IEA Bioenergy
Technology Collaboration Programme

Universidade de São Paulo
Instituto de Química

Marine Biofuels: Friend or Foe of the Climate Change Mitigation Effort?

Glaucia Mendes Souza

Full Professor at the University of São Paulo

Leader of the International Energy Agency Bioenergy TCP **IEA Bioenergy Task 39** Biofuels for Decarbonization of Transportation

SYNTHESIS OF LITERATURE

BIOFUELS AS AN IMMEDIATE AND EFFECTIVE SOLUTION FOR DECARBONIZATION OF TRANSPORTATION

BIOETHANOL: AN ESSENTIAL CONTRIBUTION TO TRANSPORT DECARBONIZATION

Inform and provide clarification on the potential and sustainability of biofuels.

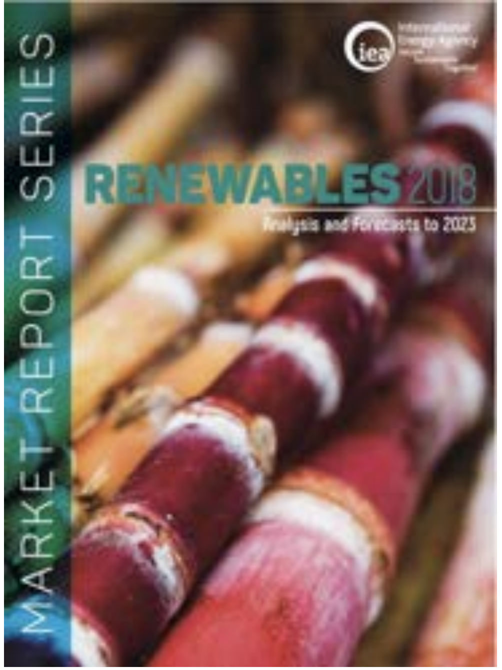
The focus is on biofuels that can be produced sustainably, with sufficient capacity to be relevant for decarbonization efforts.

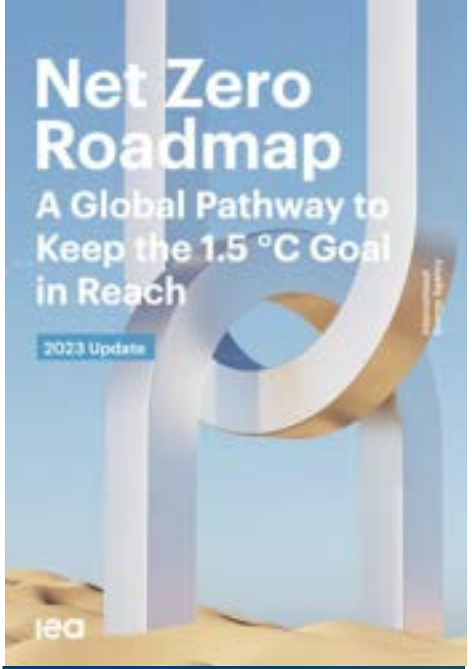
Discuss the Brazilian model of agriculture and its technological developments.

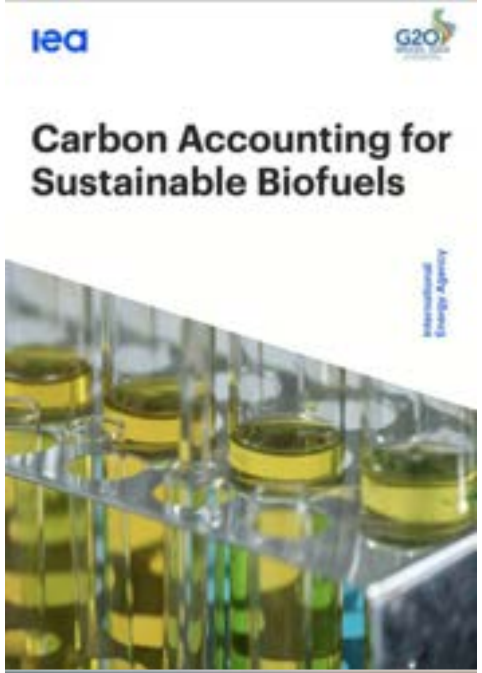
Show how bioenergy is generating social-economic benefits and reducing emissions without the need for extensive land areas.

