

# Research in Integrated Energy Planning and Reflections on the Electrification of Transport Networks

Prof. Roberto Schaeffer

Symposium:

Electrification of Public Transport and Vehicle Depots in Brazil and Germany

Rio de Janeiro, 10<sup>th</sup> September 2025



# Part 1

## Introduction



@Cenergialab

<https://www.cenergialab.coppe.ufrj.br/>

**Who** we are



**Where**

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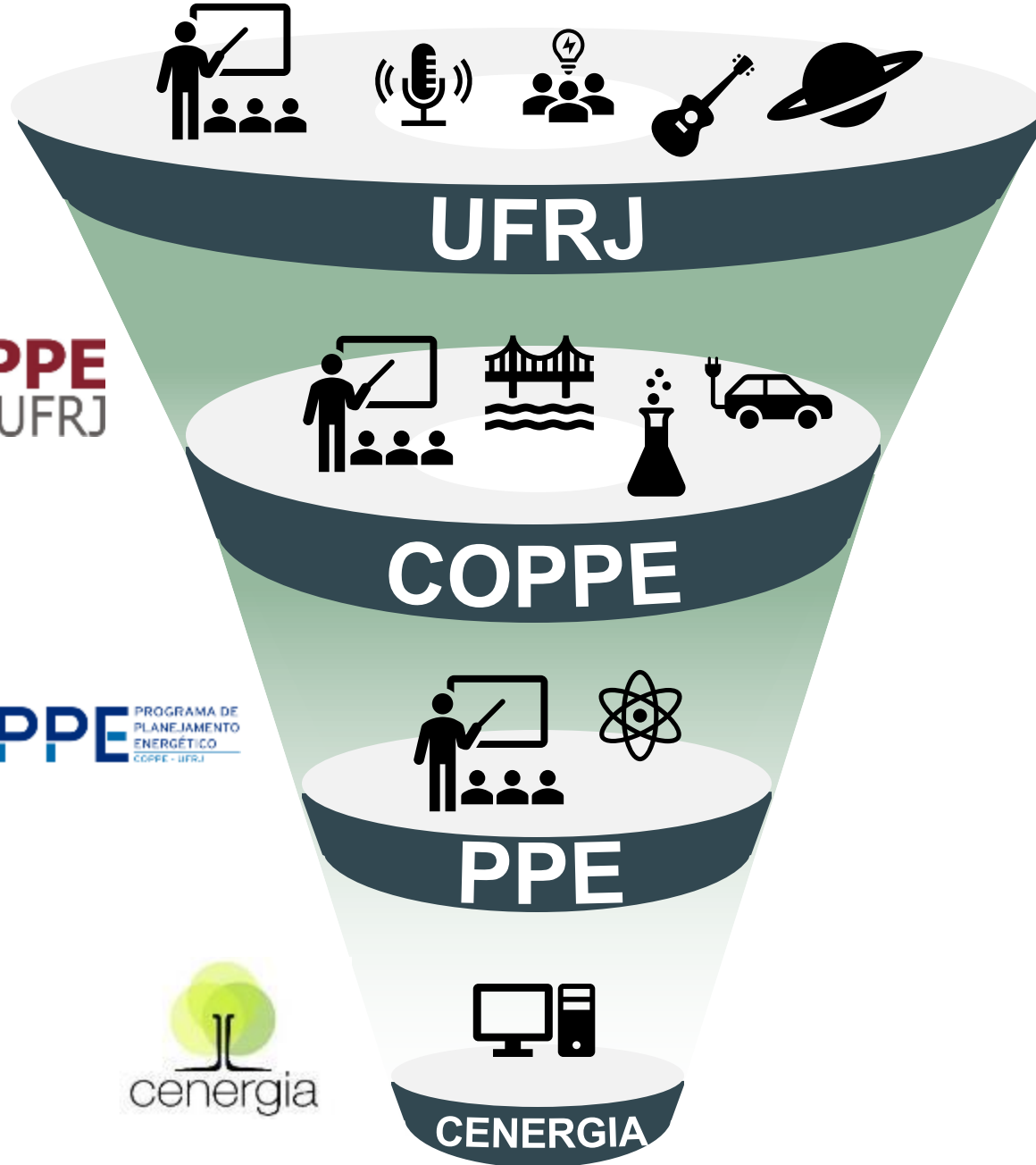
we are

**What**

---

we do

**CENERGIA**



**COPPE**  
UFRJ

**PPE** PROGRAMA DE PLANEJAMENTO ENERGÉTICO  
COPPE - UFRJ



**Where**  

---

**we are**

# Who

---

we are



**Professors**

**5**



**Pos-doc  
Researchers**

**8**



**PhD Students**

**14**



**MSc students**

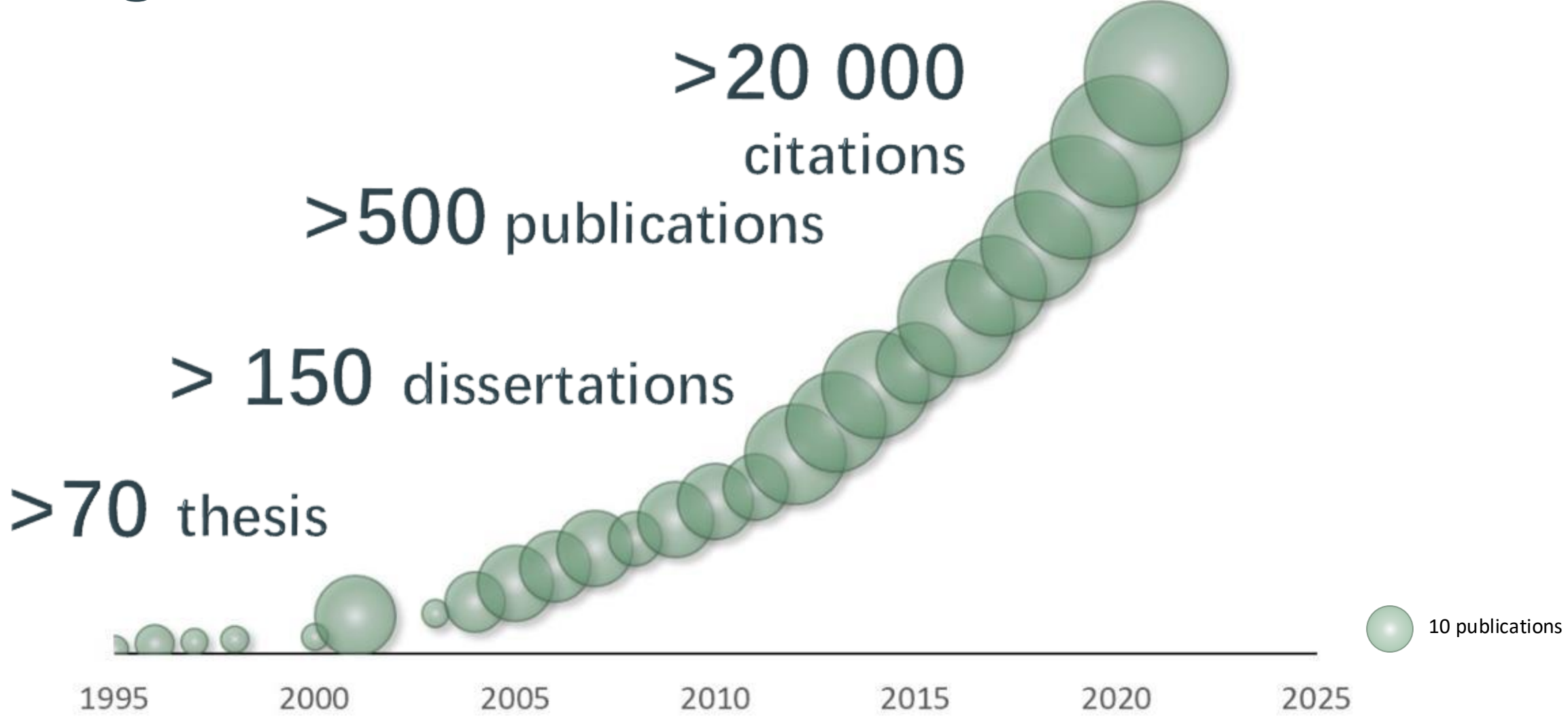
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**Meet the team:**

