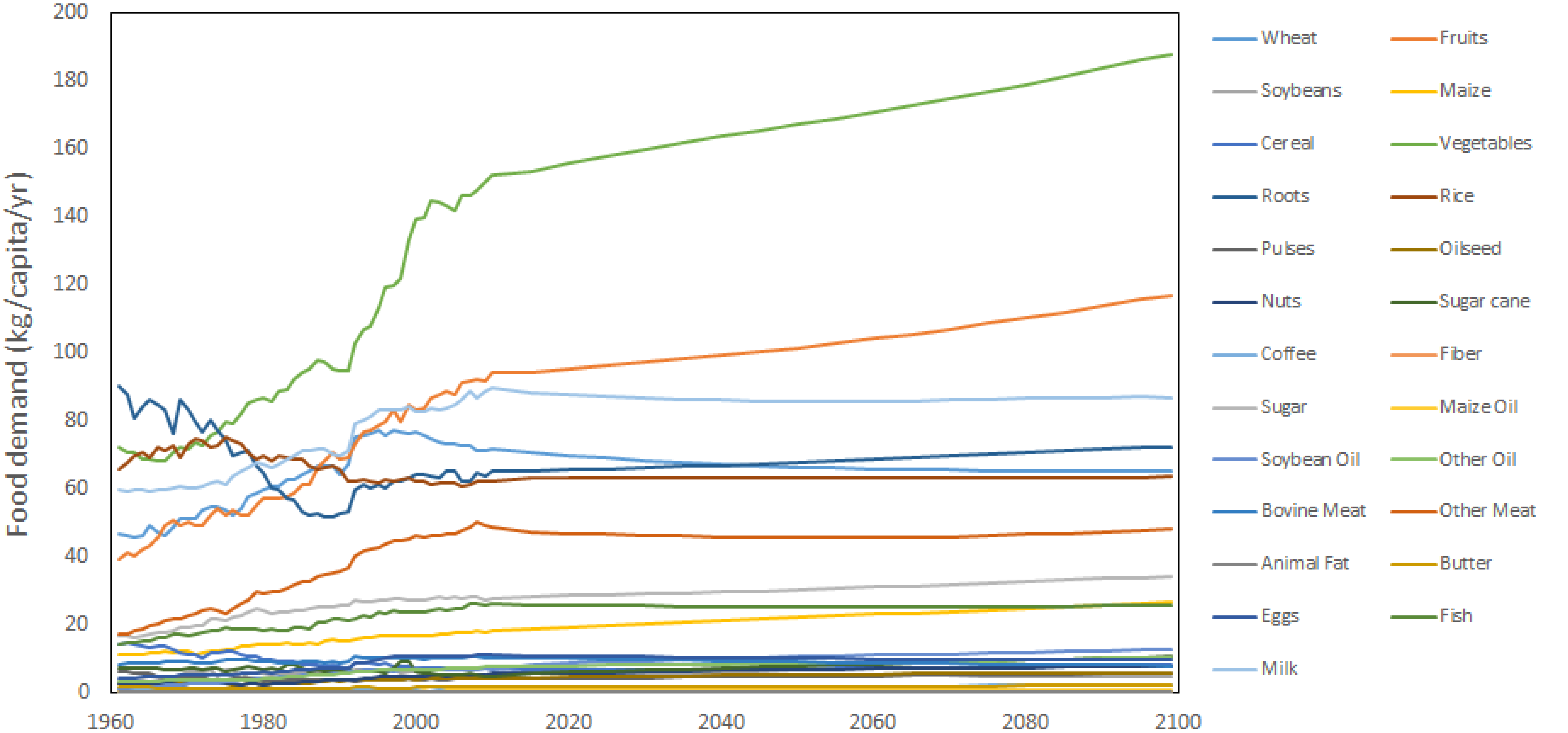
- Productivity
  - Simplification of agriculture productivity and land profitability
    - Productivity index
    - Limitations of this methodology (Ex: assessment of yields)