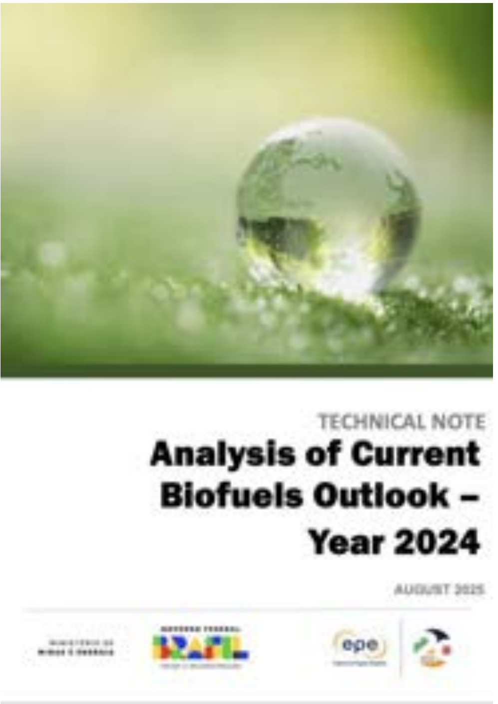
Discuss the potential for biofuel production in the global south.

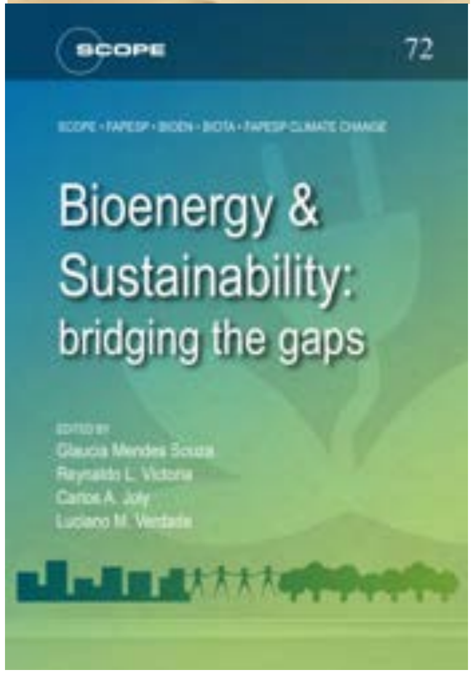
https://bioenfapesp.org/biofuels-as-an-immediate-and-effective-solution-for-decarbonization-of-transportation-factsheet/
https://sbenergy.org.br/bioethanol-an-essential-contribution-to-transport-decarbonization/