<https://www.cenergiab.coppe.ufrj.br/>

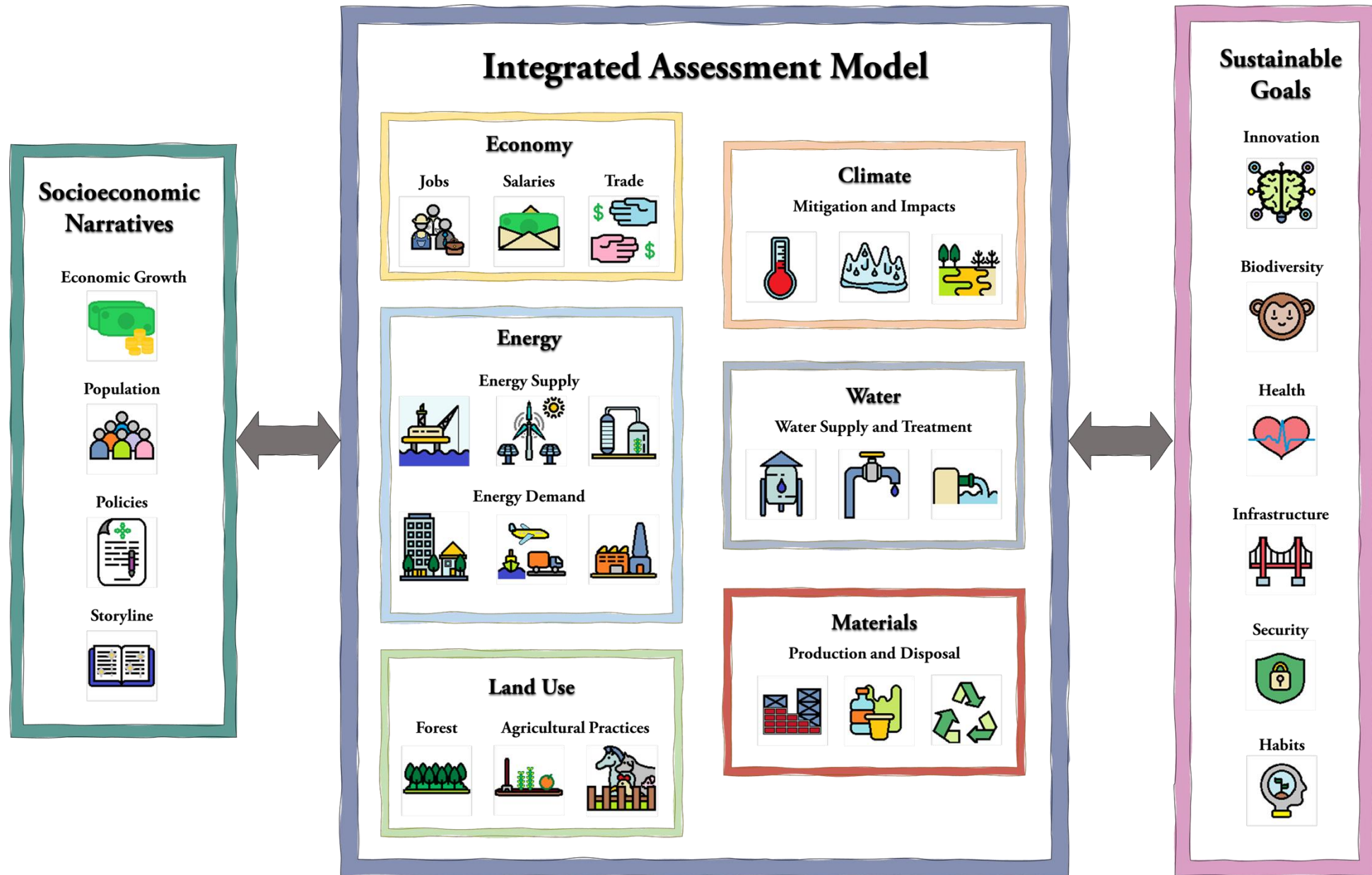
<https://twitter.com/CenergiaLab>

# Cenergia lab: our academic excellence\*



\* As of 09/2025

# IAMs



# What we do

## Renewables



**MESH**  
Concentrated Solar Energy

## Transportation



**HERMES**  
Mobility Model

## Power Sector



**STORM**  
Dispatch Model

## Global Economy



**TEA**  
Global CGE model

## Global Energy and Land-Use



**COFFEE**  
Global Bottom-up IAM

## National Energy and Land-Use



**BLUES**  
National bottom-up IAM

## Refinery



**CAESAR**  
Simulation

## Refinery

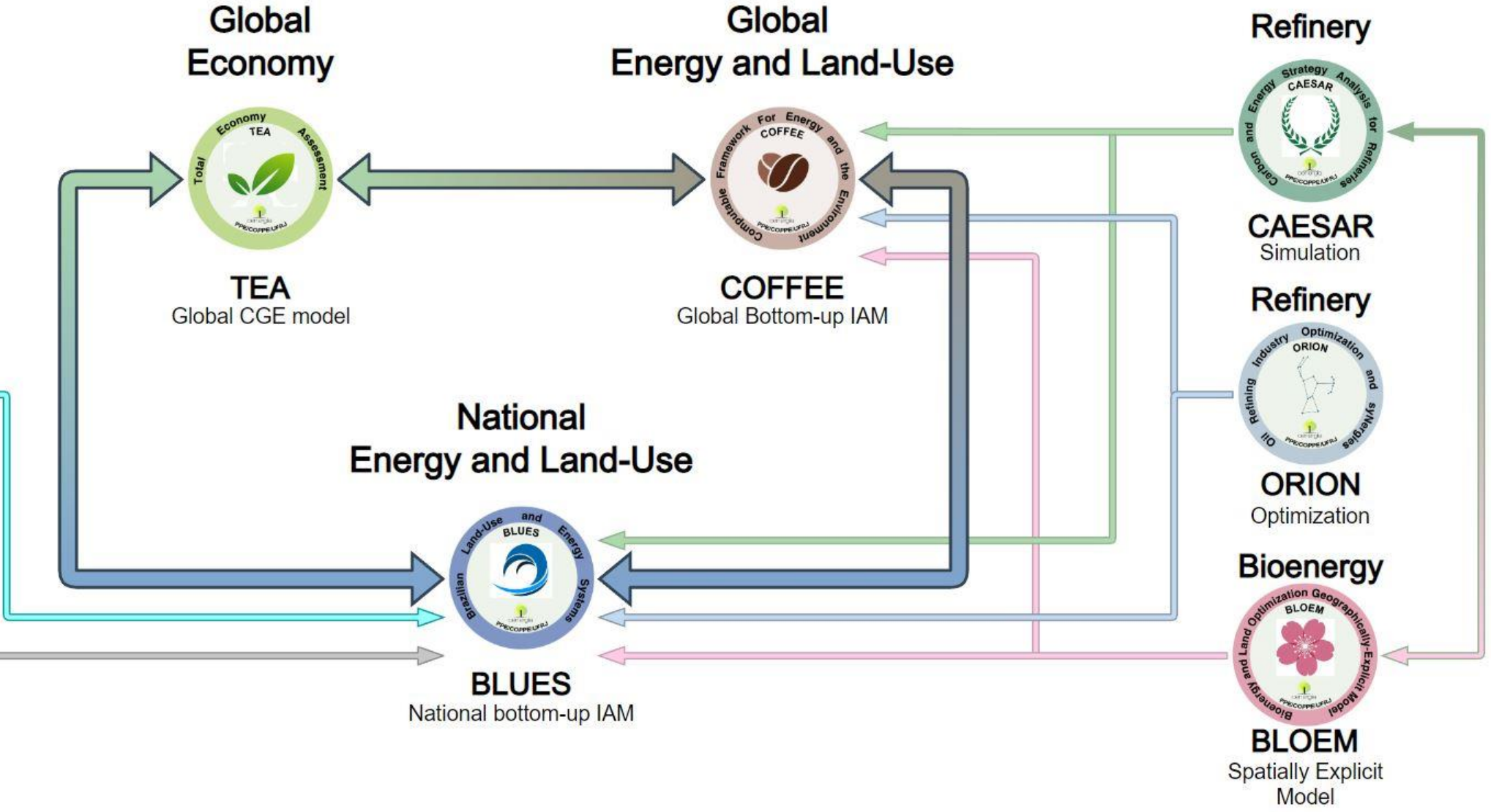


**ORION**  
Optimization

## Bioenergy



**BLOEM**  
Spatially Explicit Model



# Global IAMs (OECD and non-OECD)



# Part 2

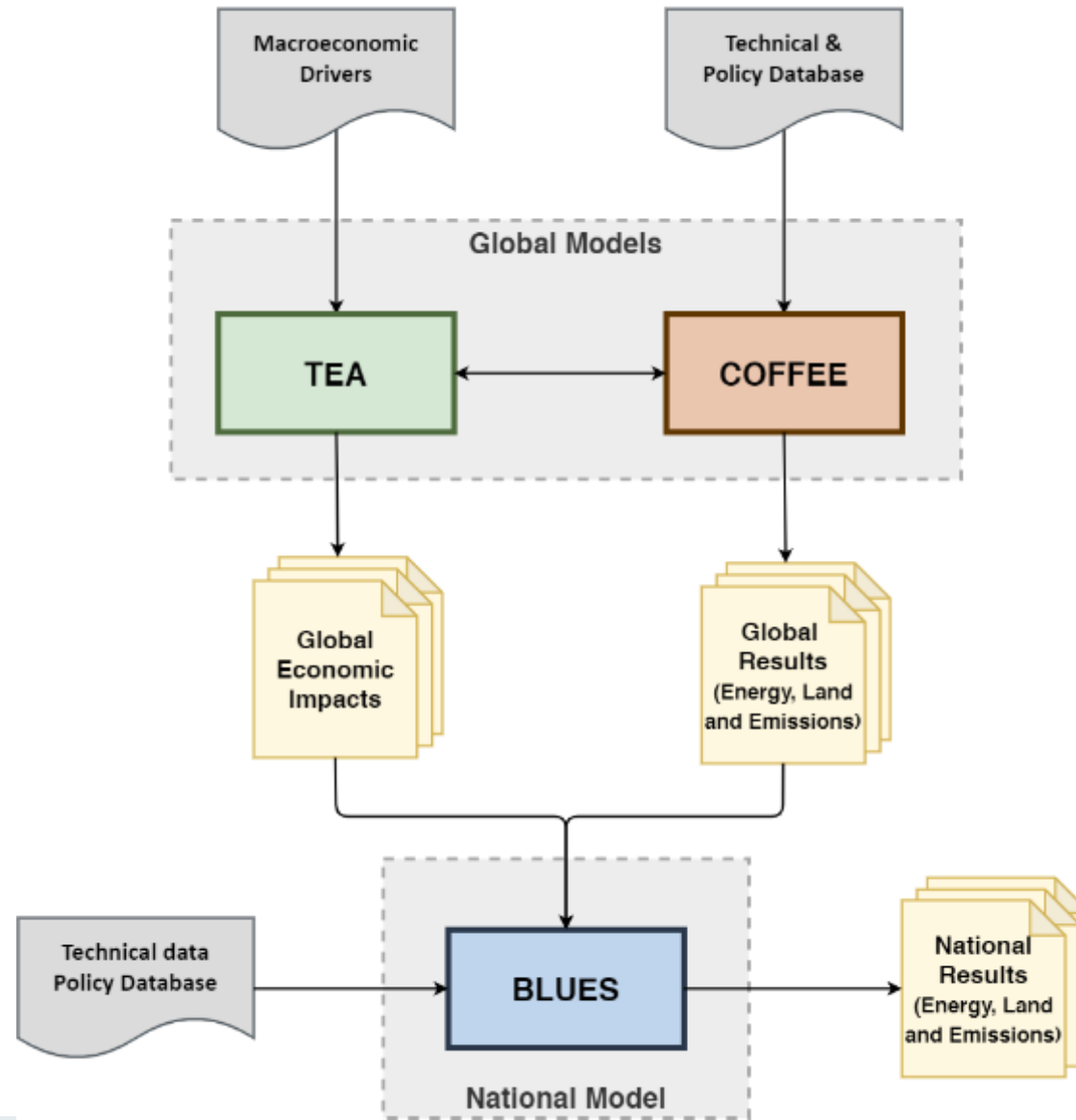
## Our Modelling Platforms: the IAMs



<https://www.iamcdocumentation.eu/index.php/>

<http://www.cenergialab.info/tools>

# Our Modelling Platforms



# Total-Economy Assessment (TEA) Model

Computational general equilibrium (CGE)

Reference: GTAP in GAMS

- Features:
  - Recursive dynamic: evolution of the global economy until 2100
  - Multi-regional: the same 18 COFFEE model's regions
  - Multi-sectorial: agriculture, energy, industry, transport and services represented in 16 sectors
  - Productive factors: labor, capital, land and resources
  - Full set of bilateral trades: transport costs, export taxes and tariffs
  - Energy sector representation: current and backstop techs

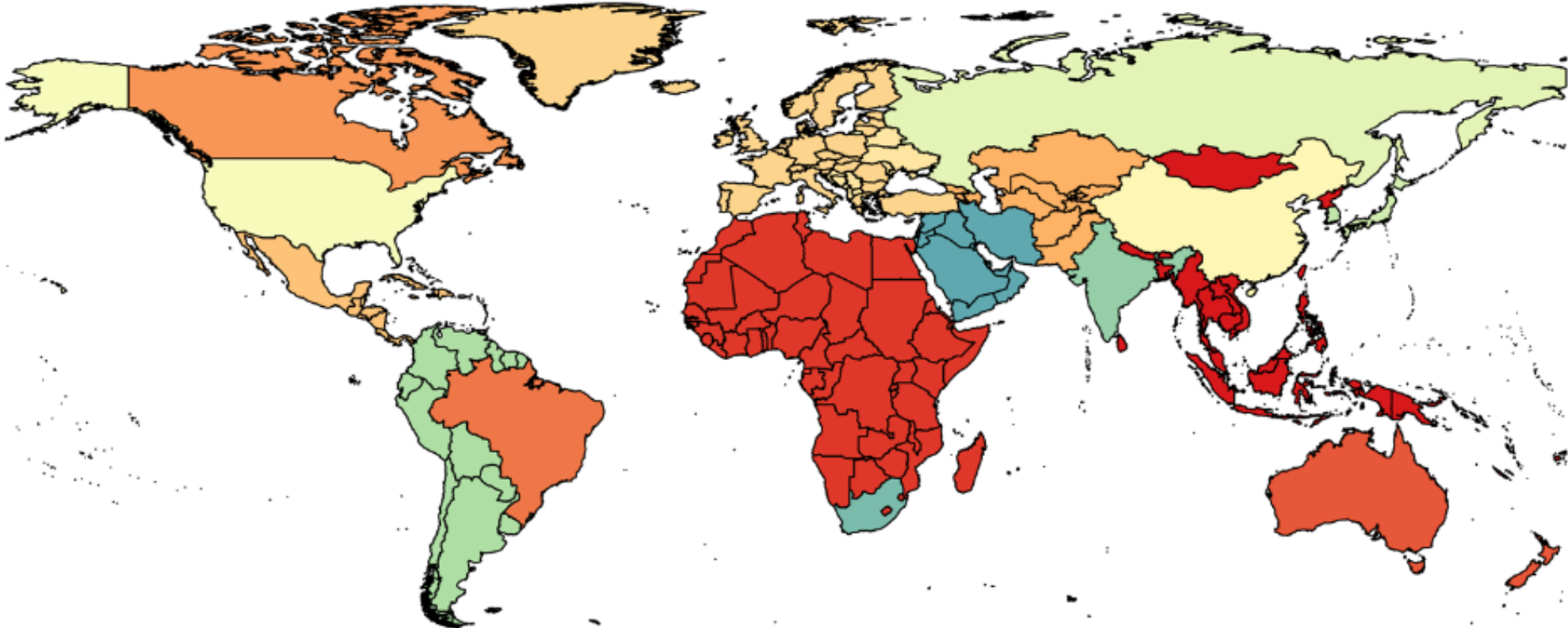


# COmputable Framework For Energy and the Environment (COFFEE) Model

- Global model with 18 regions
- Time horizon: 2010 to 2100
- Perfect foresight
- Bottom-up model
- Hard-link integration between land use, energy and materials
- Detailed representation of international maritime and aviation sectors