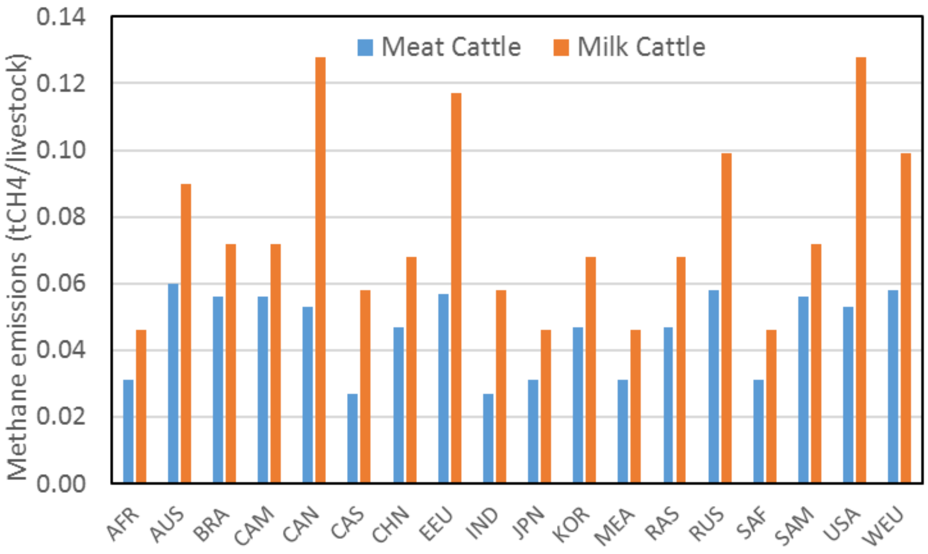
- Distance
  - Associated with profitability (transport cost)
  - Indirectly proportional to time of travel
    - Information available at level of detail required
    - Simplified methodology and similar to other global models



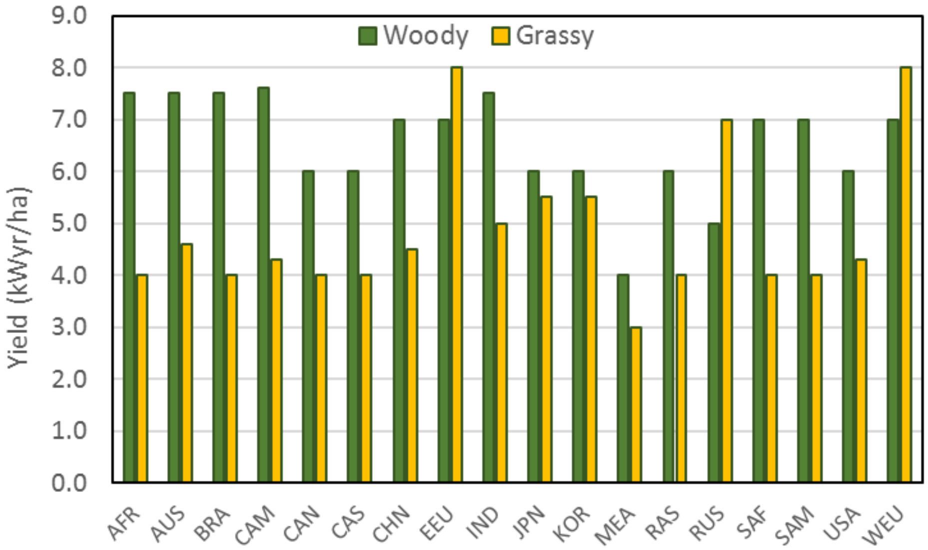
- Food and diet: global averages



- Animal husbandry:
  - Estimates from inventories (eg: cattle), animals per area, production and average yields
    - Ex: slaughter rate (# of slaughters per year), animals per area, yield (kg of meat per animal)
    - Very important also to estimate methane emissions
      - Enteric fermentation and animal wastes



- Bioenergy:
  - Woody and grassy biomass
    - Energy crops and deforestation
  - Oilseeds
  - Agricultural residues
    - Available potential



Region	Residues (EJ)		
	Theoretical	Ecological	Available
AFR	4.7	2.6	1.4
AUS	0.9	0.5	0.3
BRA	6.3	3.5	1.8
CAM	1.7	0.9	0.5
CAN	1.3	0.7	0.4
CAS	1.8	1.0	0.5
CHN	7.2	4.0	2.1
EEU	8.1	4.4	2.3
IND	5.9	3.2	1.7
JPN	0.1	0.1	0.0
KOR	0.0	0.0	0.0
MEA	0.8	0.4	0.2
RAS	7.9	4.4	2.3
RUS	1.4	0.8	0.4
SAF	0.3	0.2	0.1
SAM	3.4	1.9	1.0
USA	9.0	4.9	2.6
WEU	1.6	0.9	0.5
World	62.4	34.3	18.1

- Bioenergy:
  - Ethanol from 8 different sources
    - Including first- and second-generation ethanol
  - Methanol from biomass
  - Biodiesel from 4 different sources
    - Ethyl and methyl routes