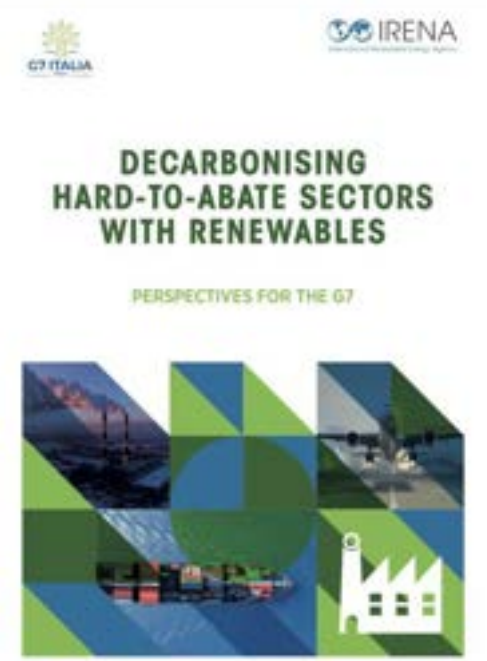


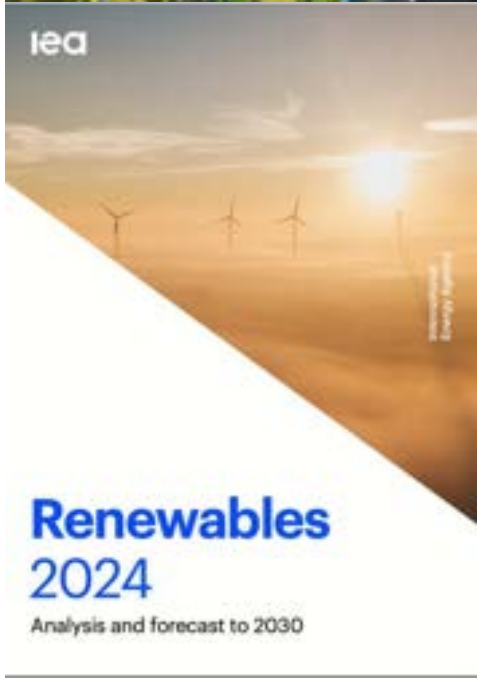


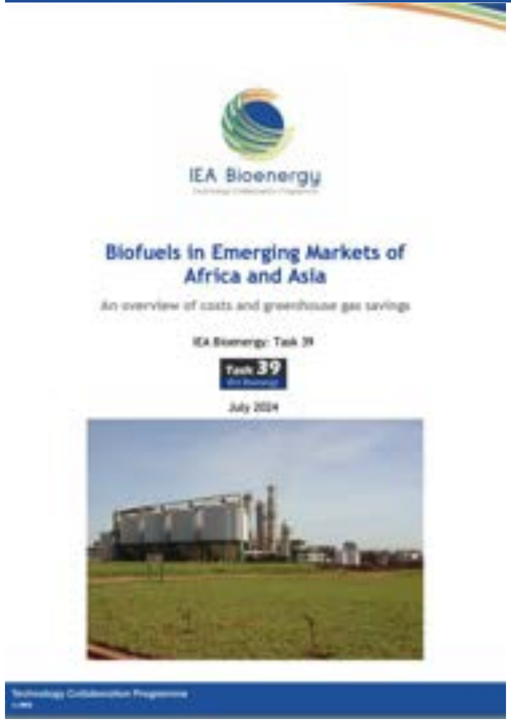












+100 references to major reports and open access high impact scientific articles

Historically, biofuels have reduced oil demand the most bringing in energy security.

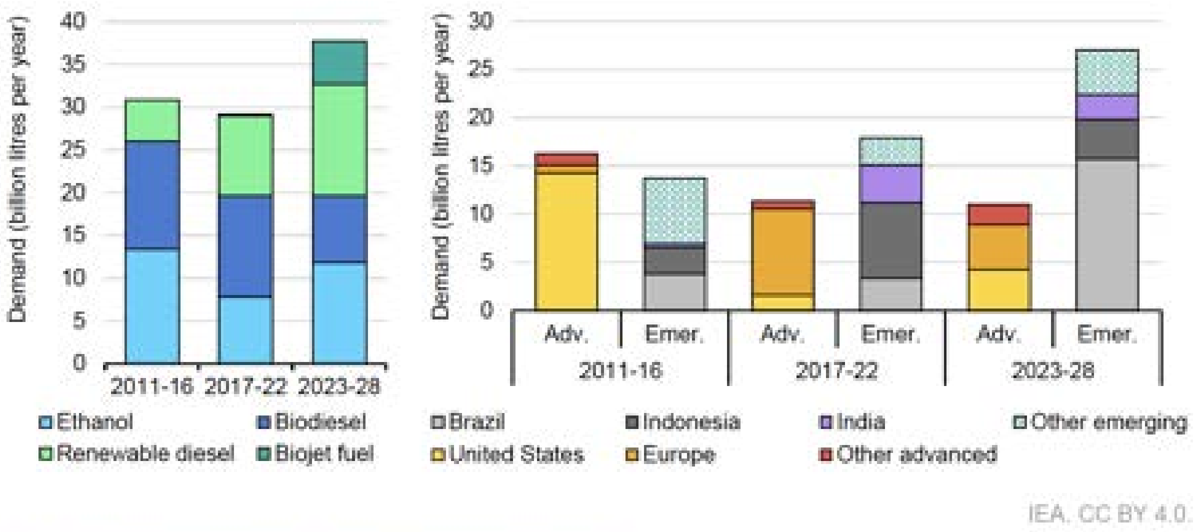
Studies from IEA show emerging economies accelerating growth in biofuels use.

In the United States, Europe and China, renewable electricity use in transport is forecasted to expand.

In much of the rest of the world, however, biofuels remain the primary decarbonisation option, accounting for near 90% of avoided oil demand in 2028.

Globally biofuels increased production in 50% over the last decade.

Five-year biofuel demand growth by fuel (left) and economy type (right), main case, 2011-2028



Notes: Adv. = advanced economies. Emer. = emerging economies.

Brazilian contribution to decarbonization of transportation

1. Largely renewable internal energy offer (50%) with 16.7% derived from sugarcane and 16.6% from other biomass sources
Electricity is 88.2% renewable (BEN, 2025).