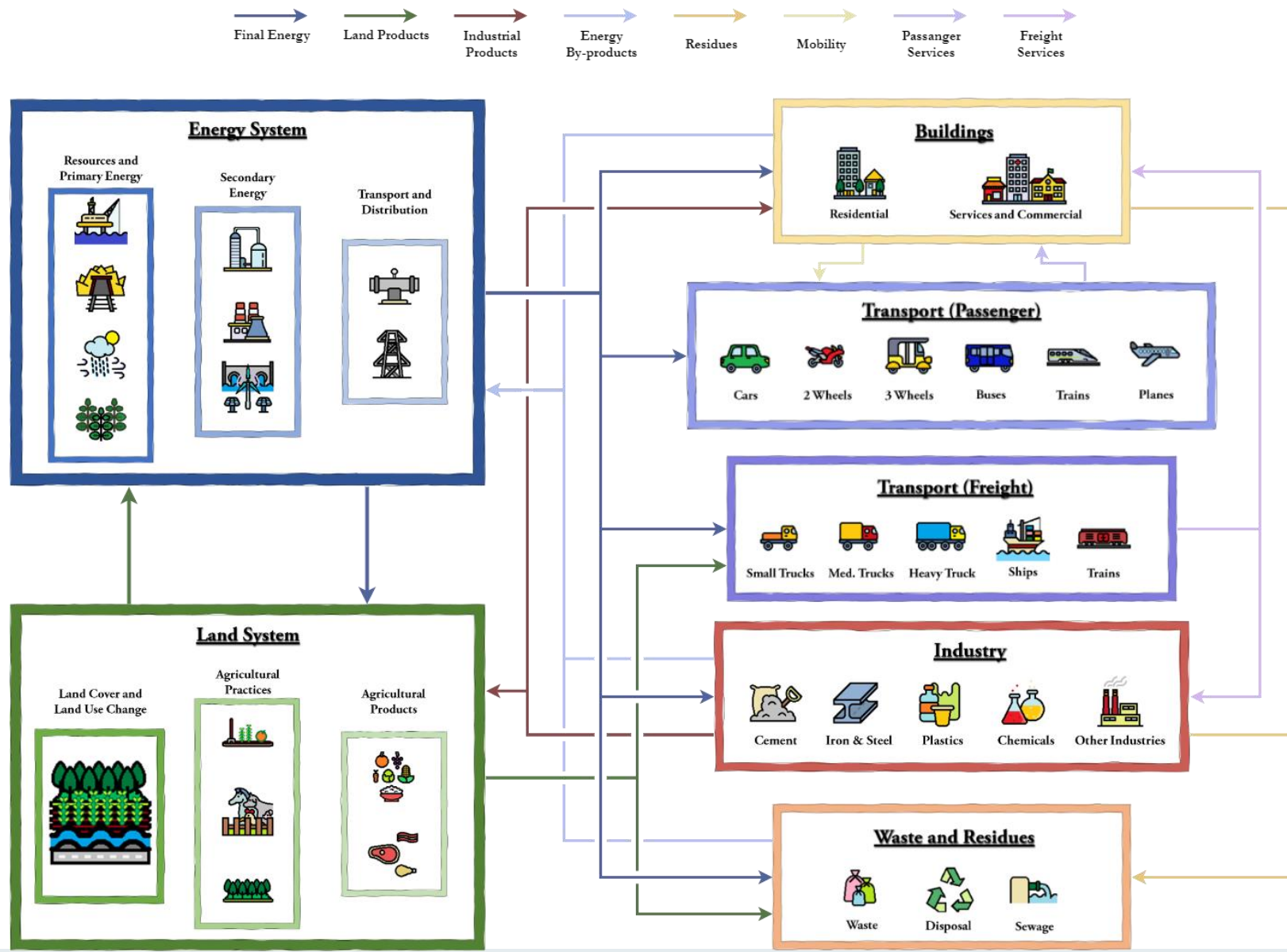


# The COFFEE Model: overview



- |   |  |  |
|---|--|--|
|  Africa                  |  China          |  Rest of Asia   |
|  Australia & New Zealand |  Eastern Europe |  Russia         |
|  Brazil                  |  India          |  South Africa   |
|  Central America         |  Japan          |  South America  |
|  Canada                  |  South Korea    |  United States  |
|  Caspian                 |  Middle East    |  Western Europe |

# The COFFEE Model: overview



# Brazilian Land Use and Energy System (BLUES) Model

- National model with 6 regions
- Time horizon: 2010 to 2060
- Perfect foresight
- Bottom-up model
- Demand-side is more technologically detailed (than COFFEE)
  - Specific technologies for Brazil
- Integration of the energy chain
- Hard-link integration between land use, energy and materials
- Environmental benefits (air pollution, water and biodiversity)



# Spatial-temporal resolution

Base year → 2010

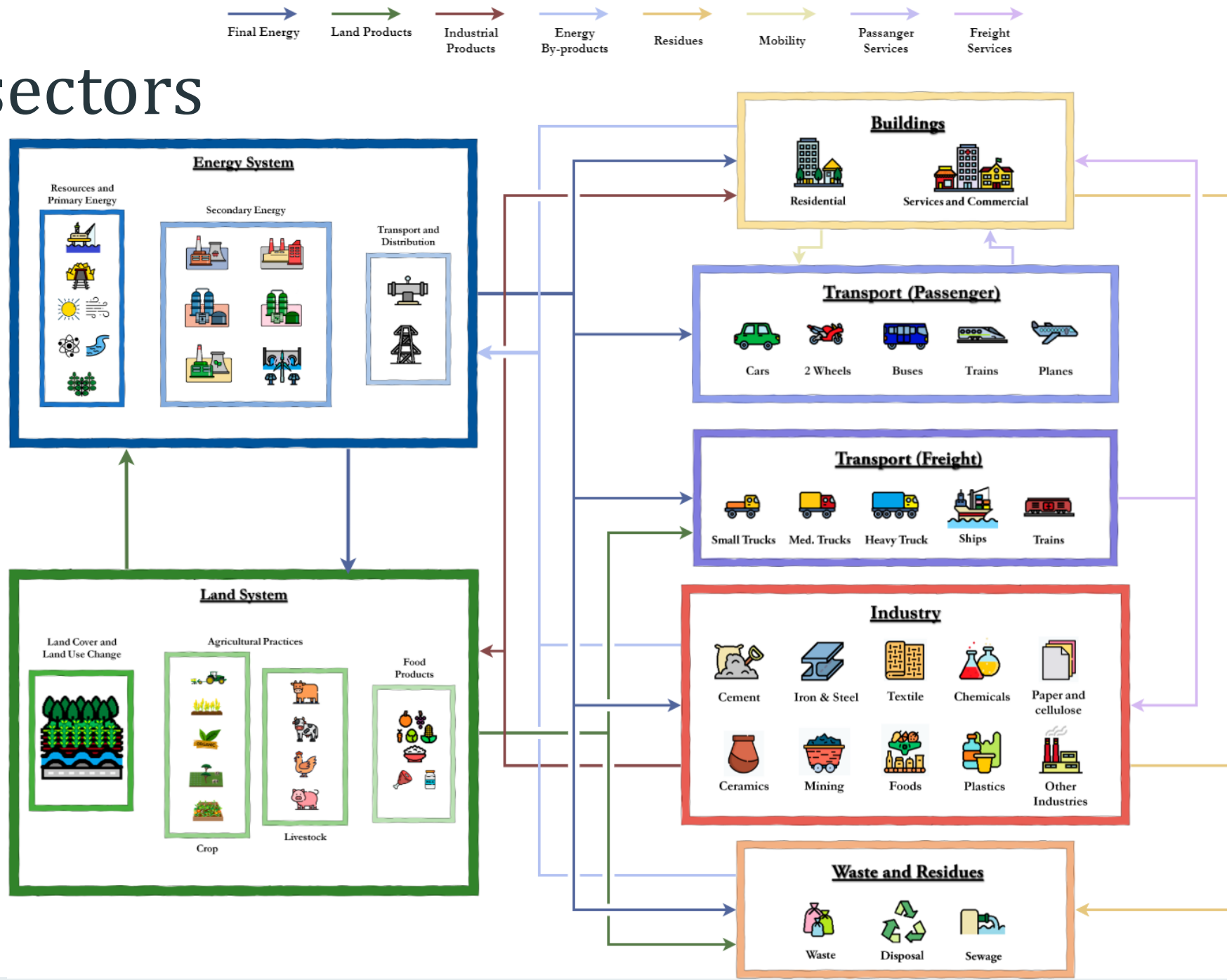
Horizon: 2010 – 2060  
5 year time step

Seasonality: 12 months

Load curve: 24 hours



# BLUES sectors

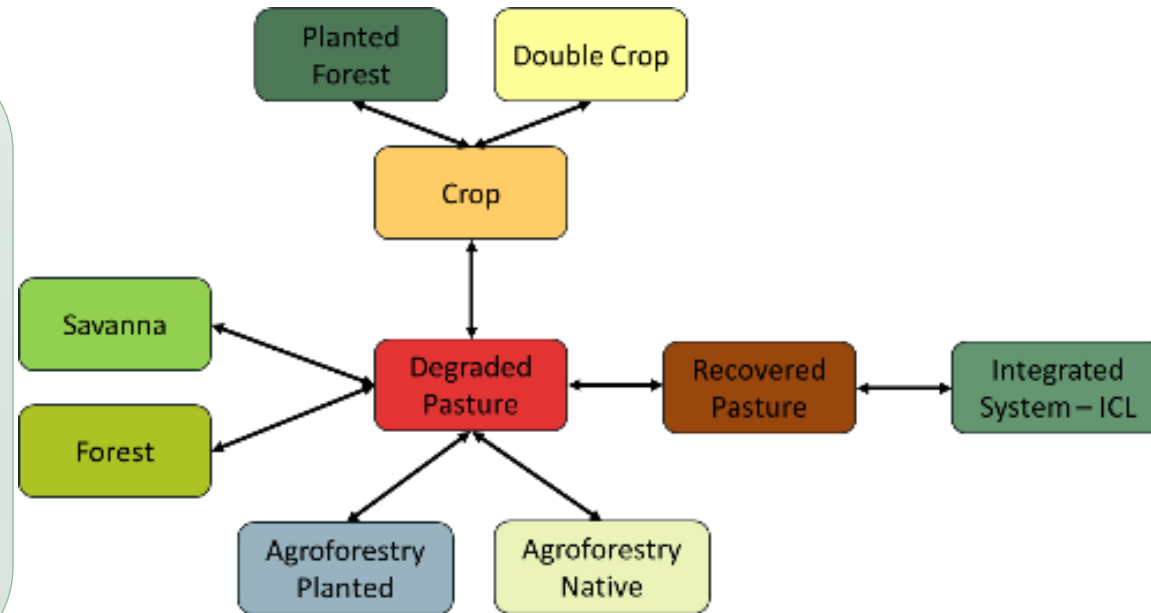


# Land System

- Land Cover: Wide range of land cover and their transitions represented and detailed at the regional level for each of the five regions of the model