Feedstock		Sugarcane	Corn	Wheat	Woody	Grassy	Beet	Bagasse	Residue*
Product		Ethanol	Ethanol	Ethanol	Ethanol	Ethanol	Ethanol	Ethanol	Ethanol
Yield	l/t_{feed}	85	375	390	340	265	100	155	155
Investment	$/kW	500	575	675	1700	1700	750	2800	2800
Fixed O&M	$/kW/yr	25	21	22	43	43	19	70	70

Feedstock		Woody	Soy Oil	Maize Oil	Animal Fat	Oilcrops**
Product		Methanol	Biodiesel	Biodiesel	Biodiesel	Biodiesel
Yield	l/t_{feed}	430	215	215	1000	230
Investmen	$/kW	1000	650	650	650	650
Fixed O&M	$/kW/yr	25	16	16	16	16

* Considering lignocellosic residue, such as straw.

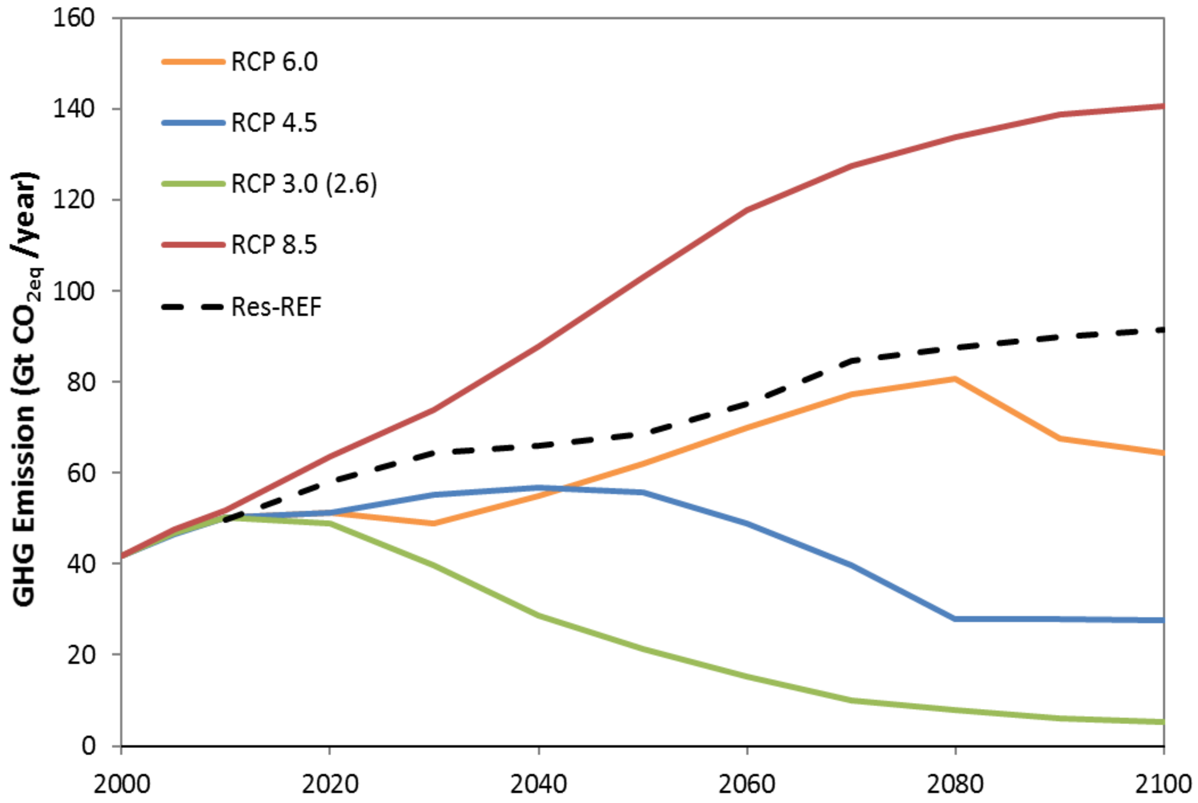
** The same efficiency and costs were used for several other oilcrops.

