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Transportation Cost, Agricultural Production and Cropland Expansion in Brazil: A Multi-scale Analysis

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Introduction

Two major growth patterns of Brazilian agriculture since late 20th century

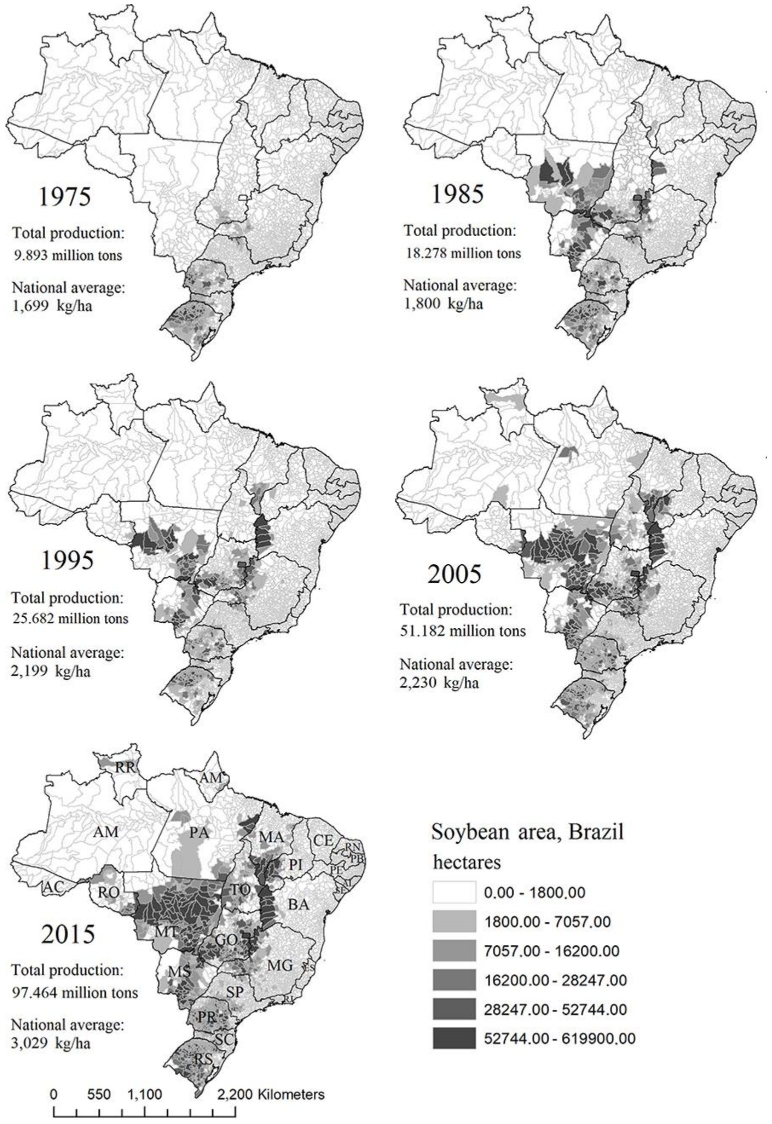
1) **Rapid increase in production and productivity**

   Major grains and oilseed production increased by 356% from 1990 to 2020; average TFP grew by 3.1% annually (IBGE)

2) **Expansion of cropland** from south to Cerrado region (inland area in Center-west)

- Take soybean as example (right)

  During 1995 – 2015, total production increased from 29.7 to 97.5 million tons, yield increased from 2.2 to 3 tons/ha



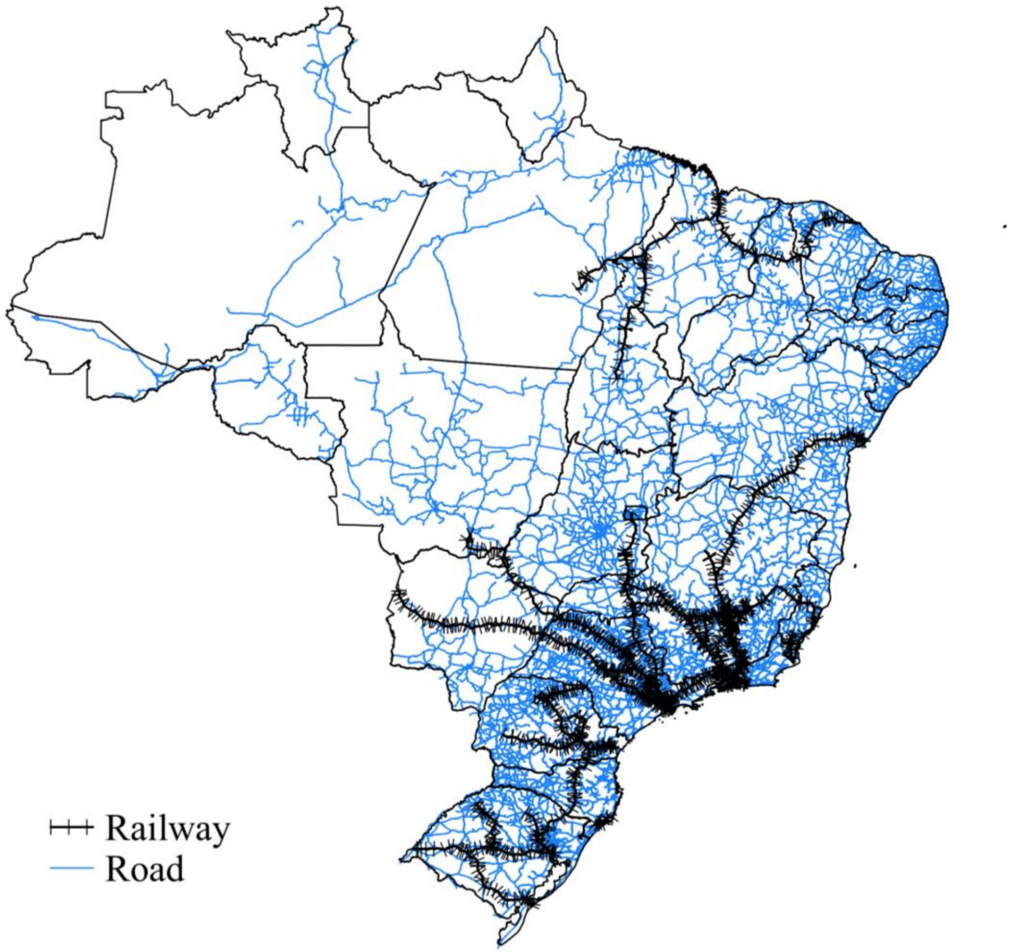
Soybean production and area expansion
Source: Fig 1 from Bicudo Da Silva et al., (2020)

Introduction

Agricultural potential of the Cerrado is limited by the higher transportation cost

- Comparing with traditional agricultural region in the south, **Cerrado region** is featured by
  - sparse transportation network
  - poor infrastructure condition
  - distant from exporting ports

- Transportation costs **11-28% of free-on-board (FOB)** price (Fliehr et al. 2019)



Transportation network in 2017
Data source: Brazil’s National Logistics Plan

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Introduction

Crop production expanding into the high transportation cost Cerrado region could weaken the competitiveness of Brazilian agriculture

- High transportation cost
  - Increases the **price wedge** between FOB and farm-gate price, lowering farmers' revenue
  - Reduces the affordability of **inputs**, resulting in lower yields (Vera-Diaz et al. 2008)
  - Undermines competitiveness of Brazil's crop **export**
- Reduced transportation cost could boost yields and spare land (**Borlaug's hypothesis**), but could also lead to cropland expansion and deforestation (**Jevons' paradox**) due to the elastic demand for Brazil produced crops

Introduction

Will the lowered transportation cost drive crop production and cropland expansion in Brazil?

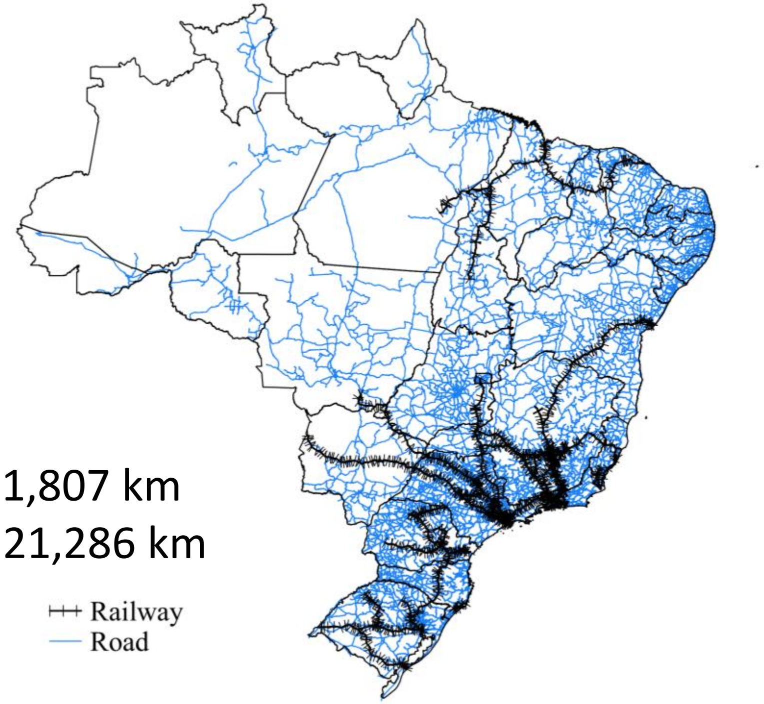
- Well documented **linkage between transportation cost and deforestation** (Lucich et al., 2015 , Fliehr et al., 2019, Schielein et al., 2021)

- However, **limitations** are observed
  - Focus on a specific region, ignore interactions with other regions and macro-level drivers (pop, GDP, tech change etc.)
  - Use travel time as a surrogate of actual transportation cost
  - Lack of spatial details in analysis

- **Contributions** of the present paper
  - The first study to **link macro drivers with local** agricultural response to improved infrastructure in Brazil
  - Developed a **grid-resolving model** to capture spatial heterogeneity
  - Allow comprehensive evaluation by establishing **global-local-global** interaction for the whole Brazil