2. Transportation is 25.7% renewable
37.3 Billion L/yr of etanol
9.2 Billion L/yr of biodiesel
424 biofuel plants
From 1975 to 2024 Brazil consumed 888 Billion L of ethanol displacing 1.4 Billion ton CO_2eq.
85% of the fleet is flex
(BEN, 2025; EPE, 2024; Nogueira et al., 2024)

3. "Fuel of the Future" legislation. Current target is 705 Mt CO_2 eq by 2037 of avoided emissions. Currently E30 and B15 (B20 by 2030).

4. Biofuels grew at the same time as Brazil became the top exporter of food commodities. Pasture intensification freed up land. Second cropping was introduced.

5. In Brazil, energy crop expansion was predominantly linked to the conversion of degraded lands and pastures with the added benefit of soil recovery and soil carbon sequestration. (Guareghi et al., 2023)

6. Brazil preserves 66% of its territory with native vegetation. Agriculture uses 8%, pastures use 21% and urban areas 4%. (Embrapa, 2021).

Bioenergy & Food Security is not a Zero-Sum Game

+ 1 - 1 = 0

Biofuels production and use can improve energy access, purchasing power,

sustainability of agriculture,

soil health

The effects of bioenergy from edible versus non-edible feedstocks

Food availability
2/3 of the articles reported positive effects or no effects on food availability.
Bioenergy has positive effects on the household scale.

Food prices
Negative effects of bioenergy on food price were concentrated on countries with High Social Development Index (SDI) (3/4).

Food production
Bioenergy has positive effects on food production in low Social Development Index (most of the Global South) countries and at the household scale.

Bioenergy on low SDI countries has no effect on food prices.

Studies that report negative effects are most commonly based on modeling.
When observed data was used the reporting of negative impacts was lower.

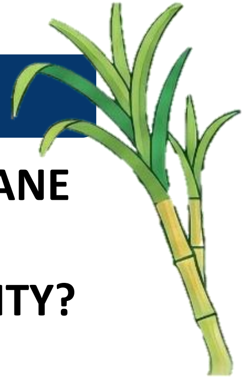
224 papers

<u>There is no correlation</u> between the type of bioenergy feedstock (edible, inedible, or both edible and inedible) and food security

Ahmed, S., Warne, T., Smith, E., Goemann, H., Linse, G., Greenwood, M., Kedziora, J., Sapp, M., Kraner, D., Roemer, K., Haggerty, J. H., Jarchow, M., Swanson, D., Poulter, B. and Stoy, P. C. (2021). Systematic review on effects of bioenergy from edible versus inedible feedstocks on food security. Science of Food (2021) 5:9

Revisiting the hypothesized trade-off between food and fuel
Empirical evidence from the case of Brazilian sugarcane

RESEARCH QUESTION



CAN INCREASES IN SUGARCANE ETHANOL PRODUCTION COMPROMISE FOOD SECURITY?

METHODOLOGY

MUNICIPAL LEVEL

- **Food security proxy:** Municipal Human Development Index (IDHM)
- **Database:** Demographic censuses
- (+5,000 municipality)
- **Econometric approach:** Panel data
- **Control variables:** Social and economic factors (Employment, Income, Gini Index, Bolsa Família)

+

HOUSEHOLD LEVEL

- **Food security proxy:** Brazilian Food Insecurity Scale (EBIA)
- **Database:** Microdata from three household surveys conducted in Brazil by IBGE
- **Econometric approach:** Probit models
- **Control variables:** Regional, demographic and socio-economics household characteristics and Bolsa Familia

RESULTS

NO EVIDENCE OF A FOOD-FUEL TRADE-OFF

The analysis found no statistical evidence that increased sugarcane ethanol production compromises food security in Brazil