- **Some model statistics**
  - **26 levels and 507 forms**
  - **26 energy-service demands and 22 food demands**
  - **1623 mathematical restrictions**
    - **GHG emissions included (CO_2, CH_4 e N_2O)**
    - **Balance of land-use categories**
    - **Other restrictions and accounting (eg: BioCCS)**
  - **7120 technologies (per region)**
- **Scenarios protocol**

Scenario	Result Tag
Reference	Res-REF
RCP 8.5	Res-RCP85
RCP 6.0	Res-RCP60
RCP 4.5	Res-RCP45
RCP 2.6	Res-RCP26

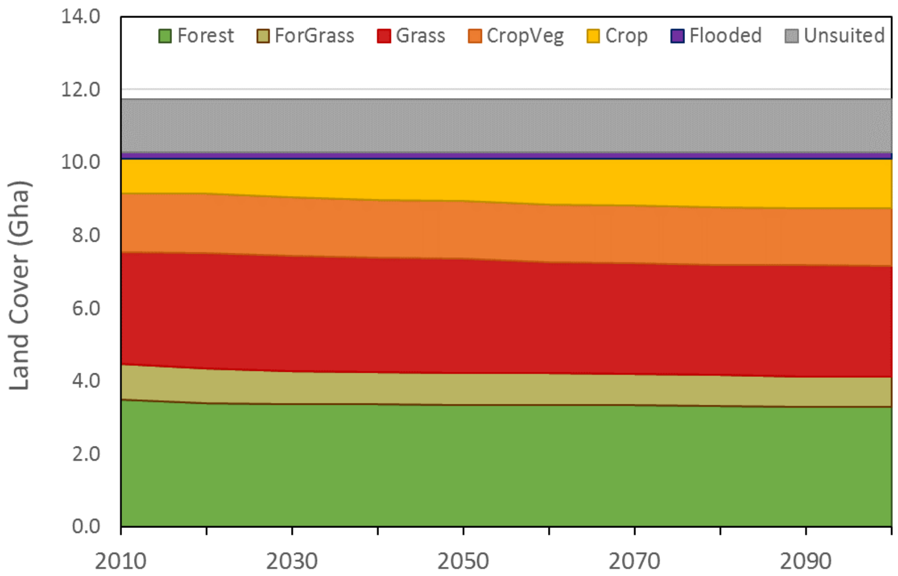
Few Results

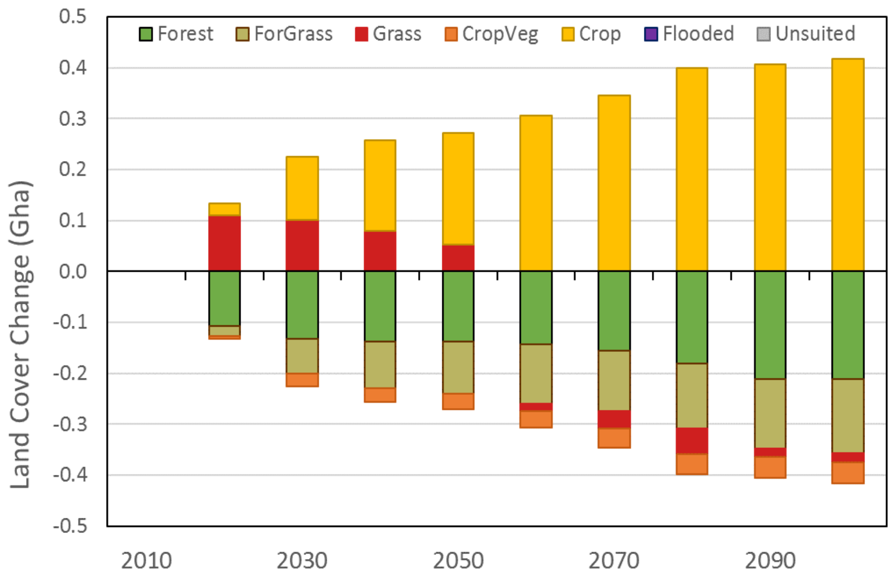
- GHG emissions: comparison with RCPs
  - Res-REF is below RCP8.5 → Non-compatibility between SSP2-RCP85