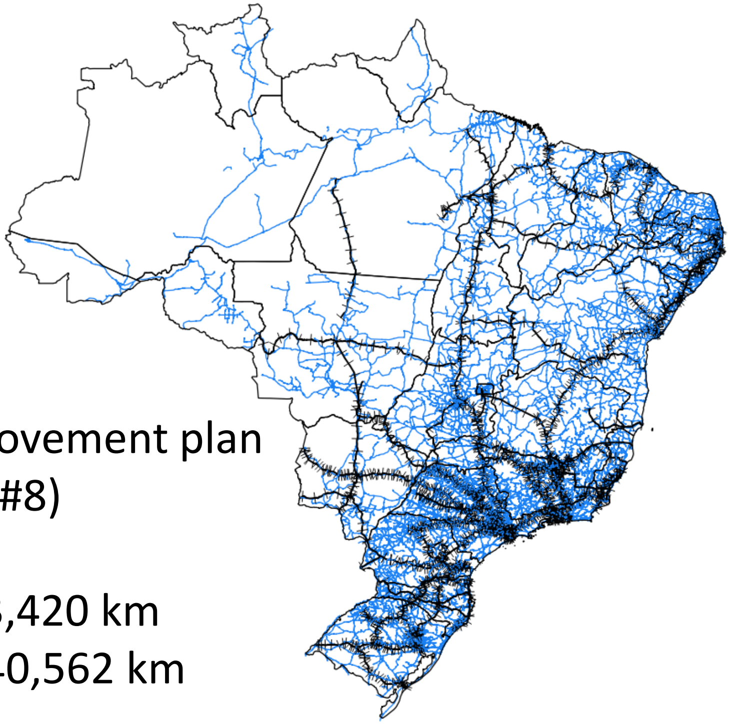
Methodology: Research design

According to Brazil’s National Logistics Plan (PNL), road and railway are expected to extend by 0.5% and 90.6% by 2035, under the max improvement plan



2017

Road: 331,807 km
Railway: 21,286 km



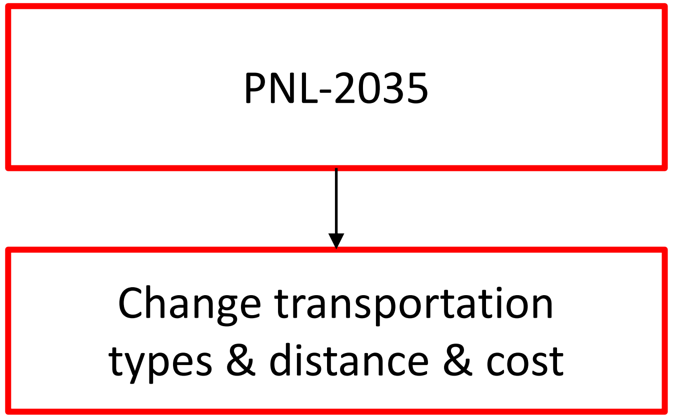
2035

Max improvement plan
(scenario #8)

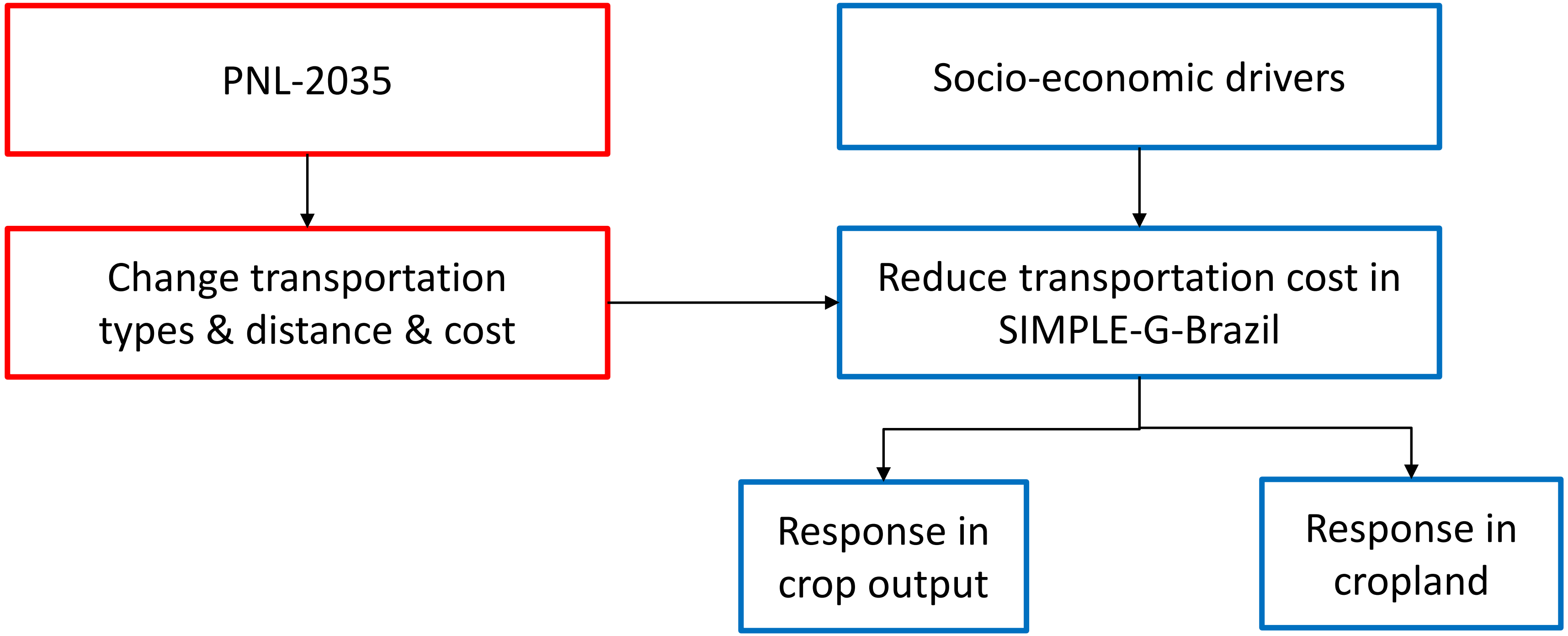
Road: 333,420 km
Railway: 40,562 km

Transportation network: 2017 (left) vs. 2035 (right)