## Land Cover

- 12 land covers
  - 2 protected native vegetation
  - 2 native vegetation
  - 2 pasture
  - 2 crop production
  - 1 forestry
  - 3 integrated systems
- Regionalized below and above ground carbon stocks for each land cover



## Land Cover Change

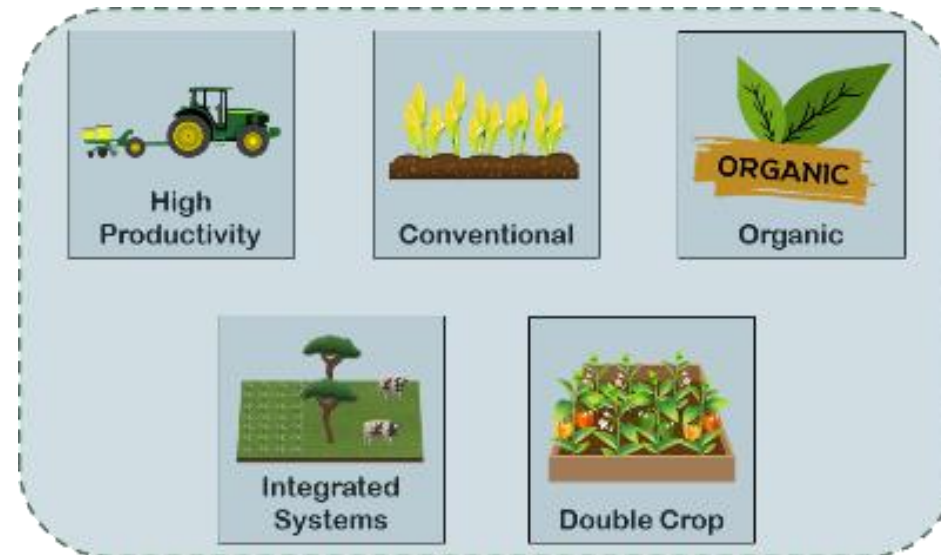
- 18 land cover changes
- Considering:
  - Variation of carbon stock below and above ground between transitions (emissions)
  - Costs
  - Annual potential for land cover change

# Land System

- Land Use: Large number of detailed agricultural practices at regional level for each of the five regions of the model
  - Including the main inputs, outputs, emissions, costs and potentials of each production technology

## Agricultural Productions

- 21 agricultural productions
  - 16 agricultural crops (cereals, coffee, fiber, fruits, grassy, maize, nuts, oilseeds, pulses, rice, roots, soybean, sugarcane, vegetables, wheat and woody)
  - 5 animal management (cattle meat, cattle milk, chicken meat, eggs and pork meat)



## Agricultural Practices

- 5 agricultural practices
  - Conventional
  - High Productivity
  - Organic
  - Double Crop
  - Integrated Systems/Agroforestry
- 21 agricultural productions
  - 16 agricultural crops
  - 5 animal management
- Inputs
  - Fertilizers (chemical and organic)
  - Pesticides (chemical and organic)
  - Water



# Energy System

- Energy Supply: very detailed representation of energy production and conversion technologies
- Including fossil and renewables, conventional and modern options



## Oil&Gas

- Post and pre-salt representation
- CCS options
- Detailed refineries
  - With biomass co-processing
- Detailed oil products
- T&D of natural gas



## Biofuels

- Various options of biomass options for energy conversion
  - Liquids
  - Solids
  - Gaseous
  - Electricity
- Several BECCS options



## Power sector

- Representation of several source and technology
  - Fossil and renewable sources
- Resources seasonality and variability:
  - Hydro, wind, solar, etc
- Several CCS options
- T&D lines and storage



Imports and exports:  
crude oil, natural gas, oil products and electricity

# Energy System

- **Energy Demand:** detailed representation of the most relevant economic sectors
  - Energy service demand for most sectors and several energy efficiency measures.

## Transport

- **Passenger transport:** cars, bikes, buses, light commercial, subway and non-motorized, airplanes and ships
- **Freight transport:** 5 types of trucks, light commercial, ships, airplanes and trains
- Energy service: passenger-kilometer (pkm) for passenger and ton-kilometer (tkm) for freights
- Energy efficiency options
- New technologies and fuels options
- Modal choice; Various electrification options



## Industrial Sector

- **11 subsectors:** cement, metals, ceramics, chemicals, food and beverage, mining, paper and pulp, textile and other industries.
- Energy and non-energy consumption
- Material demands (e.g. cement, steel, white and red ceramics, pulp and paper, chemicals, etc)
- Processes-based modelling and energy efficiency options
  - Detailing of industrial processes emissions
  - Abatement measures, including CCS



## Buildings

- **Residential and Services**
- Energy Service: lightning, cooling, water heating, cooking, refrigeration and appliances
- Specific consideration for each region, with energy efficiency options
- Includes **distributed generation** through photovoltaic solar energy

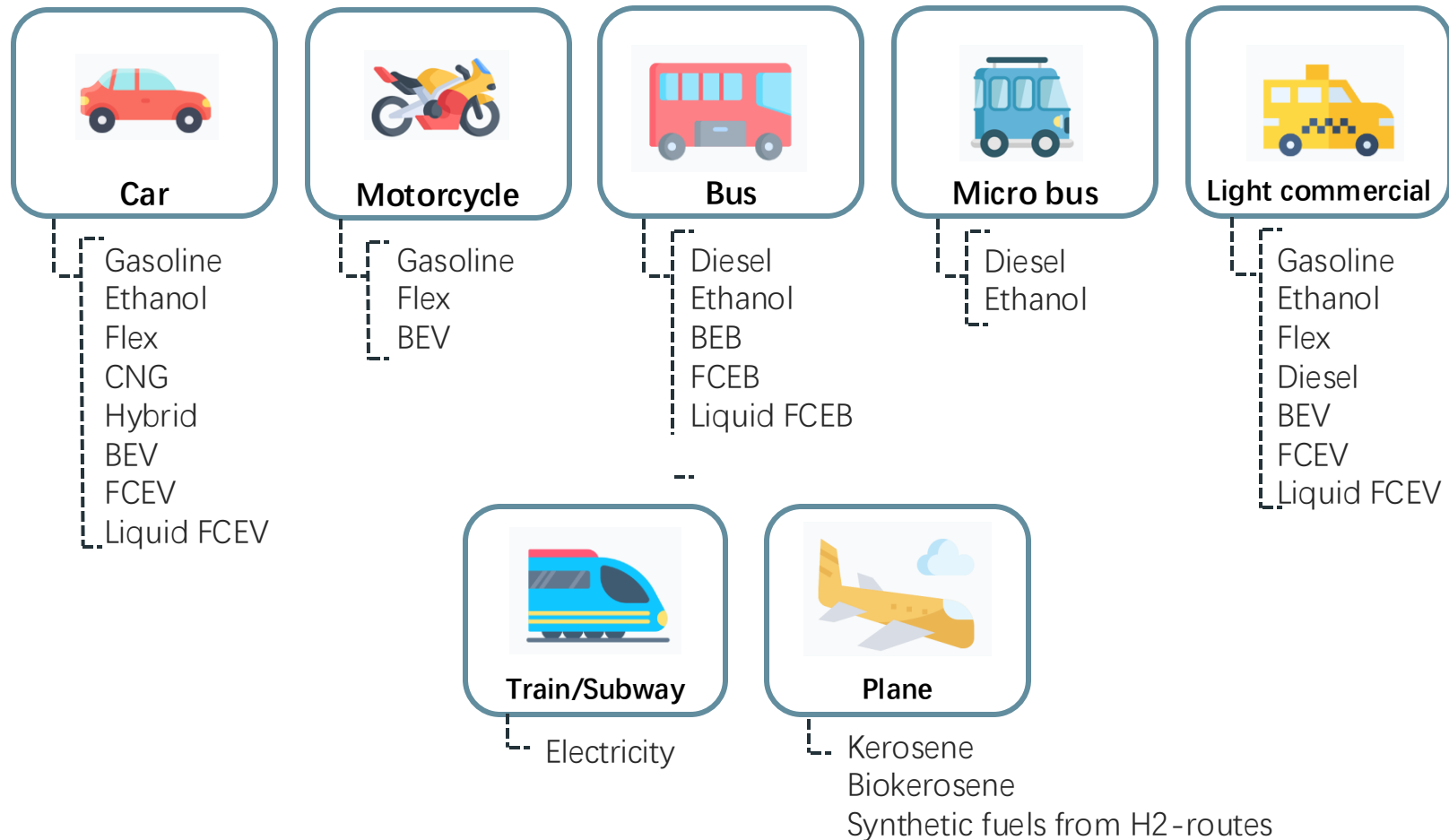


## Residues

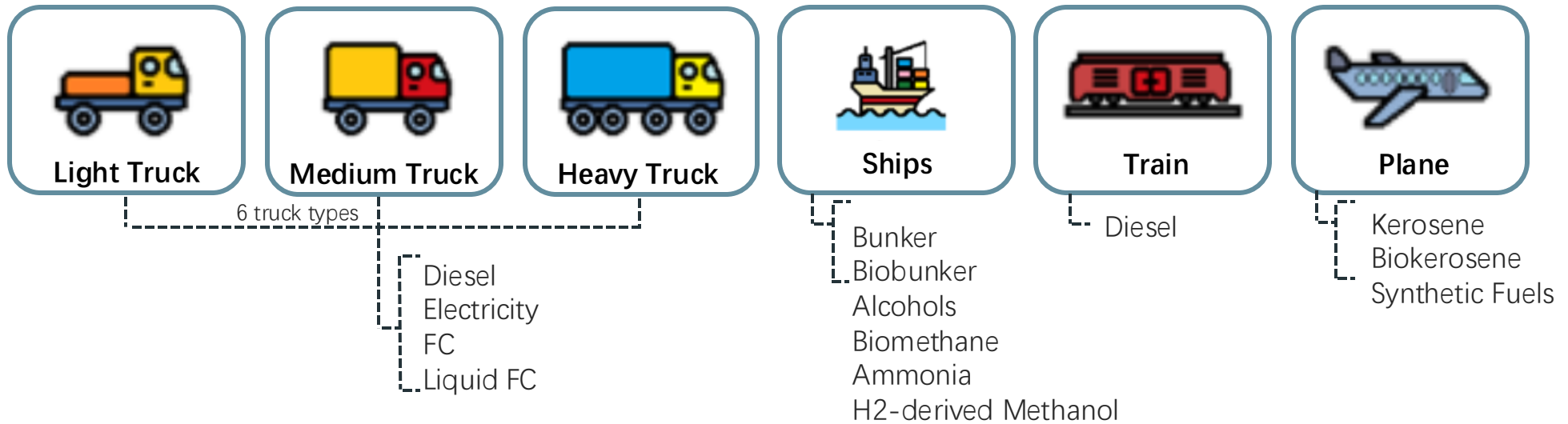
- **Urban solid waste generation and Water treatment**
- **Waste disposal:** sanitary landfill, controlled landfill, composting, recycling, biodigestion, incineration
- Waste-to-energy options available
- Several mitigation options for non-CO<sub>2</sub> gases