Few Results: Res-REF

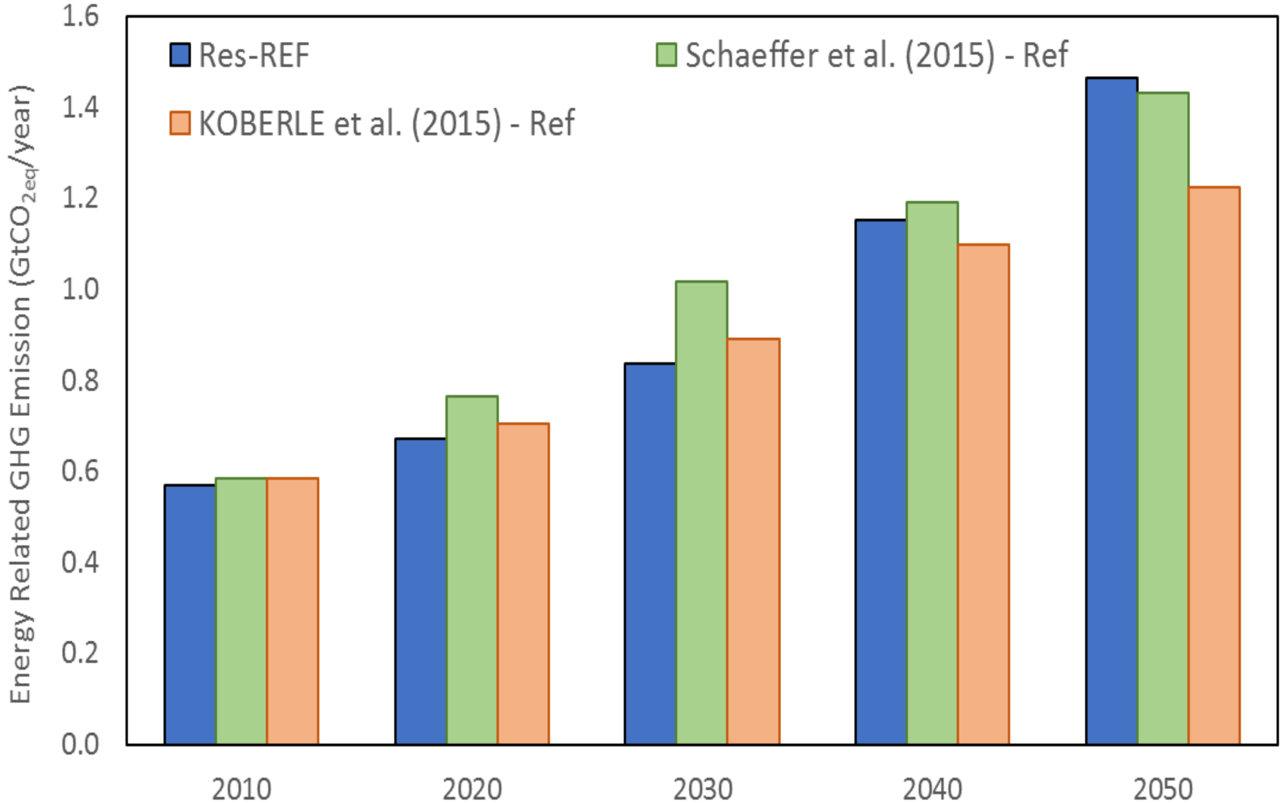
- Land-use
  - Cumulative change (2100-2010) of 0.4 Gha
    - 3% of global area
    - Some 0.21 Gha of forest deforestation and 0.15 Gha of transition to ForGrass
    - Most of the change associated with higher agricultural production