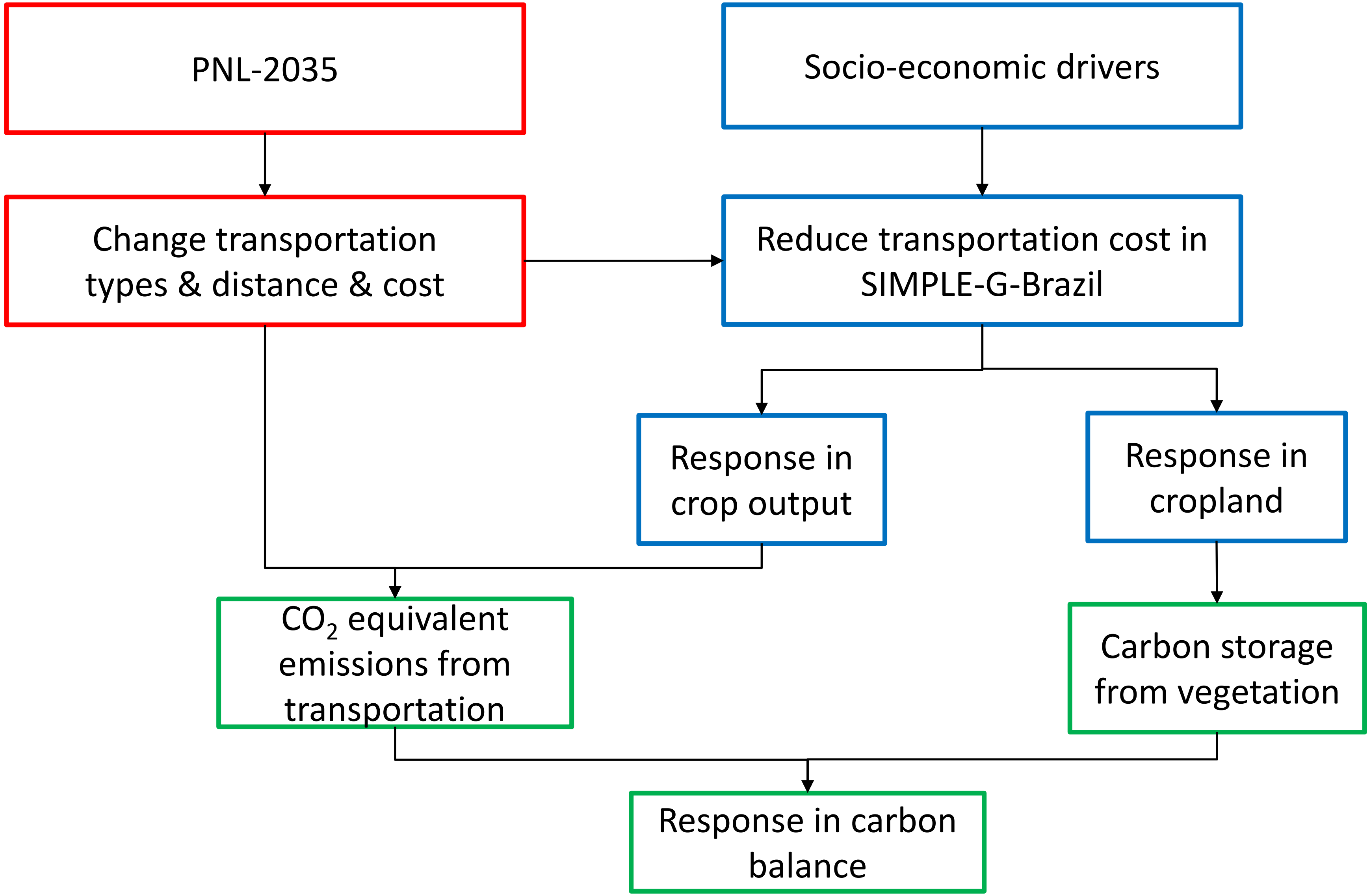
Methodology : Research design



Methodology : Research design



Methodology : Research design



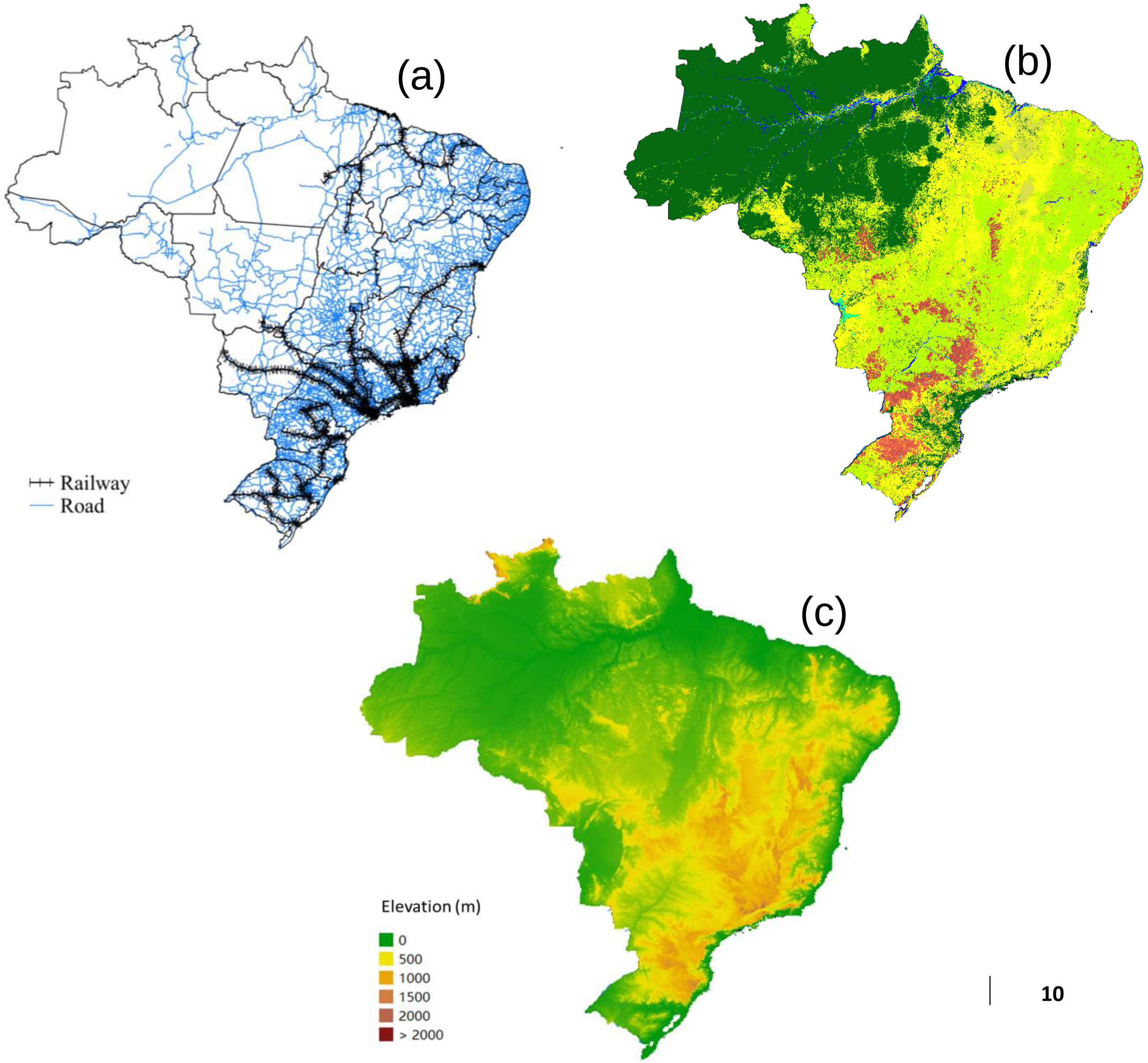
Methodology: Estimating transportation cost

Step 1: Integrate datasets

a) **Transportation network**: road (blue) and railway (black) from PNL

b) **Land cover**: MCD12Q1 V6 Dataset from Moderate Resolution Imaging Spectroradiometer (MODIS)

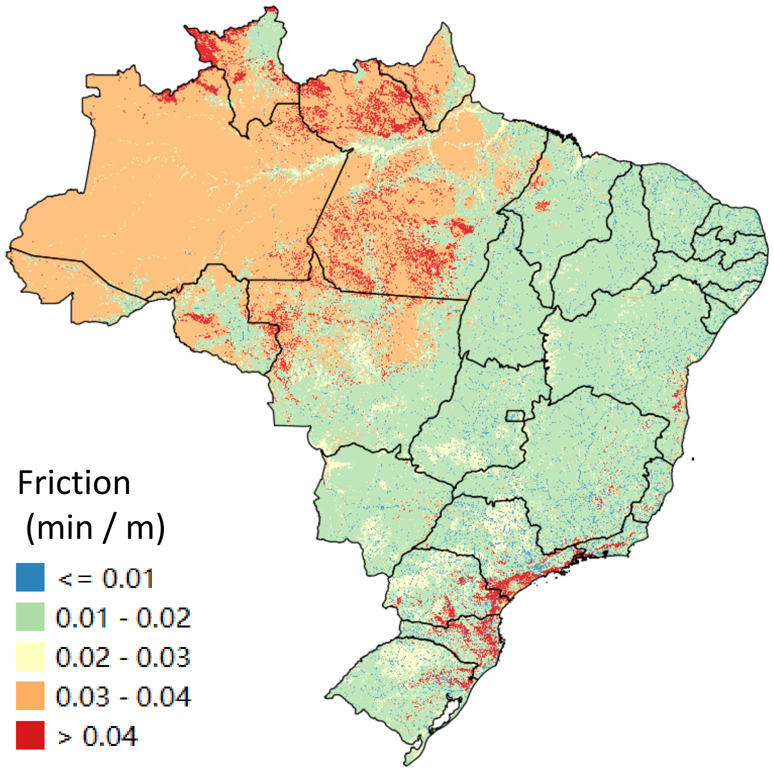
c) **Elevation**: Global Multi-resolution Terrain Elevation dataset of 2010 (GMTED2010)



Methodology: Estimating transportation cost

Step 2: Calculate transportation friction

- Transportation friction: time used to move 1 meter in each grid (Weiss et al. 2018; Victoria et al. 2021)
- Assign speed based on transportation network, land cover, elevation and slope
- Convert to gridded friction dataset



Transportation friction in 2017

Methodology: Estimating transportation cost

Step 3: Estimate transportation cost

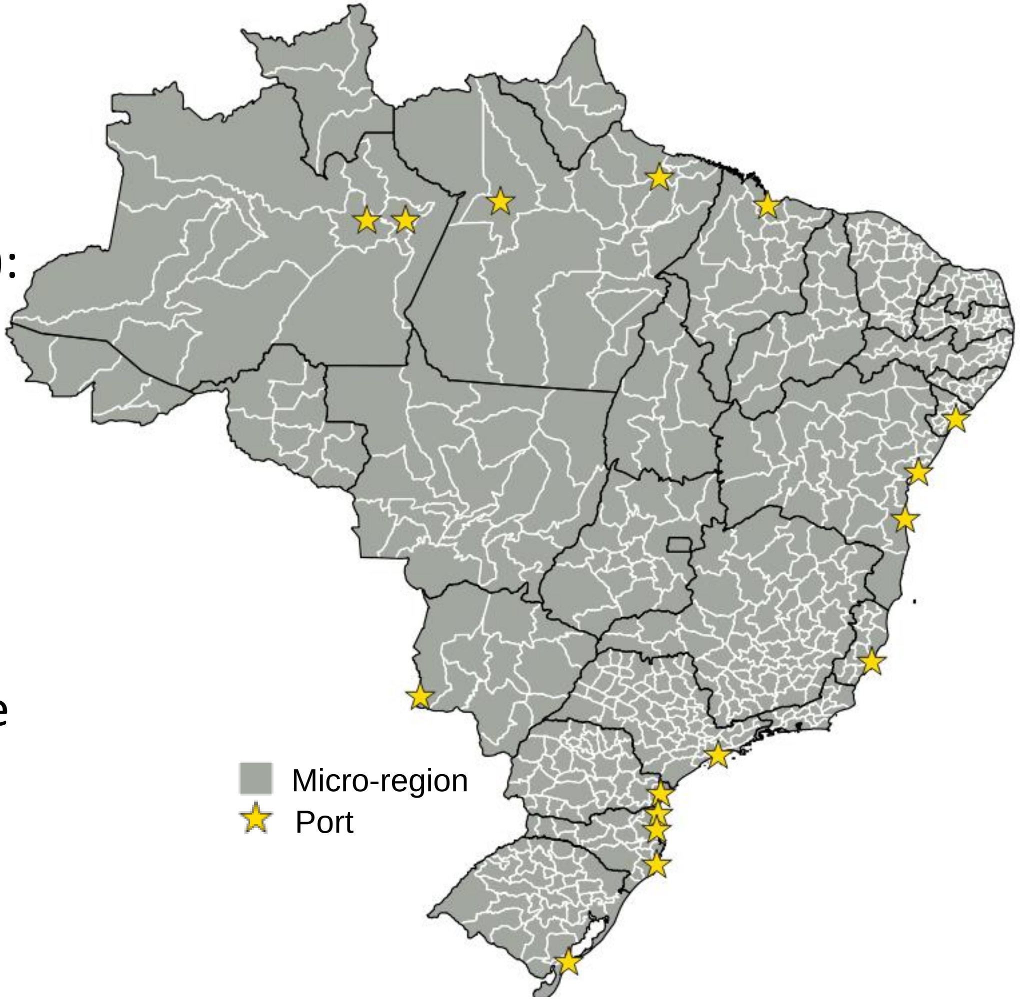
For each micro-region (county-equivalent administrative unit):

1) Use least accumulated friction algorithm to identify the **optimal path** from micro-region centroid to each port