# Zoom in the Transport Sector (Passenger)



# Zoom in the Transport Sector (Freight)



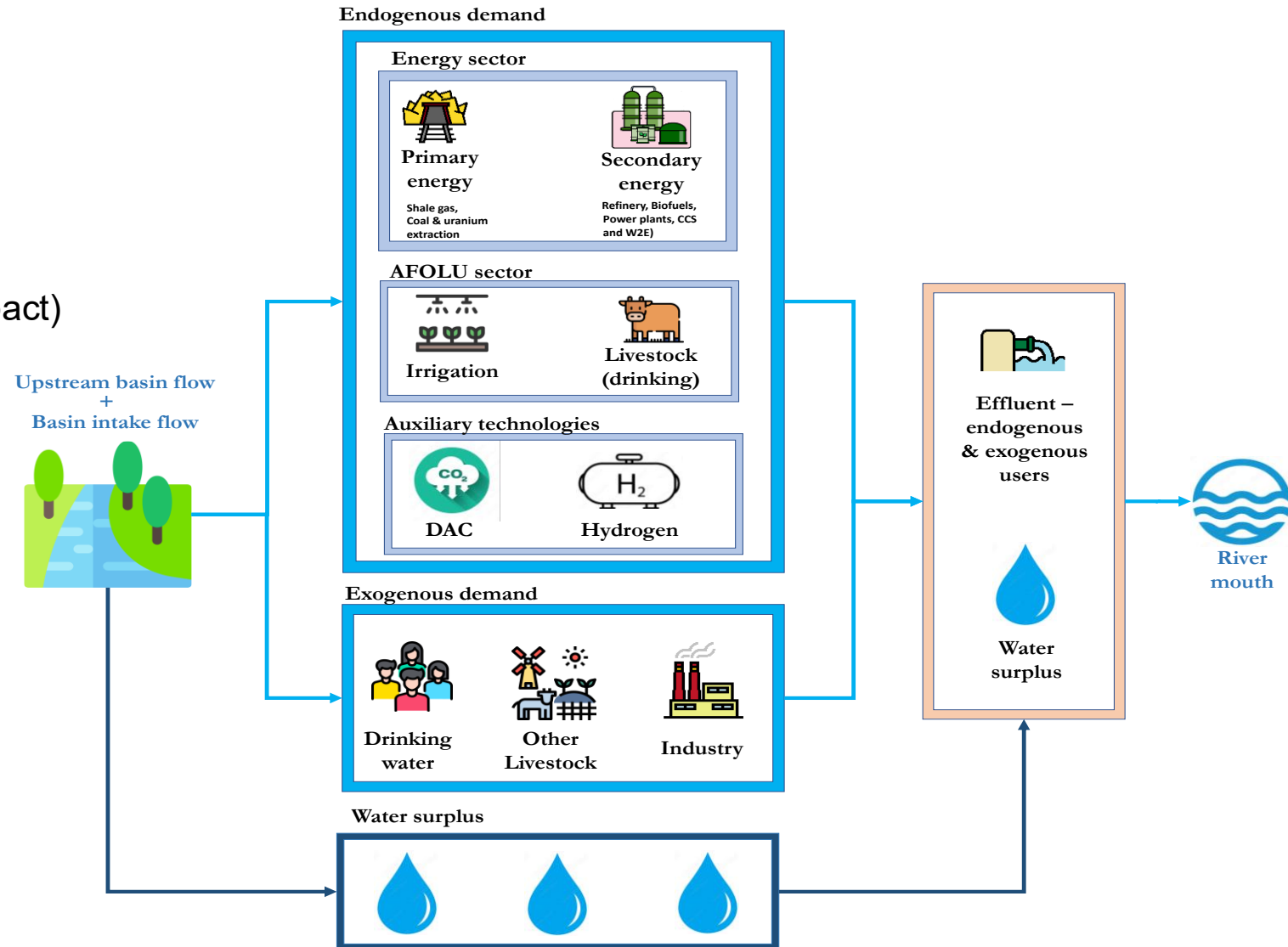
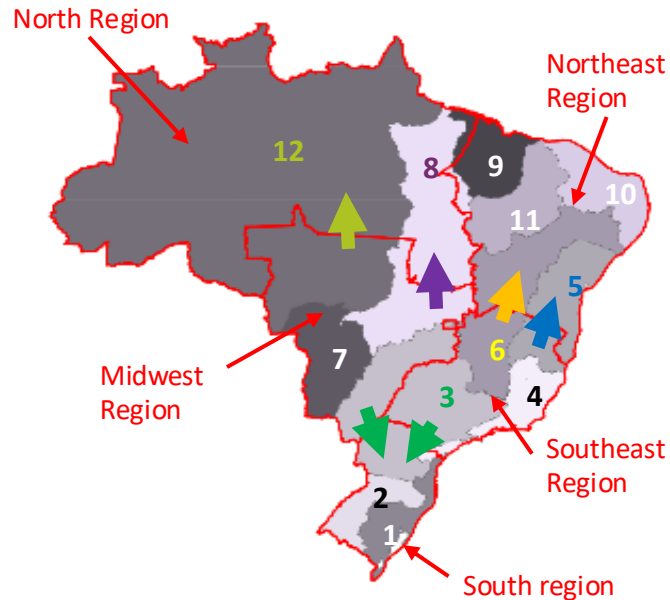
## Transport

- Energy service: passenger-kilometer (pkm) for passenger and ton-kilometer (tkm) for freights
- Energy efficiency options
- New vehicles and new fuels
- Modal choice; Electrification options

# Water Availability

Total of 18 basins: Q95 flow (default)

- Allows you to analyze:
  - Water management
  - Infrastructure and Investment
  - Assessment of availability (eg: climate impact)
  - Effects of cost/taxes for water use



# Air Pollution

Air pollutants:  $PM_{2.5}$ ,  $NO_x$ ,  $SO_2$ , VOC, CO for all sectors

- Emission factors and control measures:
  - National information as far as possible: CETESB, PROCONVE, ANP, CONAMA, among others
  - International databases: IIASA, EMEP/EEA, US EPA and scientific literature
- Control measures options for  $PM_{2.5}$ ,  $NO_x$ ,  $SO_2$  with efficiencies and costs

## Mobile sources (transport sector):



- Sulphur limits for diesel and gasoline
- PROCONVE (~EURO) limits
- Exogenous vintage curves
- Tires and brake emissions

## Stationary sources:



- Industry and energy sectors
- Combustion and process emissions

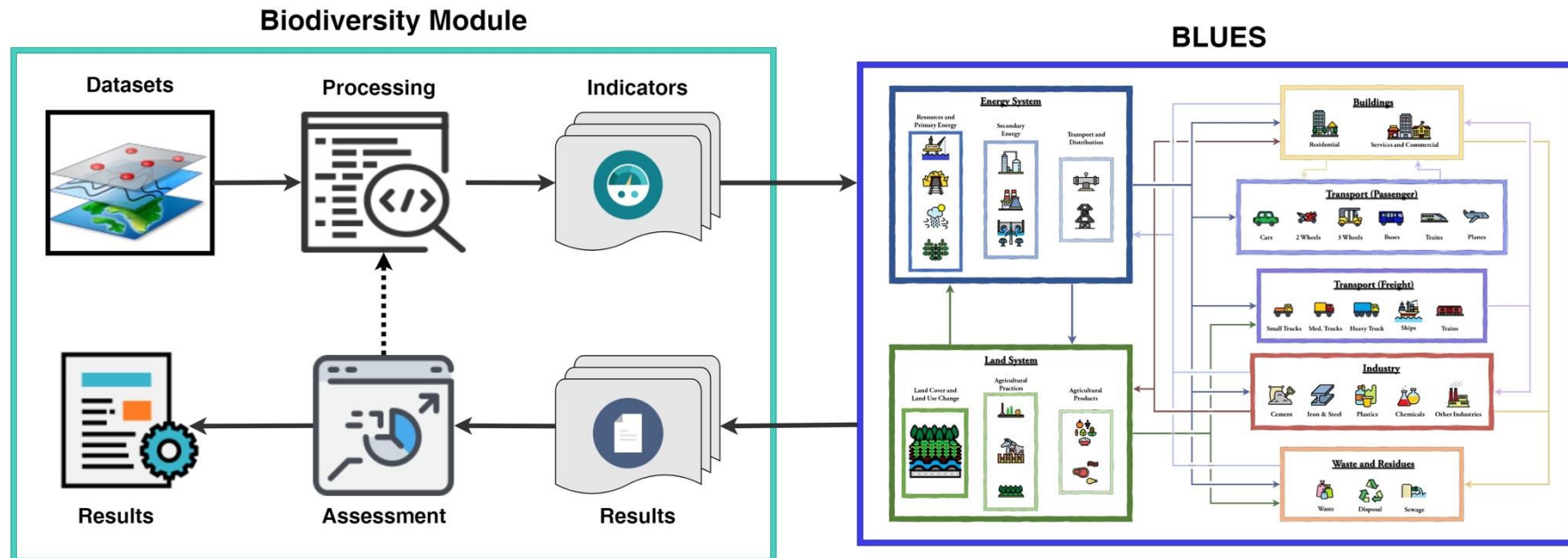


- Agriculture emissions
- Residues burned emissions (sugarcane)

# Biodiversity

Biodiversity indicators are being introduced to BLUES.

- Associated with land-use change and agricultural practices
- Biodiversity module was defined in soft-link, but is being introduced in hard-link
  - Indicators: Biodiversity Intactness Index (BII), Human Footprint (HF), Normalized Bird Richness (NBR)
  - More indicators are being developed at this time



# Part 3

## IAM Development Experience



<http://www.cenergialab.info/research>

# SCENARIOS

## 1 BRAZIL TRANSITION

Optimal cost-efficient trajectory (based on Brazil's commitments, resources, knowledge and cost expectations) to reach net zero GHG emissions by 2050

## 2 ALTERNATIVE TRANSITION

Alternative technological path for Brazil to achieve net zero GHG emissions by 2050. It is a variant of the “Brazil Transition” scenario, with greater restrictions to limit or induce the choice of technological routes through which the transition process will take shape