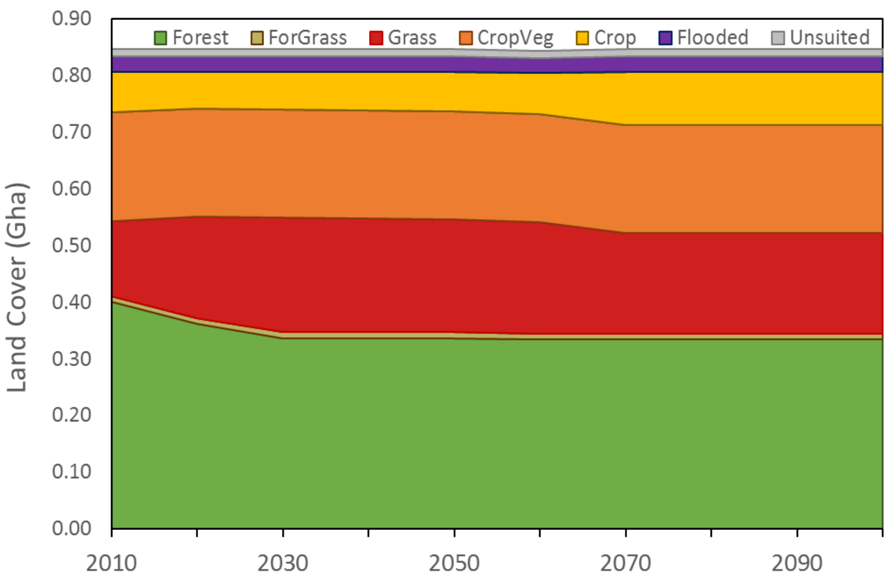
Few Results: Res-REF

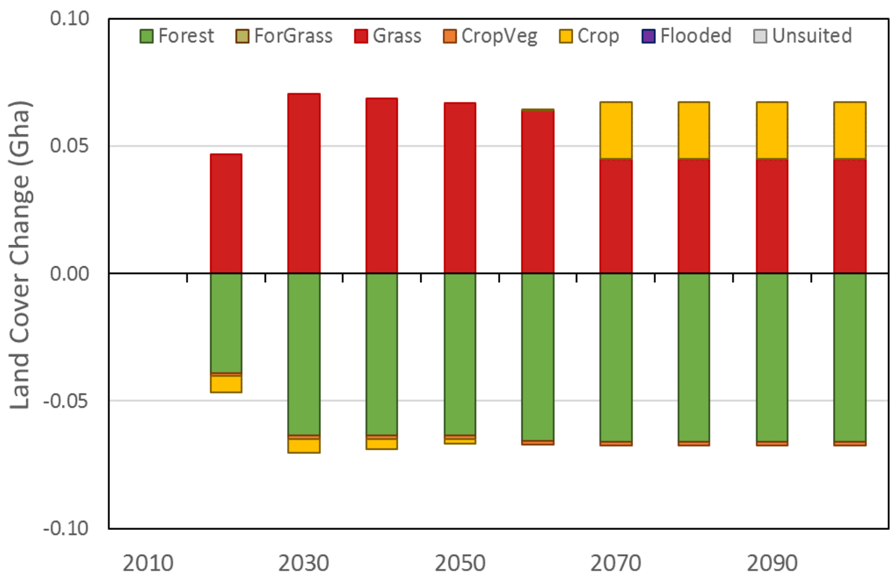
- Brazil – GHG emissions
  - Comparison with the literature



Few Results: Res-REF

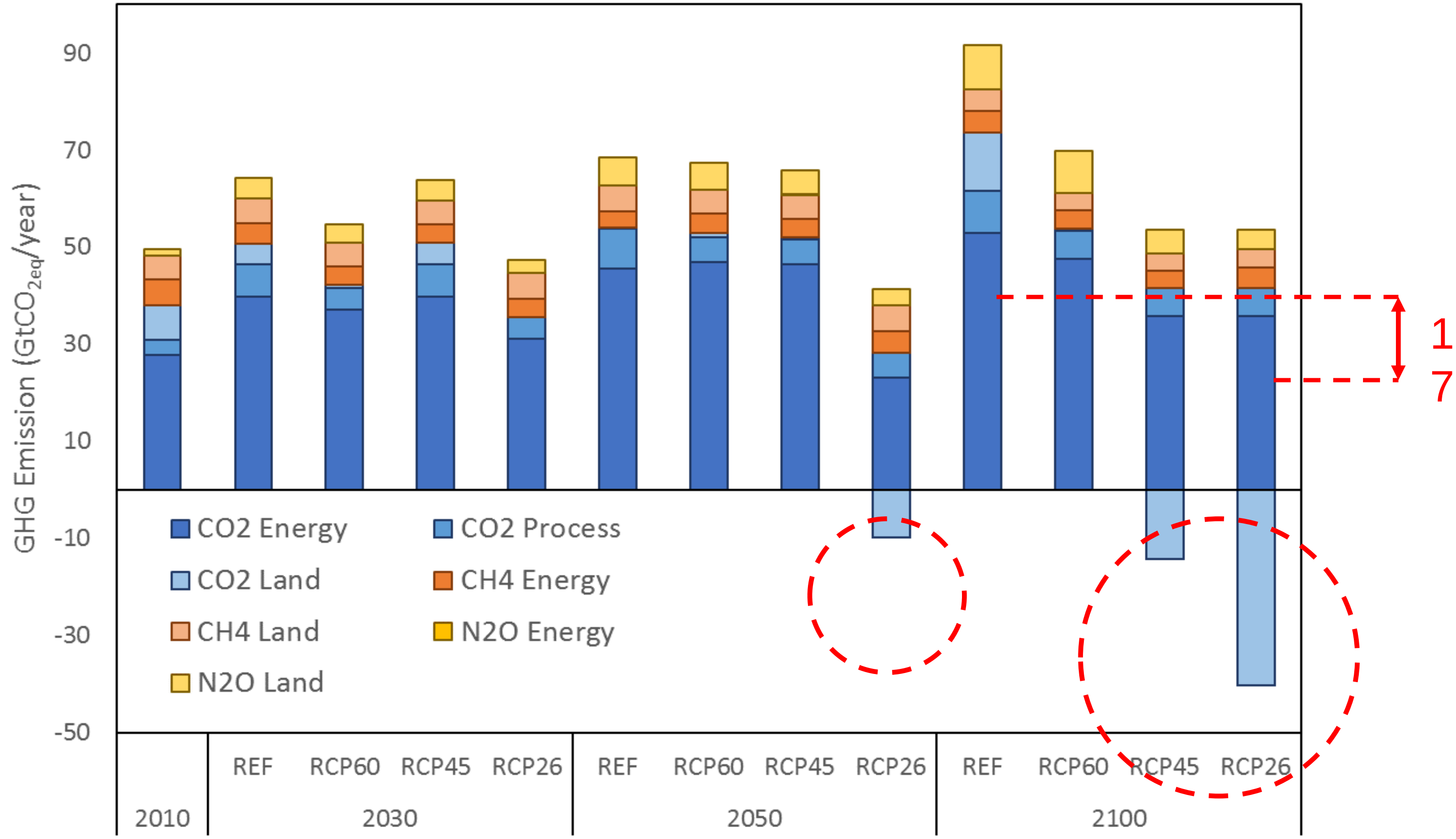
- Brazil – Land use
  - Cumulative change (2100-2010) of 0.07 Gha
    - Some 8% of the country´s area
    - Almost all conversion from forest land
    - Inital conversion from forest to pasture
    - Then from pasture into agricultural land starting in 2060