2) Calculate the **distance** of optimal path for road & railway

3) Convert distance to **cost** based on observed cost-distance relation

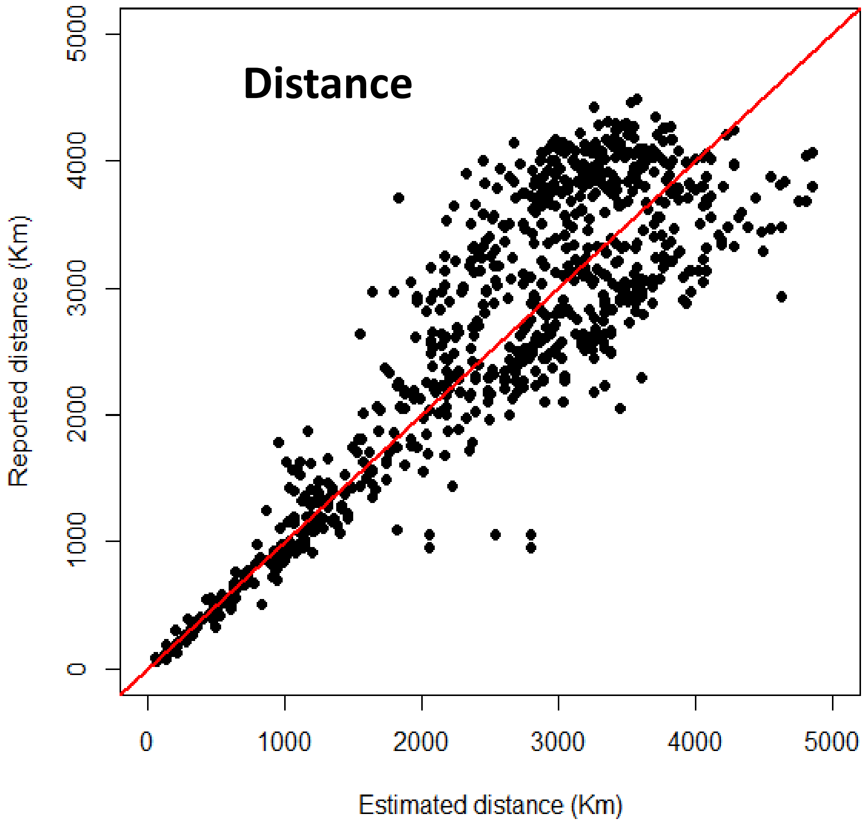
1) Select the **least cost to port** as the measurement of transportation cost



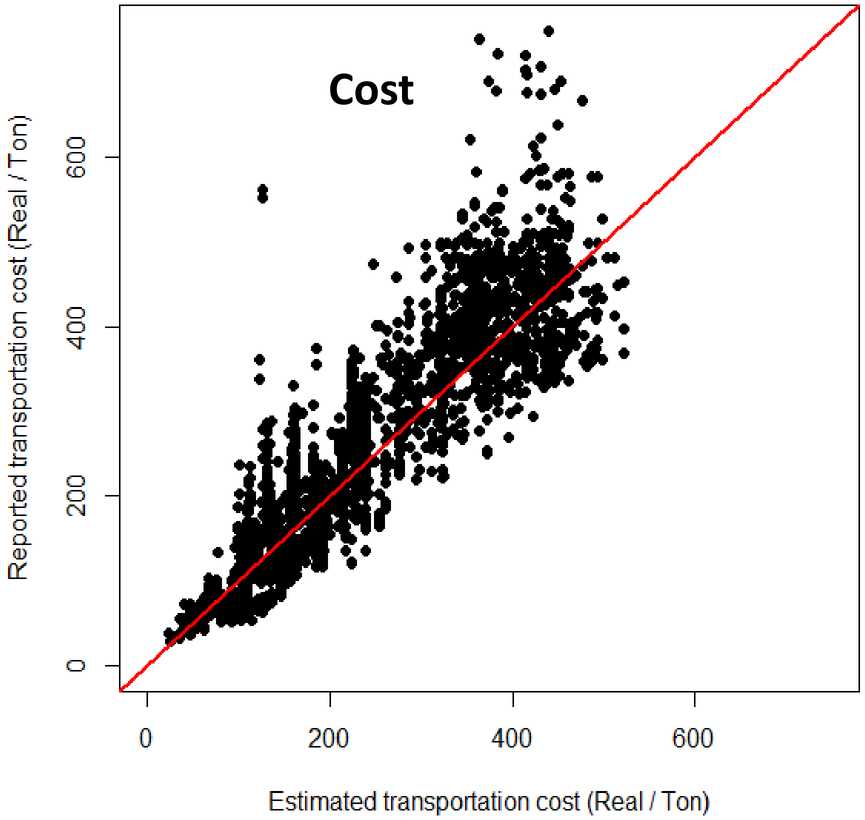
Micro-regions and port locations

Validation of transportation cost estimation

Simulated transportation distance and cost (y) compare well with observed data (x) provide by the National Supply Company (Conab) database.



$y = -36.470 + 1.035x \quad R^2 = 0.894$



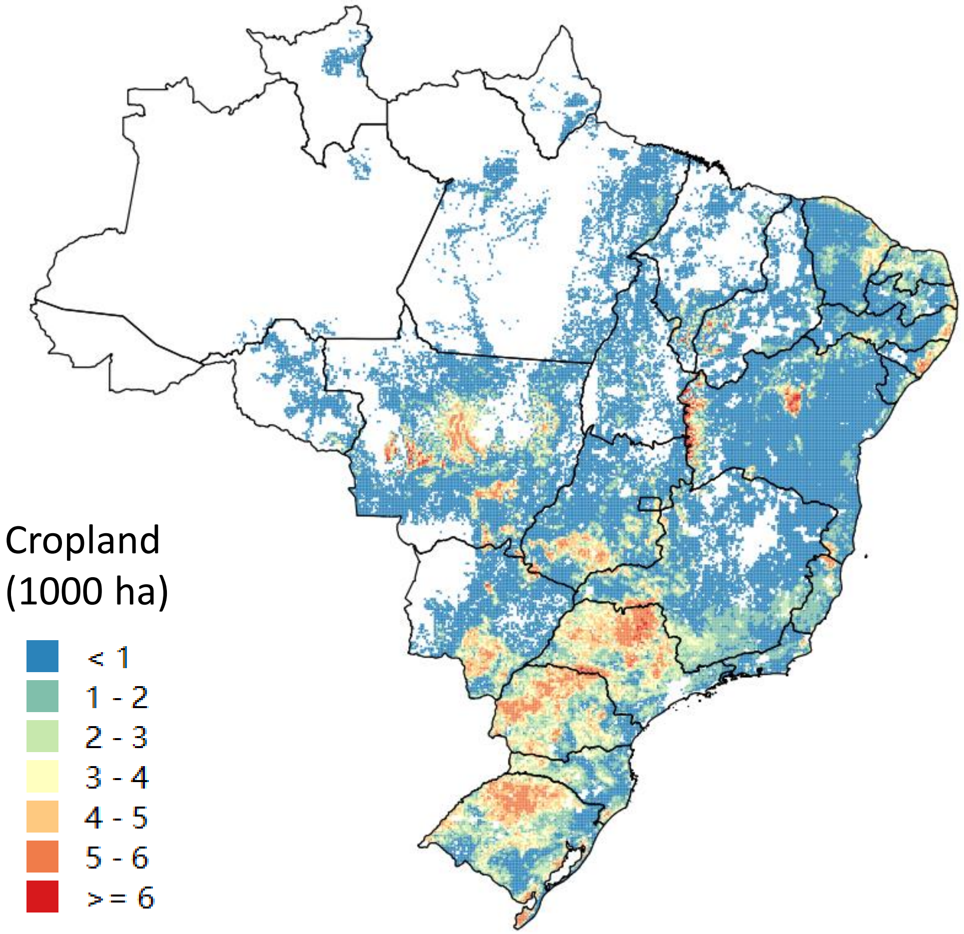
$y = 8.981 + 1.038x \quad R^2 = 0.804$

Coefficients all significant at 0.01 level
Sample size = 2,903

Methodology: SIMPLE-G-Brazil model

Simplified **I**nternational **M**odel of agricultural **P**rices, **L**and use and the **E**nvironment: **G**ridded version for **Brazil** (**SIMPLE-G-Brazil**)

- Grid-resolving partial equilibrium model for crop production and input use
- 50,598 grids in Brazil, 16 regions in rest of the world
- Baseline year: 2017