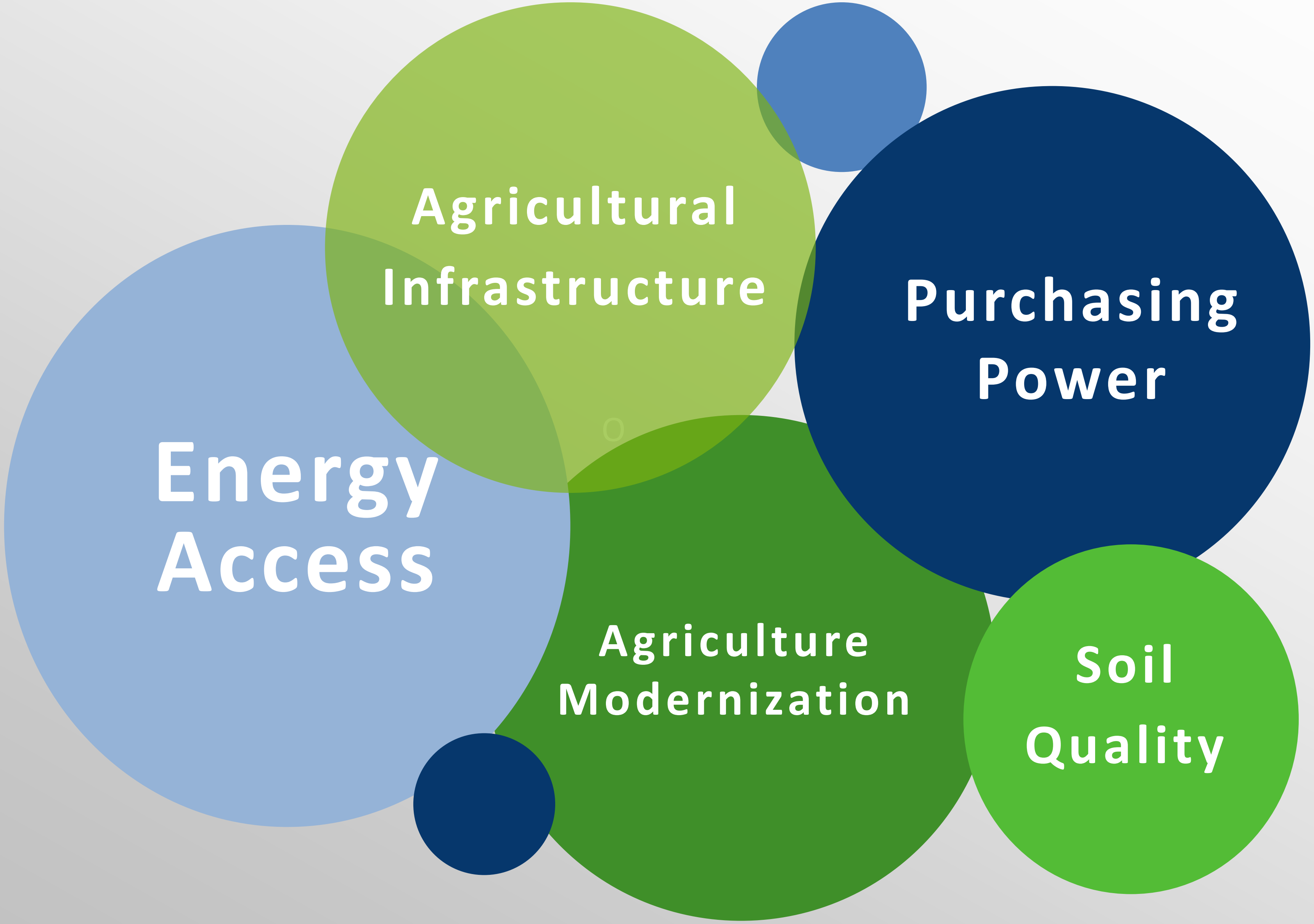
FOOD SECURITY IS DRIVEN BY SOCIAL CONDITIONS

The results strongly suggest that social and economic factors (such as income, poverty, and social policies) exert a much greater influence on food security than sugarcane ethanol production

LINKING BIOFUELS TO FOOD INSECURITY IS MISLEADING; THERE IS NO INHERENT FOOD–FUEL TRADE-OFF, AND IMPACTS MUST BE ASSESSED CASE BY CASE.

SOURCE: **Justus, et al (2025).** *Revisiting the hypothesized trade-off between food and fuel: Empirical evidence from the case of Brazilian sugarcane.* GCB Bioenergy, 17, e70085. https://doi.org/10.1111/gcbb.70085

Observed changes brought by bioenergy that contribute to food security



Observed changes brought by bioenergy that contribute to food security: purchasing power

Improved socio-economic indicators:

Literacy and schooling years

Wages

Formalization of work and working conditions

Next generations outlook (daughters and sons of workers)

↑ GDP per capita in municipalities hosting bioethanol companies

A new mill increased the municipalities GDP per capta in US$ 1,098 (first year) and US$ 1,029 (10-yr)

70,000 small sugarcane producers

75,000 small soybean producers

Job opportunities (↑biodiesel = 1.1 million new jobs added in the soybean industry in the last decade)