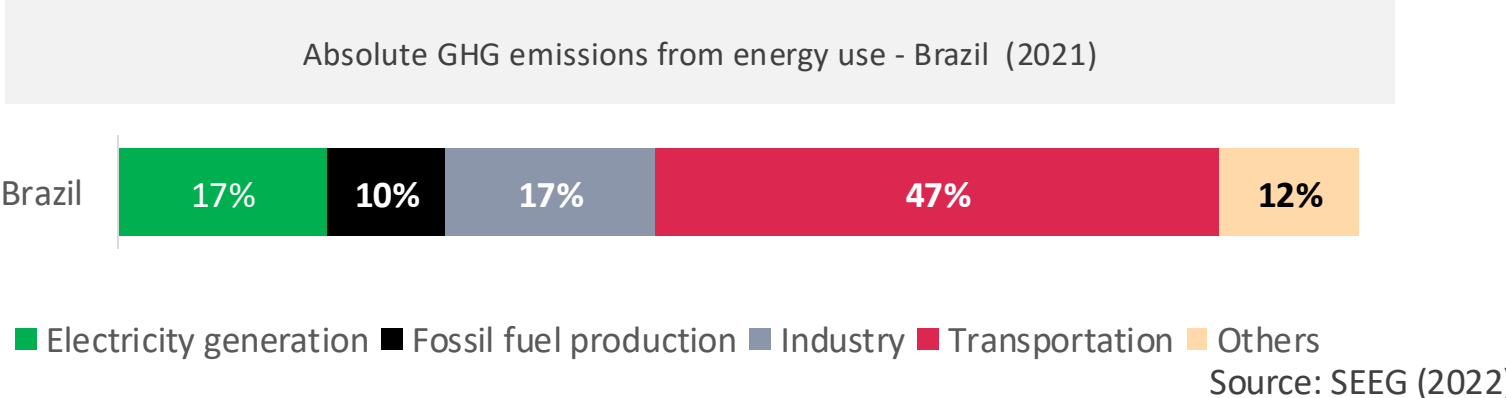
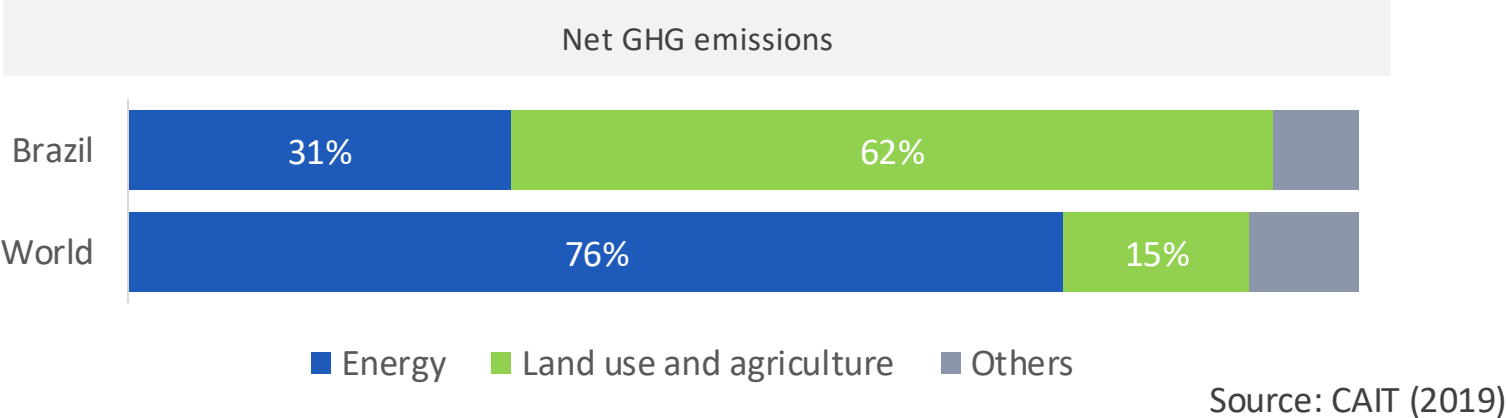
- Restrictions to CCS and hydropower
- Nuclear power
- Electrification

## 3 GLOBAL TRANSITION

Brazil's contribution in a world that seeks to limit average increase in global surface temperature to 1.5°C by 2100 in reference to pre-industrial levels. A 400 GtCO<sub>2</sub> global carbon budget gives Brazil a 13.2 GtCO<sub>2</sub> carbon budget for 2010-2050

# NET GHG EMISSIONS

Brazil's emissions profile is completely different from the global profile, which implies reconciling the agricultural, energy and environmental agendas



- > Expected growth in energy demand

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- 1. Elimination of illegal deforestation as a necessary condition

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- 2. Modernizing and creating regulatory frameworks for energy transition

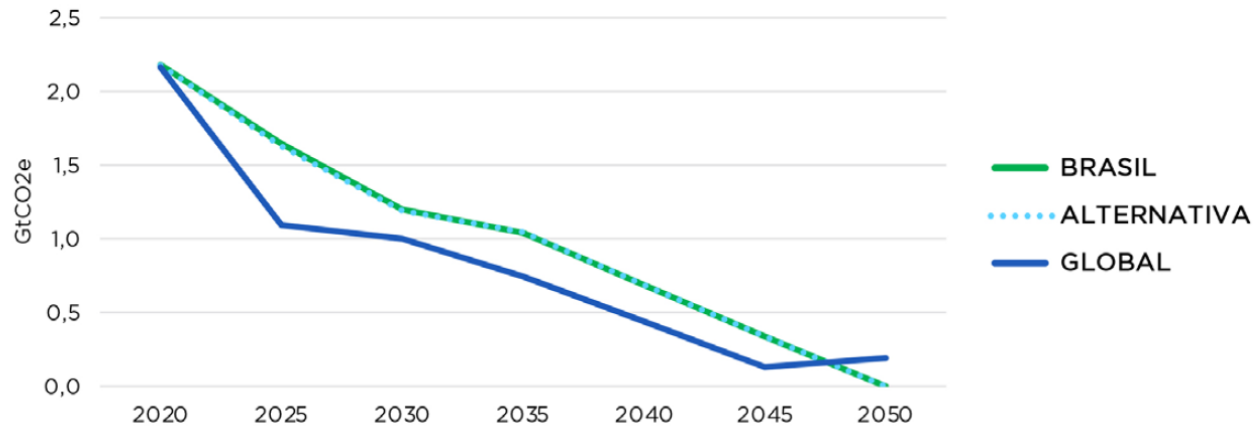
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- 3. New technologies and infrastructure require further development and more scale

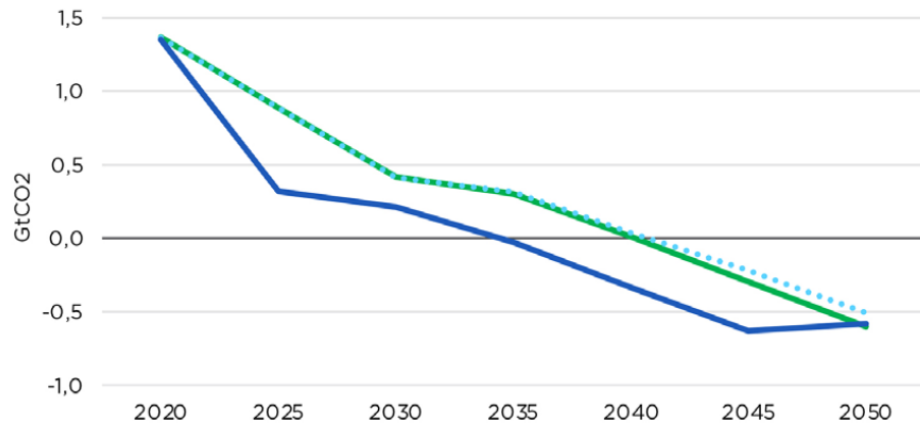
Notes: 1. Forest restoration and reforestation were deducted from land use - AFOLU (net emissions); 2. Energy answers for 18% of Brazil's total gross GHG emissions. Based on this criterion, forest restoration and reforestation by the energy industry removes carbon from AFOLU and not from energy

# GHG EMISSIONS

GRÁFICO 5 EMISSÕES DE GASES DE EFEITO ESTUFA (GEE), 2020-2050



EMISSÕES DE CO2, 2020-2050



## Challenges for reaching net zero GHG emissions

To achieve net zero GHG emissions by 2050 it is necessary to reach **net zero CO<sub>2</sub> emissions by 2035-2040**

Ending illegal deforestation will save 21 Gt CO<sub>2</sub> emissions by 2050

Keeping current deforestation rates makes the achievement of net zero GHG emissions by 2050 **unfeasible**

# ENERGY MIX

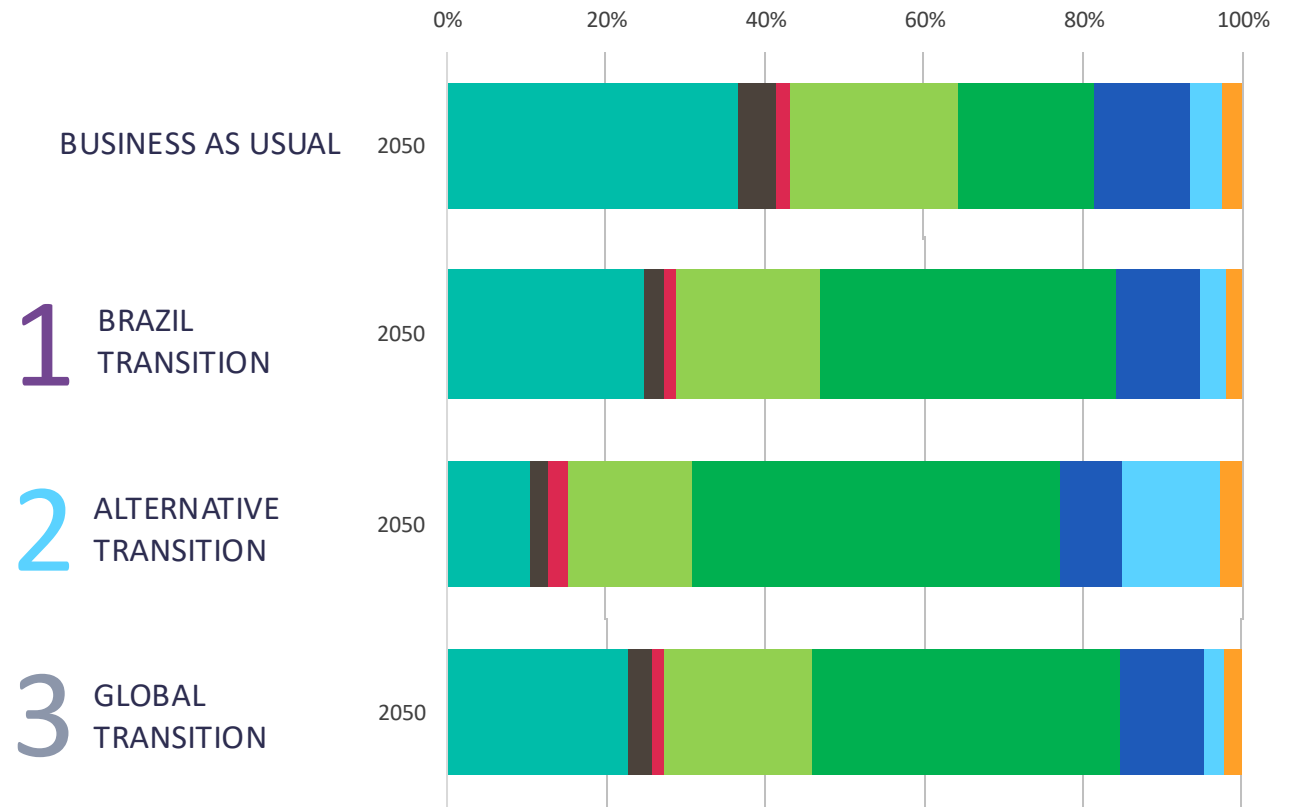
The comparison with the Business As Usual (BAU) trend shows a considerably **smaller share for oil & gas and for coal** in 2050 in all three scenarios