Cropland area in SGB at baseline

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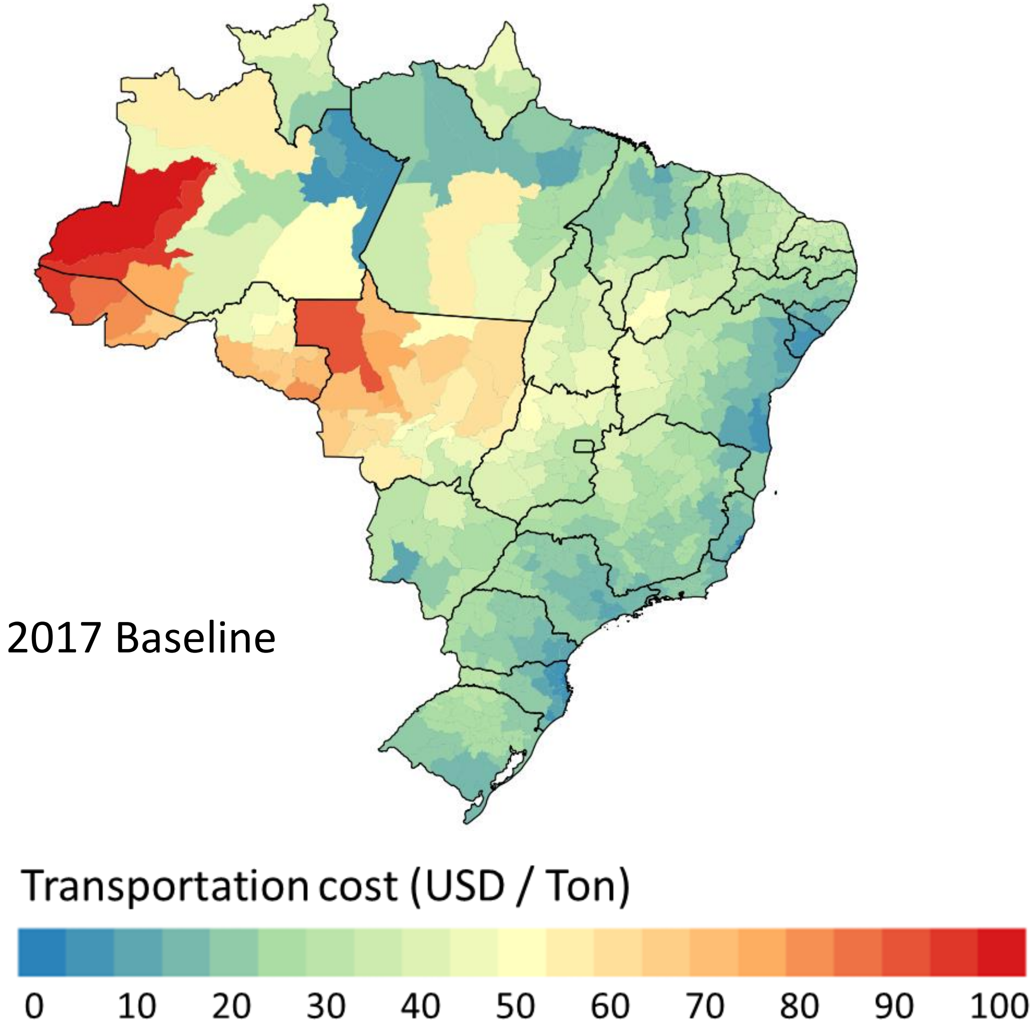
Methodology: Experiments

Interact two transportation cost scenarios with SSP2

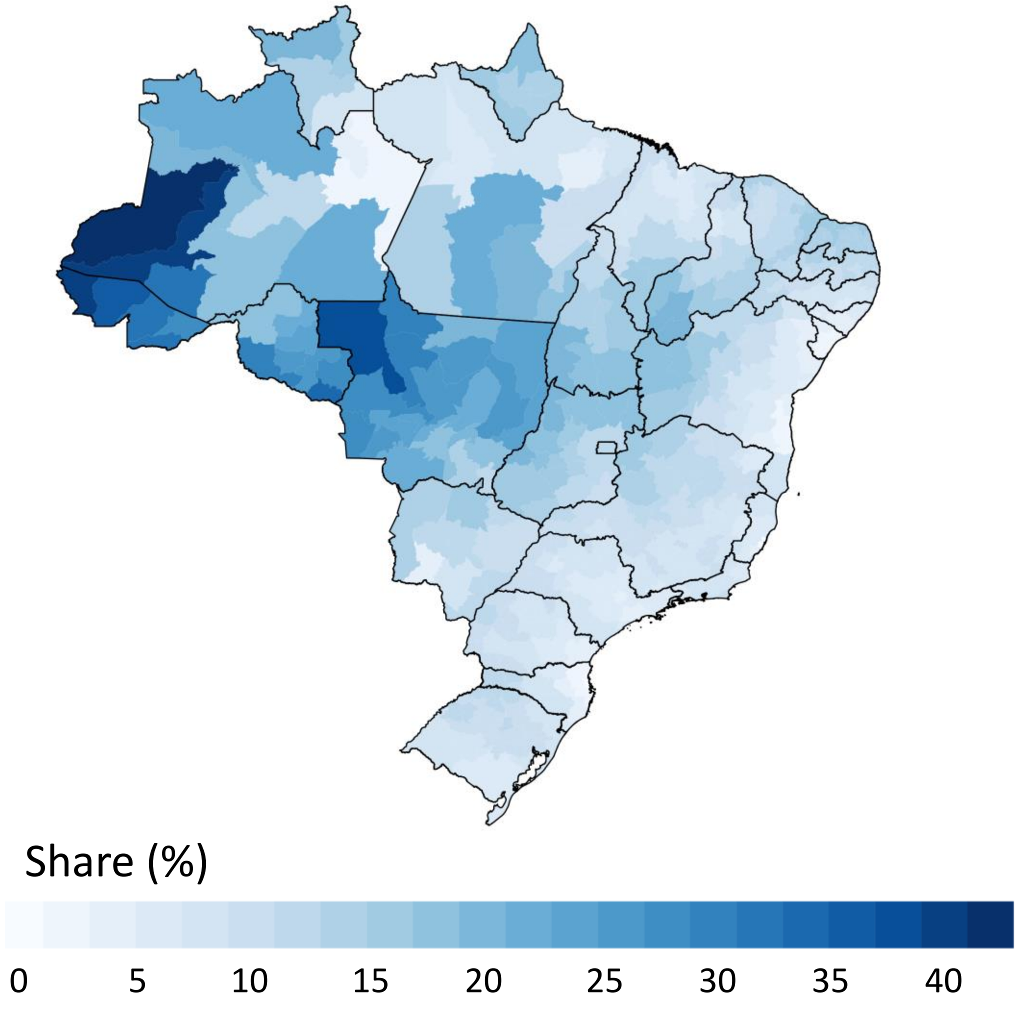
- Transportation cost scenarios:
  1) Transportation cost **reduces** under PNL's maximum improvement plan (**TCR**)
  2) Transportation cost **remains** at 2017 baseline level (Business as usual, **BAU**)

- Socio-economic drivers: population, GDP per capita, technology growths projection under **SSP2**
  - For Brazil: Population increases by 13.3%, GDP per capita increases by 103.6%, agricultural TFP increases by 77.8% during 2017 - 2050
  - Also include drivers for regions from rest of world