Purchasing Power

Moraes, M. A. F. D., Oliveira, F. C. R. and Diaz-Chavez, R. A. (2015). Socio-economic impacts of Brazilian sugarcane industry. Environ. Dev. 16,31-43.
Moraes, M. A. F. D., Bacchi, M. R. P. and Caldarelli, C. E. (2016). Accelerated growth of the sugarcane, sugar, and ethanol sectors in Brazil (2000–2008): Effects on municipal gross domestic product per capita in the south-central region. Biomass Bioenergy 91,116–25.
https://unicadata.com.br/listagem.php?idMn=158

Observed changes brought by bioenergy that contribute to food security: increased energy access

666 to 730 million people do not have electricity in the world (80% in rural areas)

SDG7 is stagnant (IRENA, 2023; IEA, 2025)

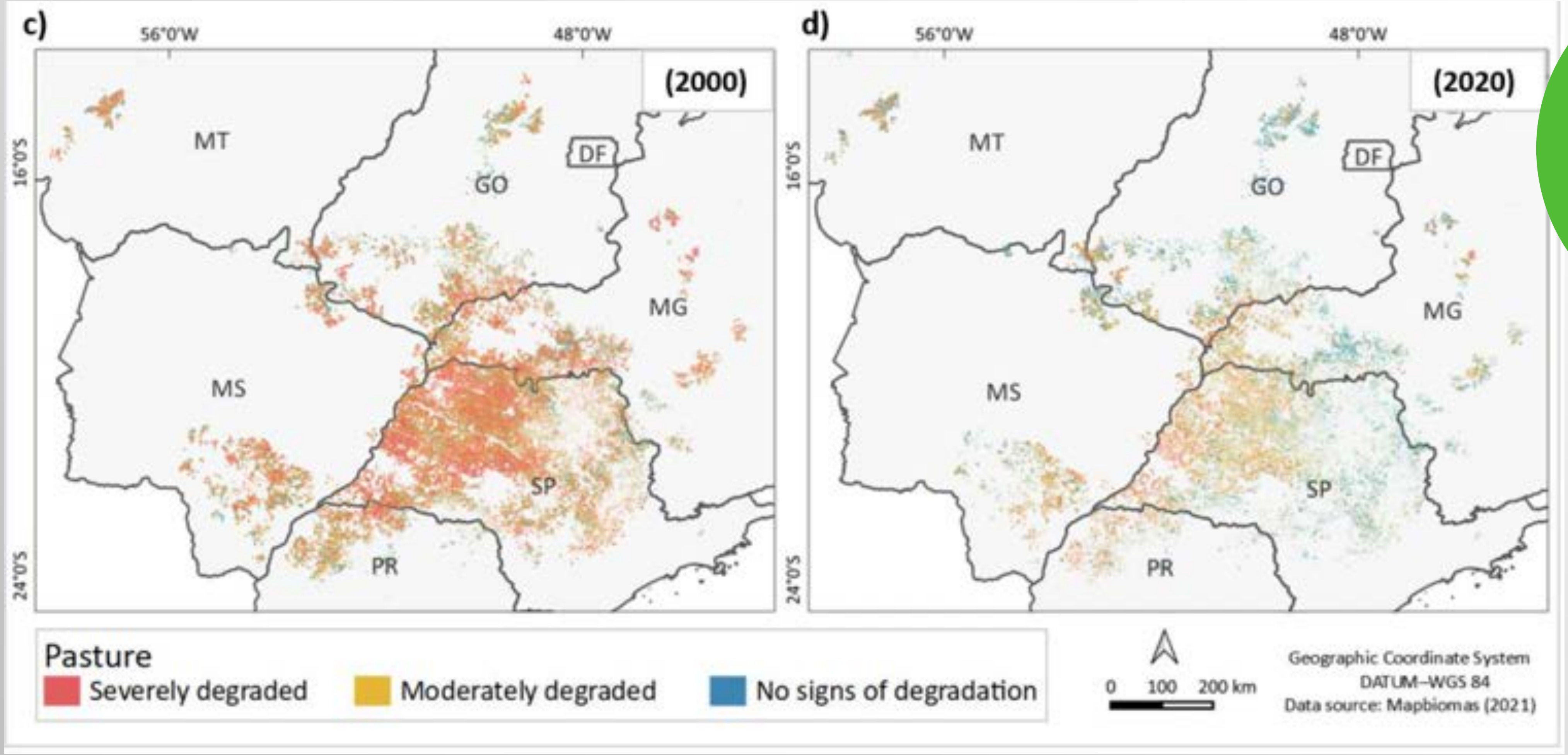
Food security increases with energy access.