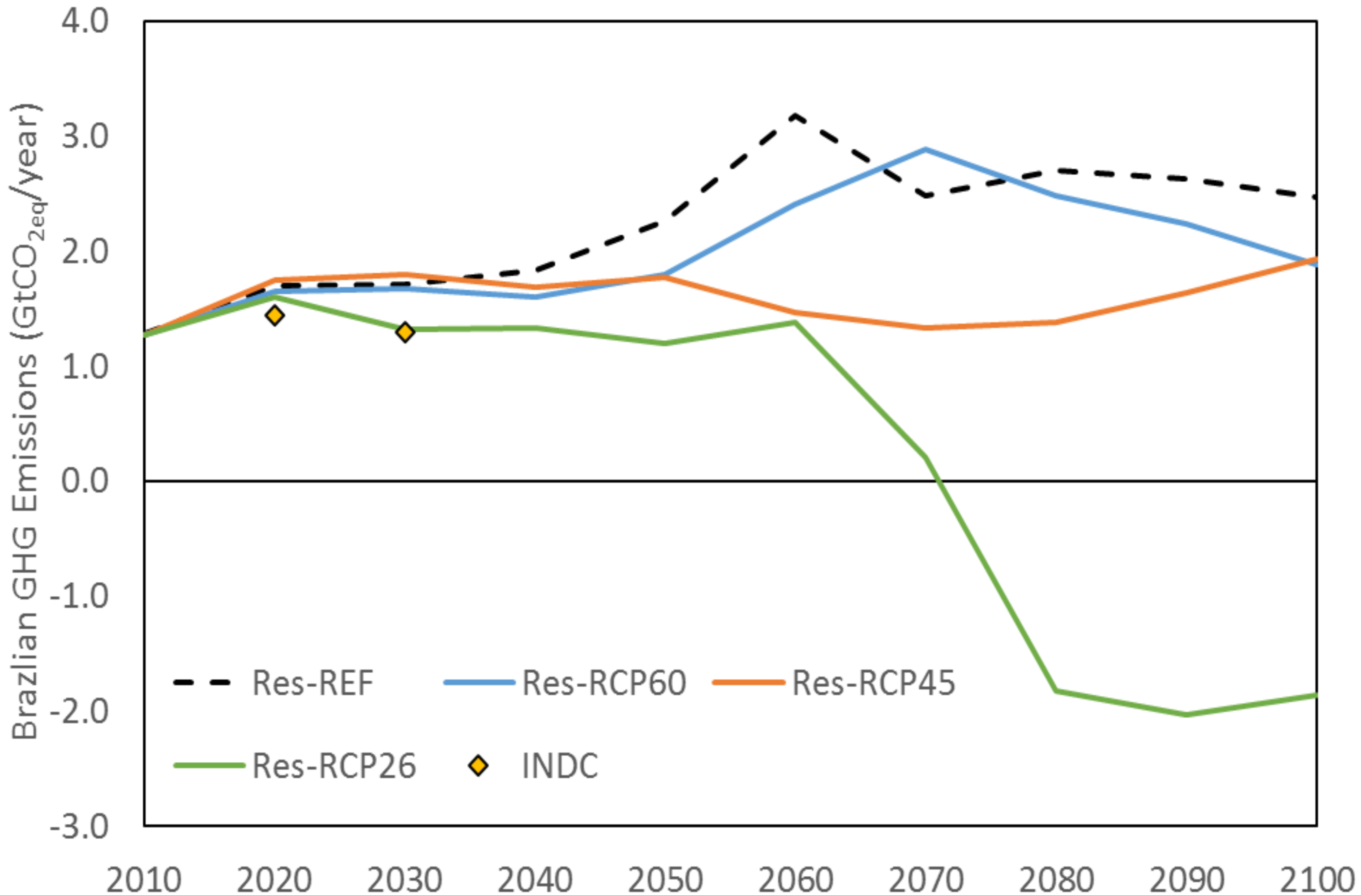
Few Results:

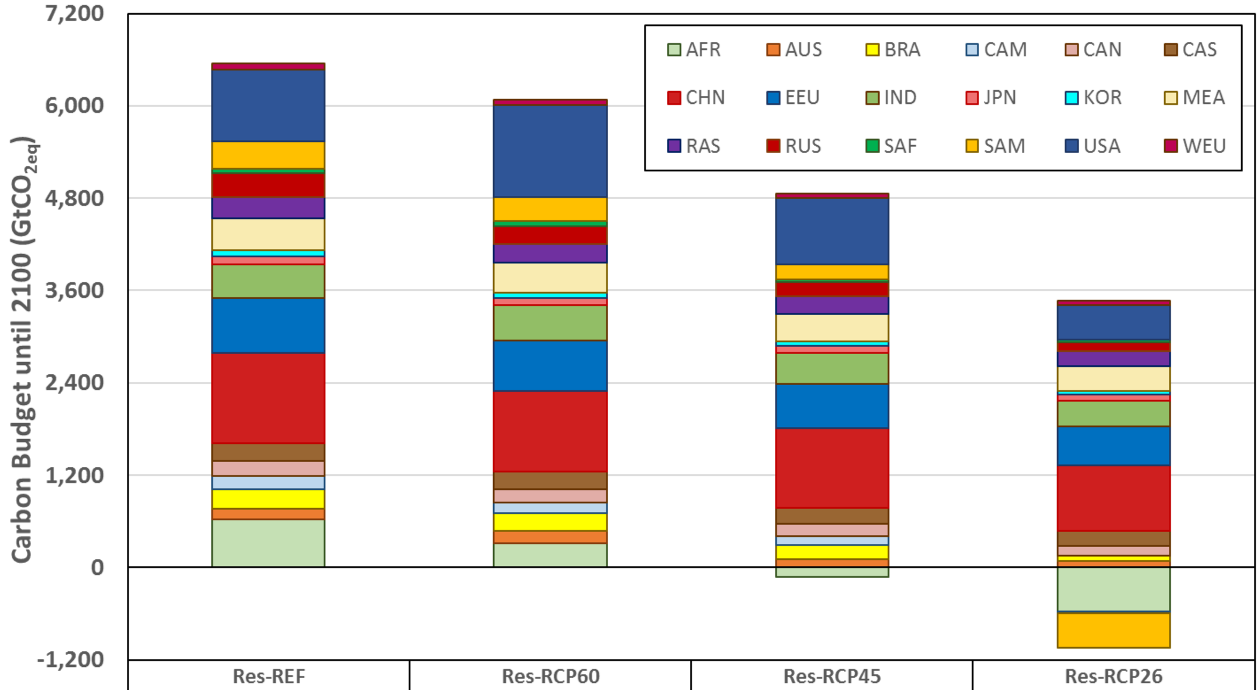
- GHG emissions



Few Results: Brazil

- GHG emissions: comparison with the Brazilian INDC





	Res-REF	Res-RCP60	Res-RCP45	Res-RCP26
WEU	84	71	63	57
USA	932	1188	856	456
SAM	356	320	195	-449
SAF	52	61	44	33
RUS	312	236	185	118
RAS	278	240	224	187
MEA	412	391	354	324
KOR	78	64	59	51
JPN	108	95	89	83
IND	439	466	410	328
EEU	710	651	575	508
CHN	1170	1049	1035	855
CAS	236	228	203	189
CAN	195	177	161	133
CAM	170	138	113	-20
BRA	250	225	191	65
AUS	140	157	105	83
AFR	629	319	-124	-569

What next?

- Incorporation of water nexus
- **How cost overruns** in energy megaprojects lead to suboptimal decisions in energy sector planning
- This is because our research is showing an increase in overnight construction costs (OCC) and lead time escalations for energy megaprojects over time

- Global Integrated energy Model (COFFEE) + Global CGE model (TEA): up to June 2017

- Incorporation of a simple Climate Model into COFFEE, so as to move from GHG emissions, to GHG concentration, radiative forcings and temperature increase: up to August 2018

- To be continued ...

Tks

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