Results #1: Estimated transportation cost in Brazil

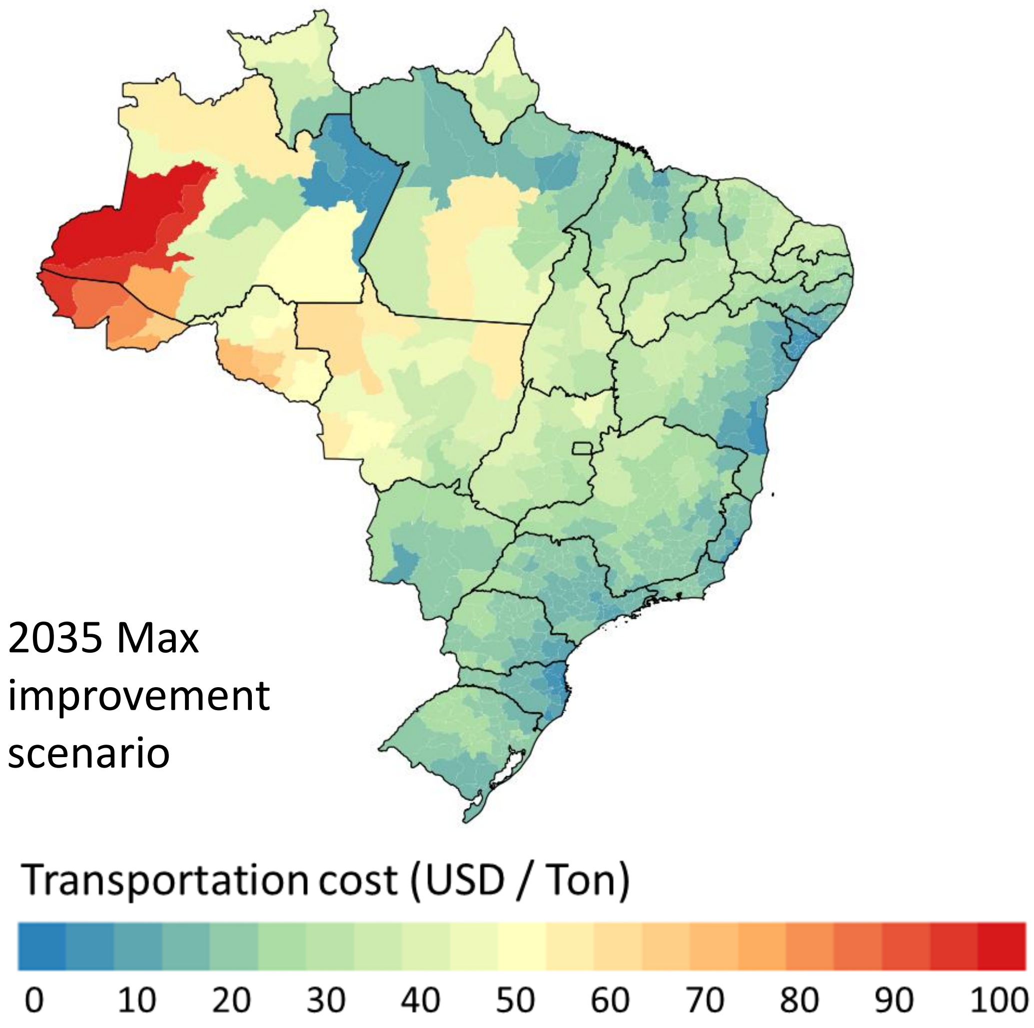


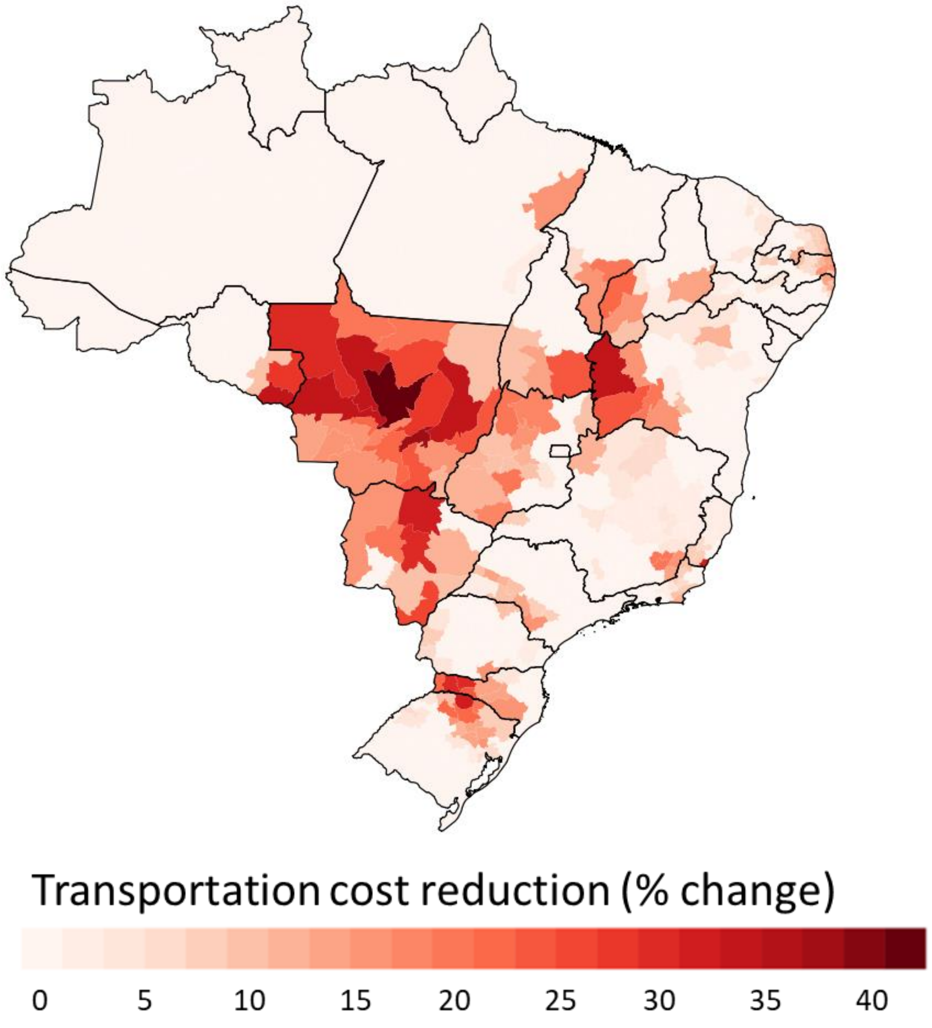
Estimated transportation cost (2017 baseline)



Transportation cost as a share of the FOB price

Results #1: Estimated transportation cost in Brazil





Estimated transportation cost under the ‘max improvement’ scenario

Results #2: Impact of transportation cost reduction

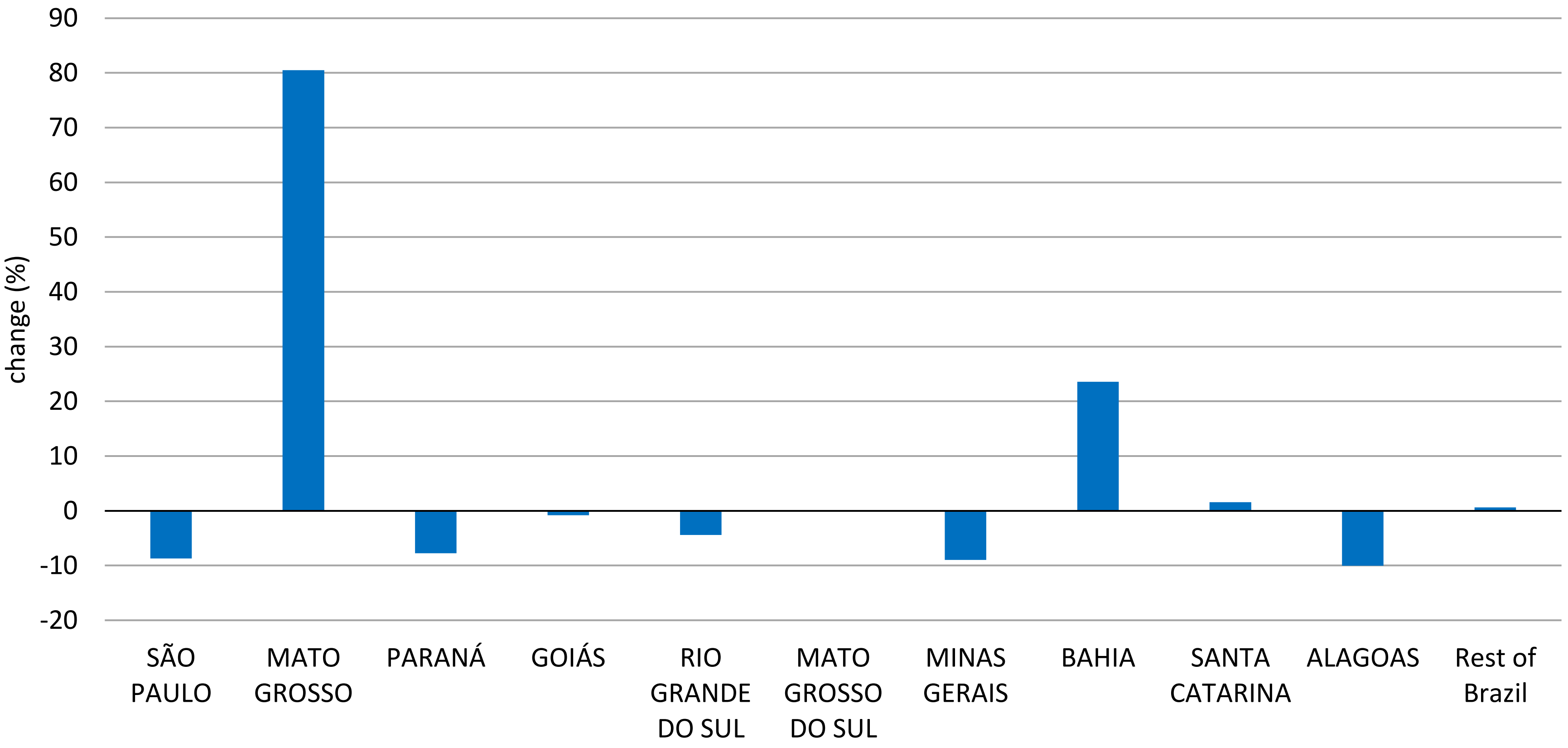
Impact of transportation cost reduction: change from BAU to TCR scenario
(Socio-economic drivers are the same)

National level: compared to BAU, under TCR total crop output increases by 16.21 M Ton (1.34%), and total cropland expands by 0.39 M ha (0.60%)

Results #2: Impact of transportation cost reduction

Impact of transportation cost reduction: change from BAU to TCR scenario
(Socio-economic drivers are the same)