Cane bioelectricity can power 10.8 million homes increasing energy access in rural regions.

Energy Access

In addition to meeting the internal energy demands of sugar mills, sugarcane bagasse has been used to generate surplus electricity since the 1980s, which is supplied to the Brazilian power grid. In 2024, sugarcane residues accounted for 75% of all bioelectricity fed into the grid, totaling 21,218 GWh. (UNICA, 2024).

Observed changes brought by bioenergy that contribute to food security: recuperating degraded land and increasing soil carbon



Soil Quality

98% of sugarcane expansion has occurred mainly over degraded pastures and land in use for agriculture in the last 20 years

M.M. Guarenghi, D.F.T. Garofalo, J.E.A. Seabra, M.M.R. Moreira, R.M.L. Novaes, N.P. Ramos, S.F. Nogueira, C.A. de Andrade. Land Use Change Net Removals Associated with Sugarcane in Brazil. Land 2023, 12(3), 584

Agriculture Modernization

Best Management practices exist that can increase sustainability

Beyond feedstock classifications, what matters most is how it is cultivated

Biofuels

Used in farming equipment, reduces emissions.

Use of residues

Organic residues are used instead of mineral fertilizers. Filter cake is composted to mineralize nutrients.

Biological Control

Pests such as Diatrae saccharalis, Mahanarva fimbriolata, Sphenophorus laevis, controlled through biological control.

Vinasse Recycling

Micronutrients (K, S, N, Ca, P) that substitute K fertilizer. Vinasse mixed with other nutrients applied in rows, all nutrients in one operation.

Weed Control

Herbicides applied by drones, greater accuracy and less amount of products.

Biodigestion

Filter cake and vinasse can be biodigested to produce energy without losses of nutrients.

Native Vegetation Preservation

Properties must maintain 20% of area as forests and riparian regions (20 to 50 m), improving biodiversity, soil and water conservation

New Varieties

Breeding for locally adapted climate resilent cultivars, biotechnological tools for improved yields and disease resistance.

Soil Preparation and Amendments

Planting in beds, no-till or minimum till. Lime and gypsum applied only in beds and rows. Reduces GHG emissions. GPS for traffic control, avoiding soil compaction.

Fertilization

Adoption of low C fertilizer sources, balanced nutrient doses, organomineral fertilizers, compost, live manure.

Biofertilizers and Bioinputs

Enhance sugarcane metabolic efficiency, improves soil+plant microbial interaction, greater nutrient uptake, increased yields

Food-Energy Integrated Systems

Soy + Livestok integrated systems; soy + livestock + forestry integrated systems; soy as an intermediate crop for cereals. Spare-land technologies with Low-ILUC.

Straw Layer

4-10 ton dry matter/yr protects soil from erosion, maintains soil water, recycles nutrients.

Irrigation and Fertirrigation

Precision water management, low C fertilizer sources, balanced nutrient doses, organomineral fertilizers, compost, manure

Crop rotation

Soybean, peanuts, cultivated in replanting areas reduce fertilizer use and improve biodiversity. Corn adds biofuels & feed (DDG). Low-ILUC risk.

Precision Agriculture

Sensors into planters, haversters, agricultural equipment, enhances efficiency, minimizes soil compaction, row trampling and fuel use.

Biofuels produced in Brazil have very low emissions, one reason being we save on fertilizers, one of the main contributers to emissions

Sugarcane production is alternated with cultivation of peanuts and soybeans in the areas of sugarcane field reform