**Renewable** sources will increase in all scenarios exceeding 70% share of primary energy demand

**Biomass** will be the source that will grow the most within Brazil's energy mix, followed by wind and solar

**Primary energy** demand will go from 268 Mtoe in 2020 to around 400 Mtoe in 2050 in all scenarios

Primary energy by source in 2050



- Oil and Gas ● Coal ● Nuclear ● Sugarcane
- Biomass ● Hydro ● Wind ● Solar

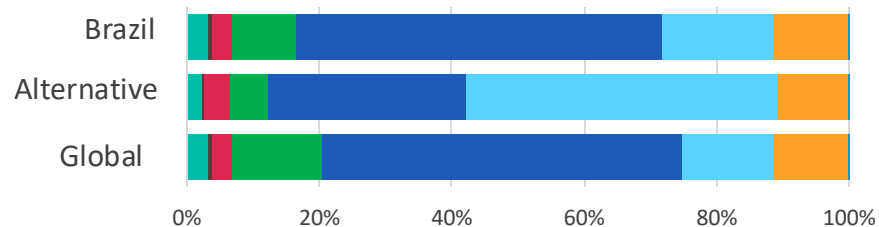
# POWER GENERATION

## 1 BRAZIL TRANSITION

## 2 ALTERNATIVE TRANSITION

## 3 GLOBAL TRANSITION

Generation breakdown in 2050



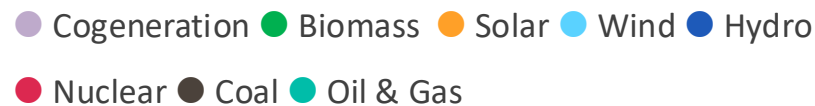
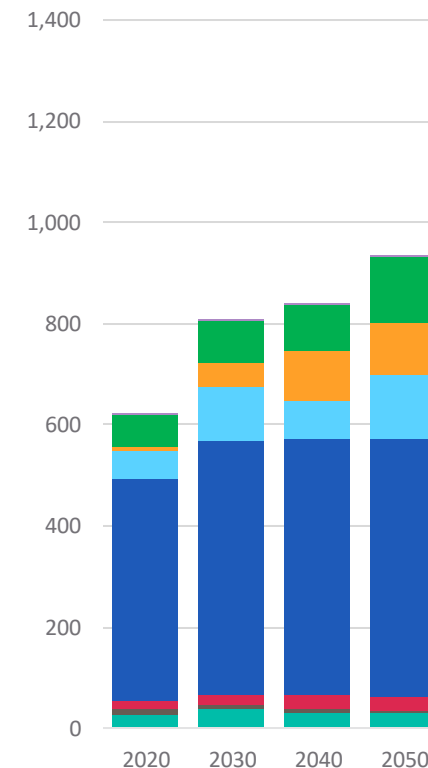
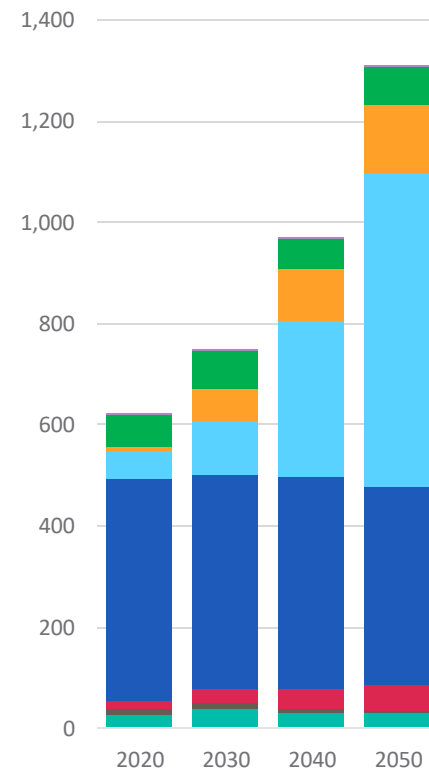
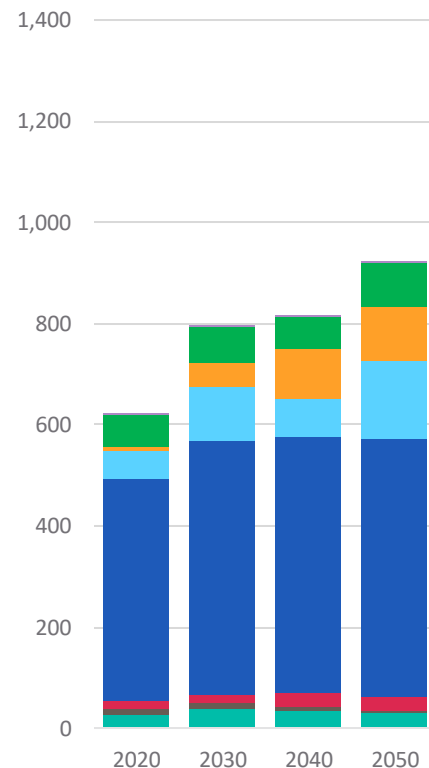
A portion of the generation from biomass in the Brazil and Global scenarios is associated with CCS

New power generation 2020-2050 (TWh)

	BRAZIL	ALTERN.	GLOBAL
Biomass	+11	+12	-19
Biomass CCS	+18	-	+85
Wind	+102	+565	+76

In all scenarios, natural gas will become less important for power generation

Power generation (TWh)



# OIL

The Brazilian economy will use less oil but domestic production will likely grow to meet **foreign demand**

The increase in production is based on the **resilience of Brazilian oil**: lower cost and lower carbon footprints

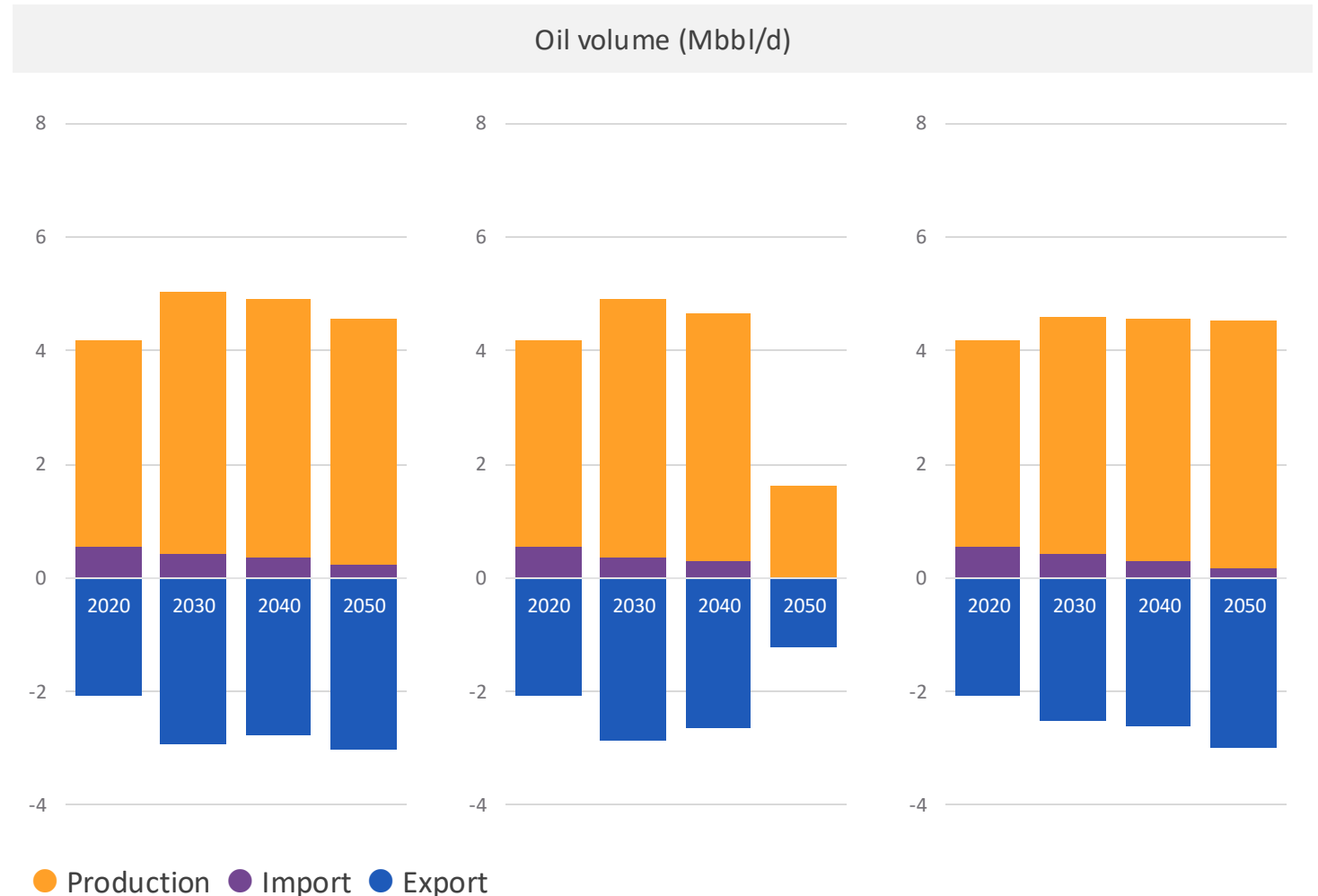
**Non-energy uses** will represent 12.3% of domestic demand for oil products by 2050

**Natural Gas** will become less important for power generation purposes but more so in construction and industrial activities, driven by the chemical, cement, ceramics and other industries

## 1 BRAZIL TRANSITION

## 2 ALTERNATIVE TRANSITION

## 3 GLOBAL TRANSITION



# BIOFUELS

**Conventional biofuels** (ethanol and biodiesel) grow in almost all scenarios, accounting for the largest share of biofuels by 2040

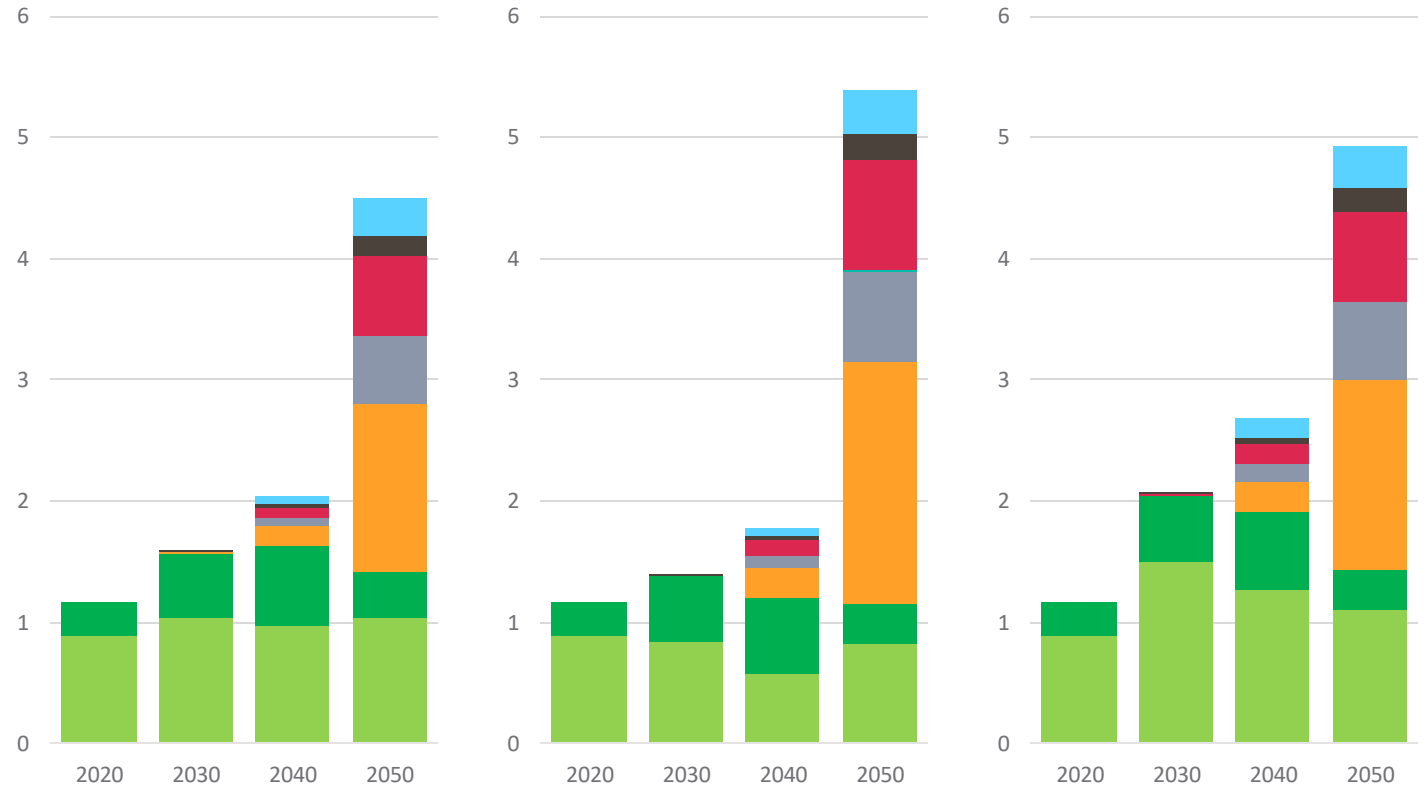
**Advanced biofuels** grow significantly in the last decade, especially to meet the demand from hard-to-decarbonize transportation activities such as freight, aviation and maritime transport