State level: impact on crop output

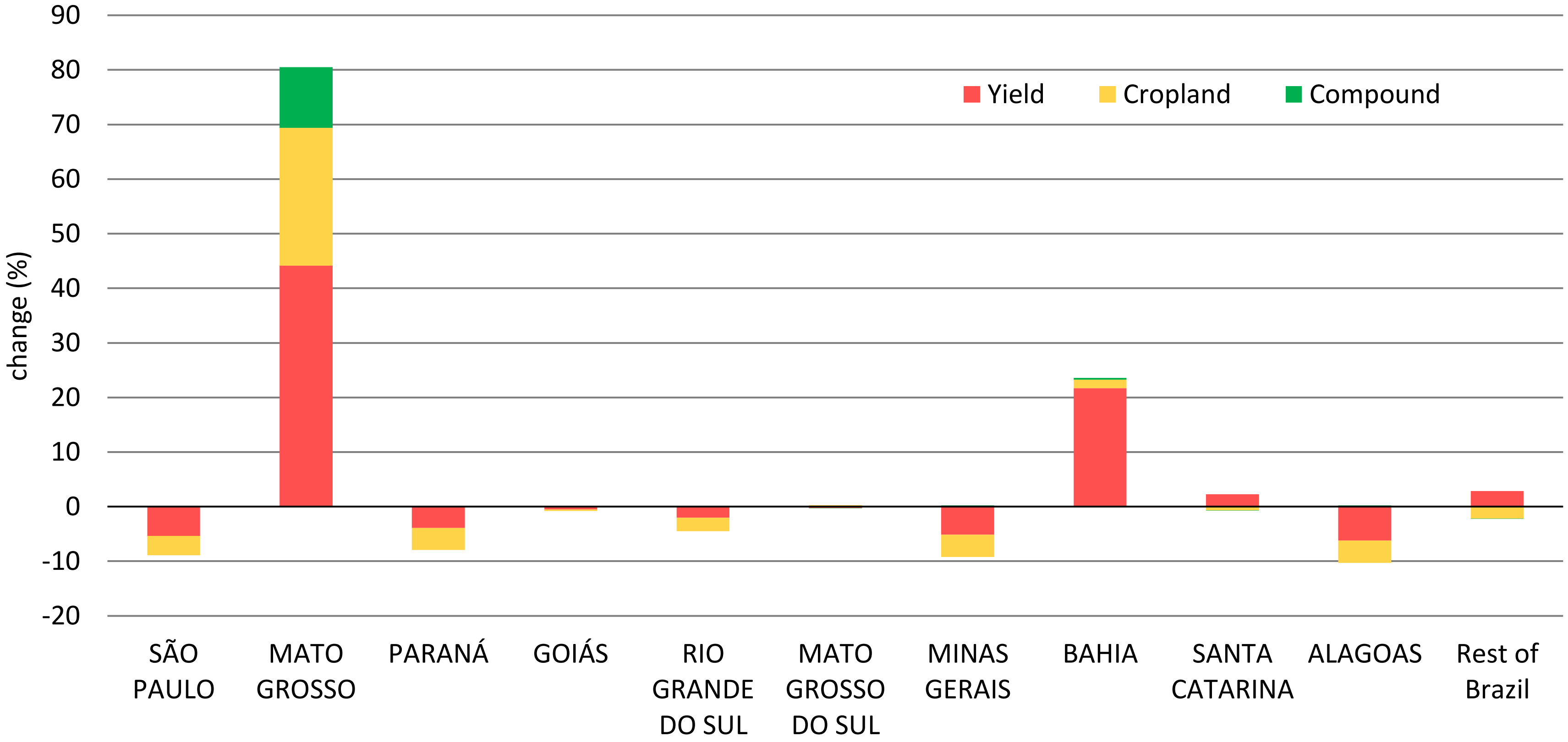


Results #2: Impact of transportation cost reduction

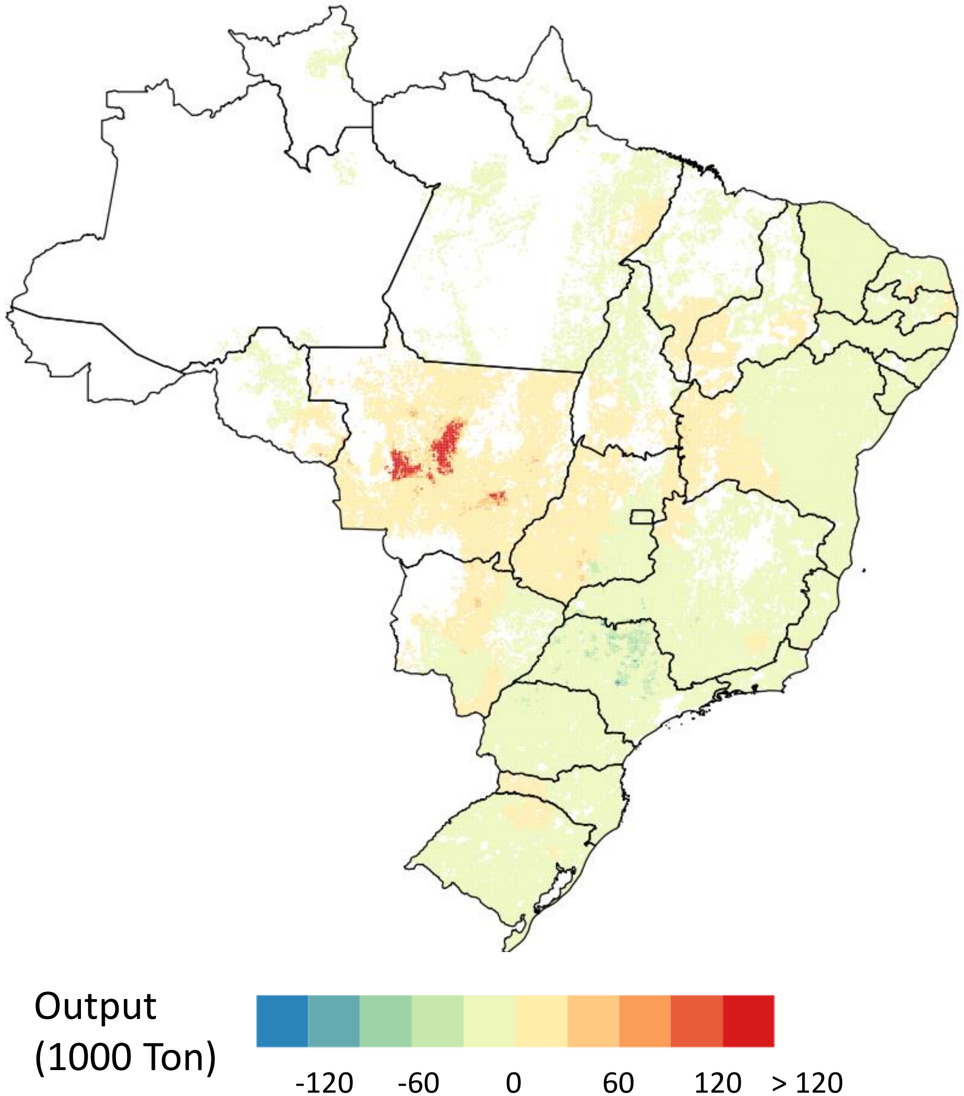
Identify reason of crop output response through **decomposition**:

$$Output = Yield \times Cropland$$

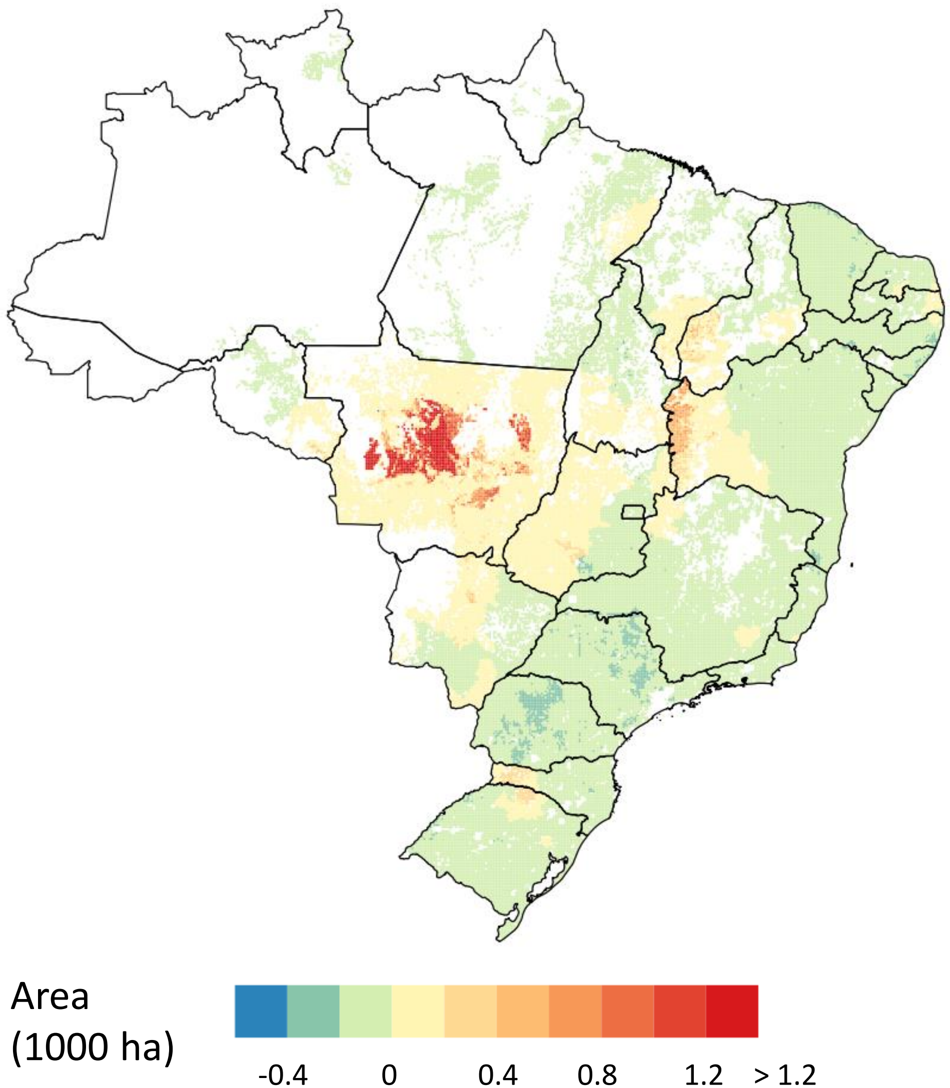
$$\%\Delta Output = \underbrace{\%\Delta Yield}_{\text{Direct effect}} + \underbrace{\%\Delta Cropland}_{\text{Direct effect}} + \underbrace{\%\Delta Yield \times \%\Delta Cropland}_{\text{Compound effect}}$$



Results #3: Impact on crop output and land, grid level



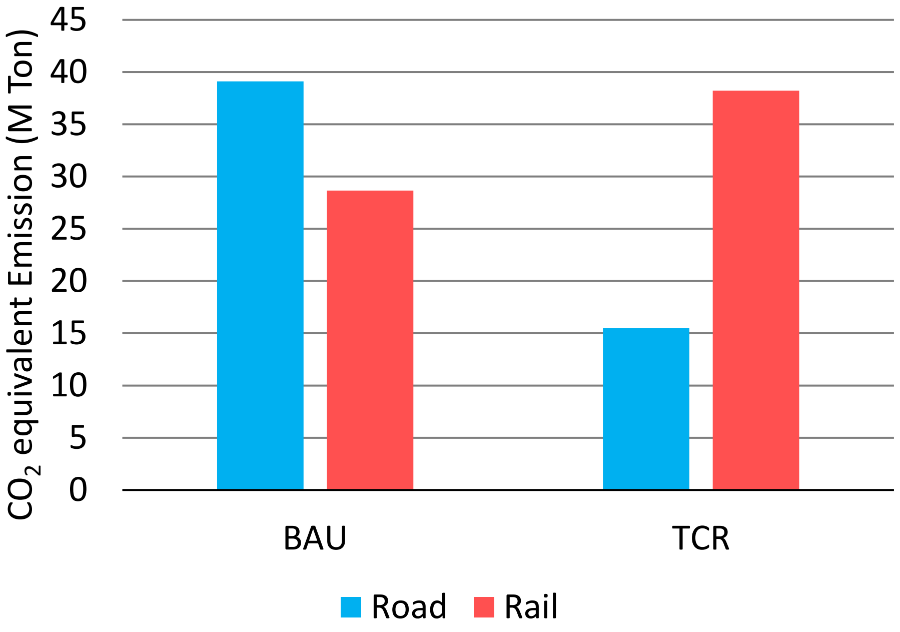
Change of crop output from BAU to TCR under SSP2



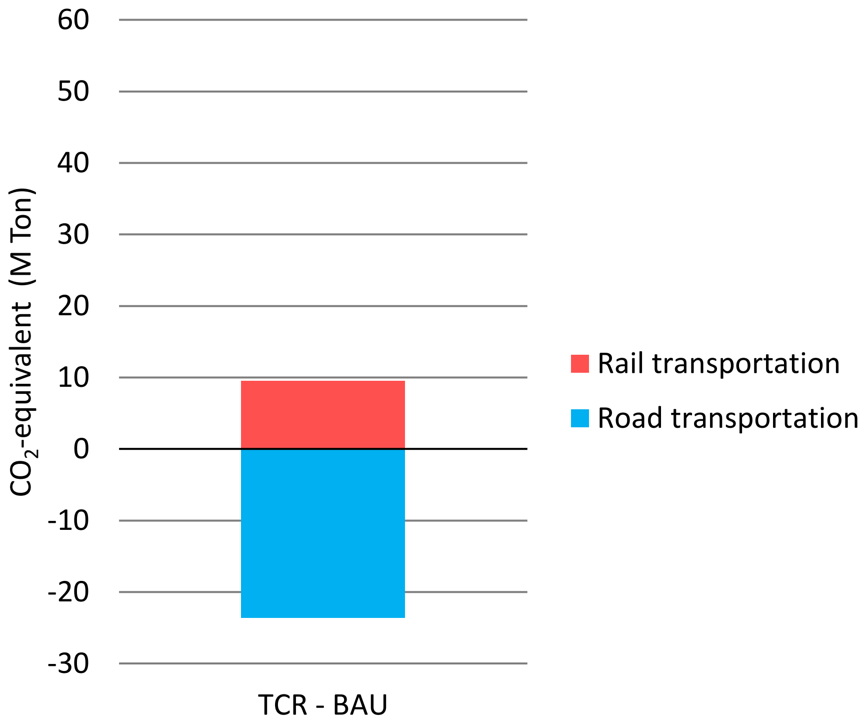
Change of cropland from BAU to TCR under SSP2

Results #4: Impact on carbon balance

CO_2 emission by vehicle: change in distance, method and quantity of crop
→ Emission reduces by 14.06 M Ton (CO_2 equivalent)



CO_2 equivalent emission by vehicle

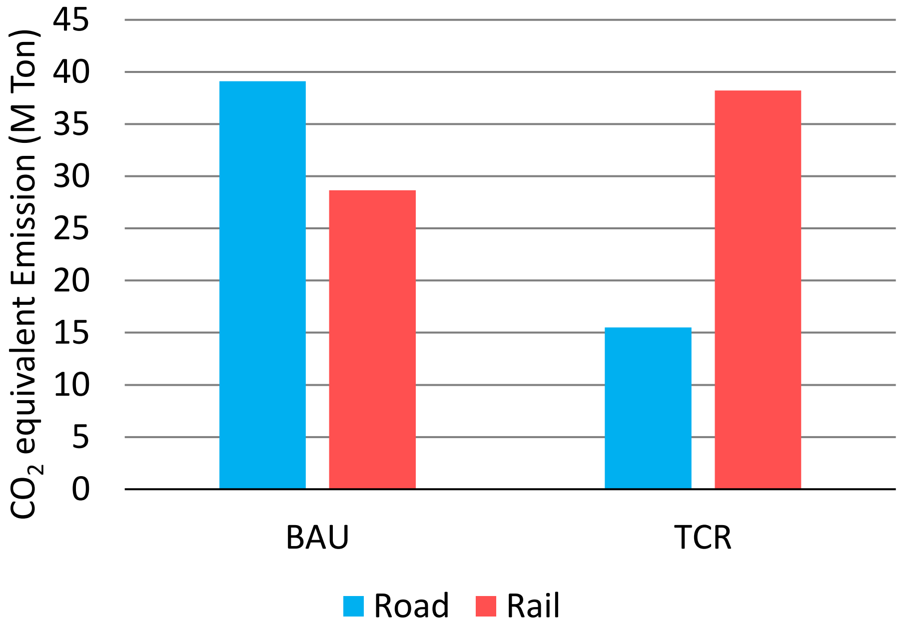


Change in net carbon balance

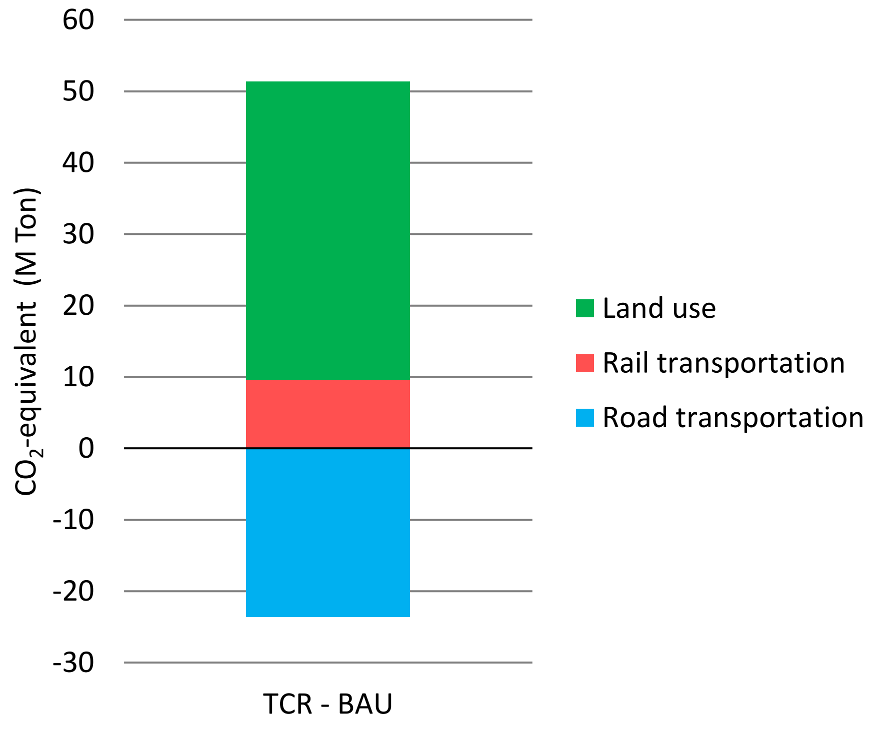
Results #4: Impact on carbon balance

CO_2 emission by vehicle: change in distance, method and quantity of crop
→ Emission reduces by 14.06 M Ton (CO_2 equivalent)

Carbon storage from vegetation: land use conversion
→ Carbon storage reduces by 41.83 M Ton (CO_2 equivalent)



CO_2 equivalent emission by vehicle



Change in net carbon balance

Conclusion

- Transportation cost in the Cerrado region accounts for **around 30%** of **FOB price.**

- Under the max improvement scenario of Brazil’s National Logistic Plan (2035), transportation cost is expected to reduce by **20 – 40 %** in Cerrado region and west Bahia.

- While the national impact is small, transportation cost reduction **changes the crop production pattern across states**, mainly in Mato Grosso and Bahia.

- Crop output change is attributed to **higher yield** driven by more non-land inputs, but also by **cropland expansion** in Mato Grosso.

- Impacts of transportation cost **vary within a state**, indicating the importance of capture **spatial heterogeneity** in research.

- While improved transportation infrastructure **reduces CO_2 equivalent emissions from vehicles**, the benefit is offset by the **lost carbon stock from cropland expansion**.

Reference

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THANK YOU!

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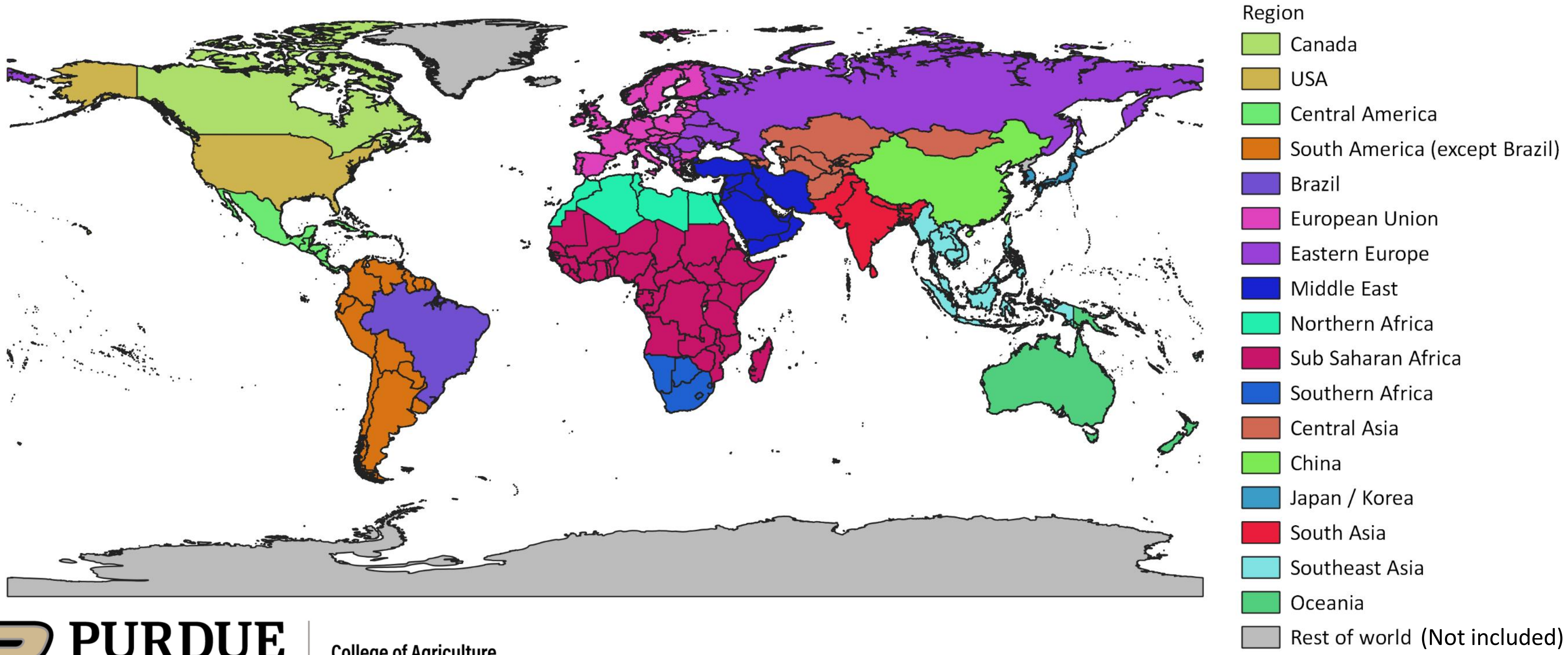
Methodology : SIMPLE-G-Brazil regions

Region aggregation in SGB



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Structure of SGB