1 BRAZIL TRANSITION

2 ALTERNATIVE TRANSITION

3 GLOBAL TRANSITION

Biofuel Production (EJ)



- Ethanol ● Biodiesel ● Green and co-processed diesel ● BioLPG
- Bionaphtha ● Biobunker ● Biokerosene

# TRANSPORTATION

## 1 BRAZIL TRANSITION

## 2 ALTERNATIVE TRANSITION

## 3 GLOBAL TRANSITION

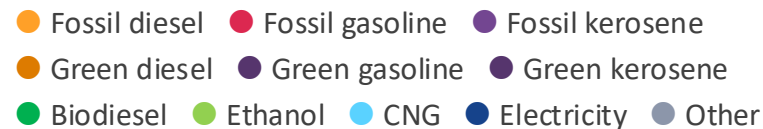
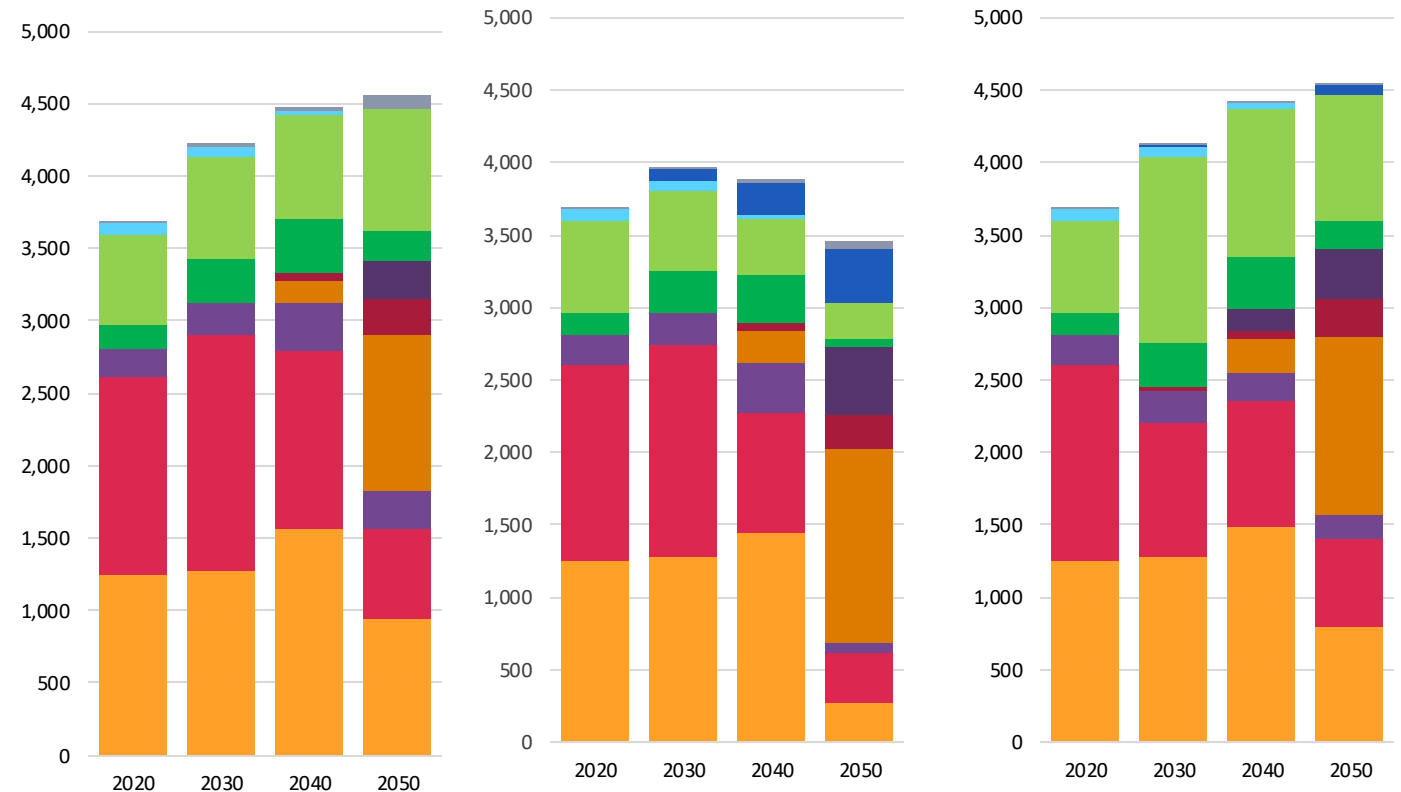
Two key technological alternatives are available to decarbonize transportation:

- (i) **fleet electrification** through the replacement of vehicles now in circulation
- (ii) replacement of fossil fuels with **biofuels**

Alternatives may **complement** each other not only in different market niches (luxury x economy) but also be combined (flex hybrid vehicles, ethanol fuel cell vehicles, etc.)

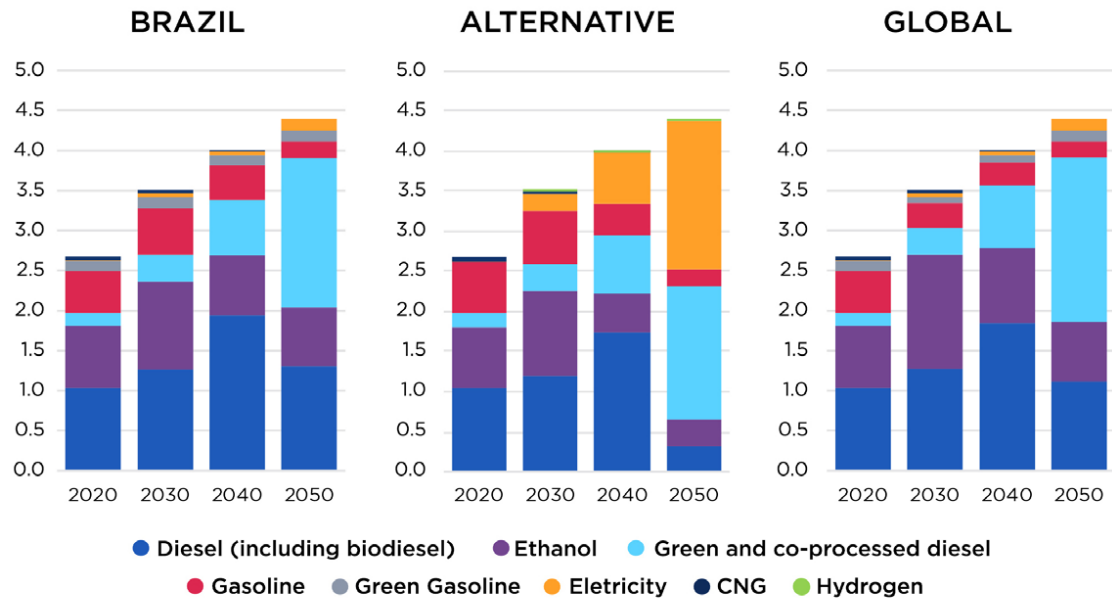
**Urban buses** and light commercial vehicles and motorcycles will give the greater contribution to the electrification of passenger road transportation

Total use in Transportation (PJ)

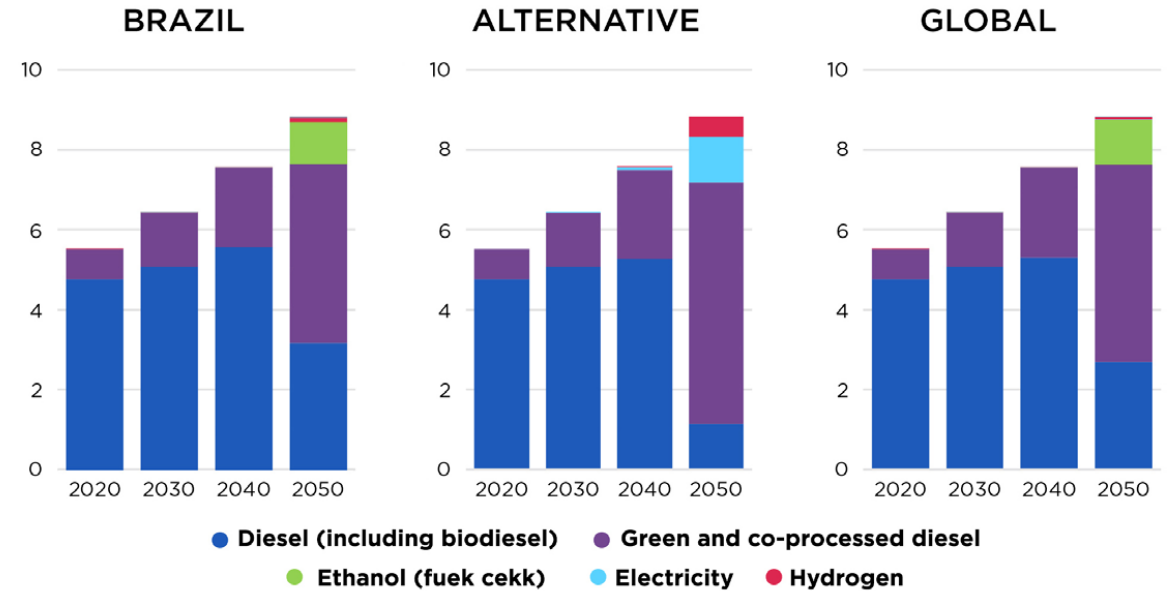


# Zoom in TRANSPORTATION

PASSENGER TRANSPORTATION BY TYPE OF FUEL (BN PKM)



FREIGHT TRANSPORTATION BY TYPE OF FUEL (BN TKM)



# Final Comments

1. Build an **energy policy agenda** and design markets that can open flexible decarbonization paths to address the technological and market uncertainties identified taking advantage of the synergies provided by Brazil's diverse energy resources in line with an economy-wide approach
2. But we have to recognize that many critical uncertainties with respect to domestic and global dynamics do exist
3. Make use of **Brazil's existing competitive advantages** to build and fund the competitive advantages of tomorrow, upgrading assets and focusing expertise on the much needed energy transition
4. With deforestation properly addressed, the next priority should be the Transportation Sector, where both biofuels and electrification are key, and electric buses can play a major role as well (diesel is Brazil's energy sector Achilles Heel)
5. Despite all their limitations, IAMs are extremely useful tools for “exploring the future” and for “trying to anticipate and plan for possible futures.”
6. Therefore, the use of IAMs can be extremely useful for those who want to think about the future of Brazil

# Thank you

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<http://www.cenergiab.info/>