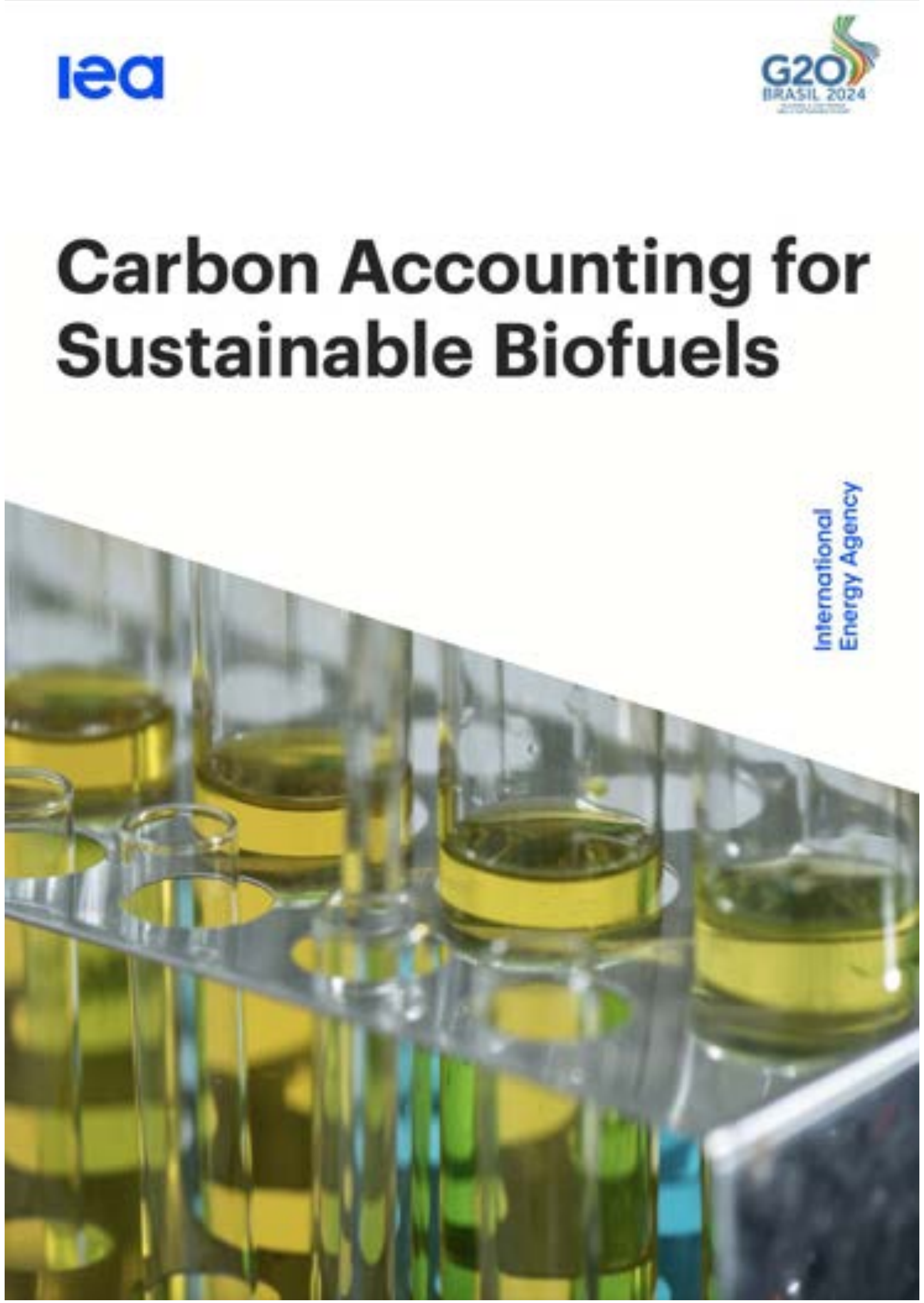
Corn as an intermediate crop with soybean

Up to 98% emissions reduction in relation to fossil fuels

This dual planting system takes advantage of the capacity for nitrogen fixation that legume species (such as soy and peanuts) have which brings nitrogen to soils reducing the need for fertilization

Dual planting systems have a direct effect on land productivity
Annual output per hectare increases by ~1.6-2.0x relative to single-crop system

Gurgel et al. (2024). Contribution of double-cropped maize ethanol in Brazil to sustainable development. Nature Sustainability, 1-12.; Silva et al., (2025).Meta-analysis of biofuels in emerging markets of Africa and Asia: green house gas savings and economic feasibility. Renewable and Sustainable Energy Reviews 213: 115465



"Policies should be <u>technology neutral and feedstock agnostic</u>".

ILUC numbers cannot be used to negate the effectiveness of biofuels to decarbonize transportation

(International Energy Agency Carbon Accounting for Sustainable Biofuels Report, 2024).

R.M.L. Novaes et al. Energy Policy 210 (2026) 115035

Fig. 1. Five main measures to allow for the deployment of sustainable biofuels on a sufficient scale to promote the energy transition while minimizing high ILUC risks.

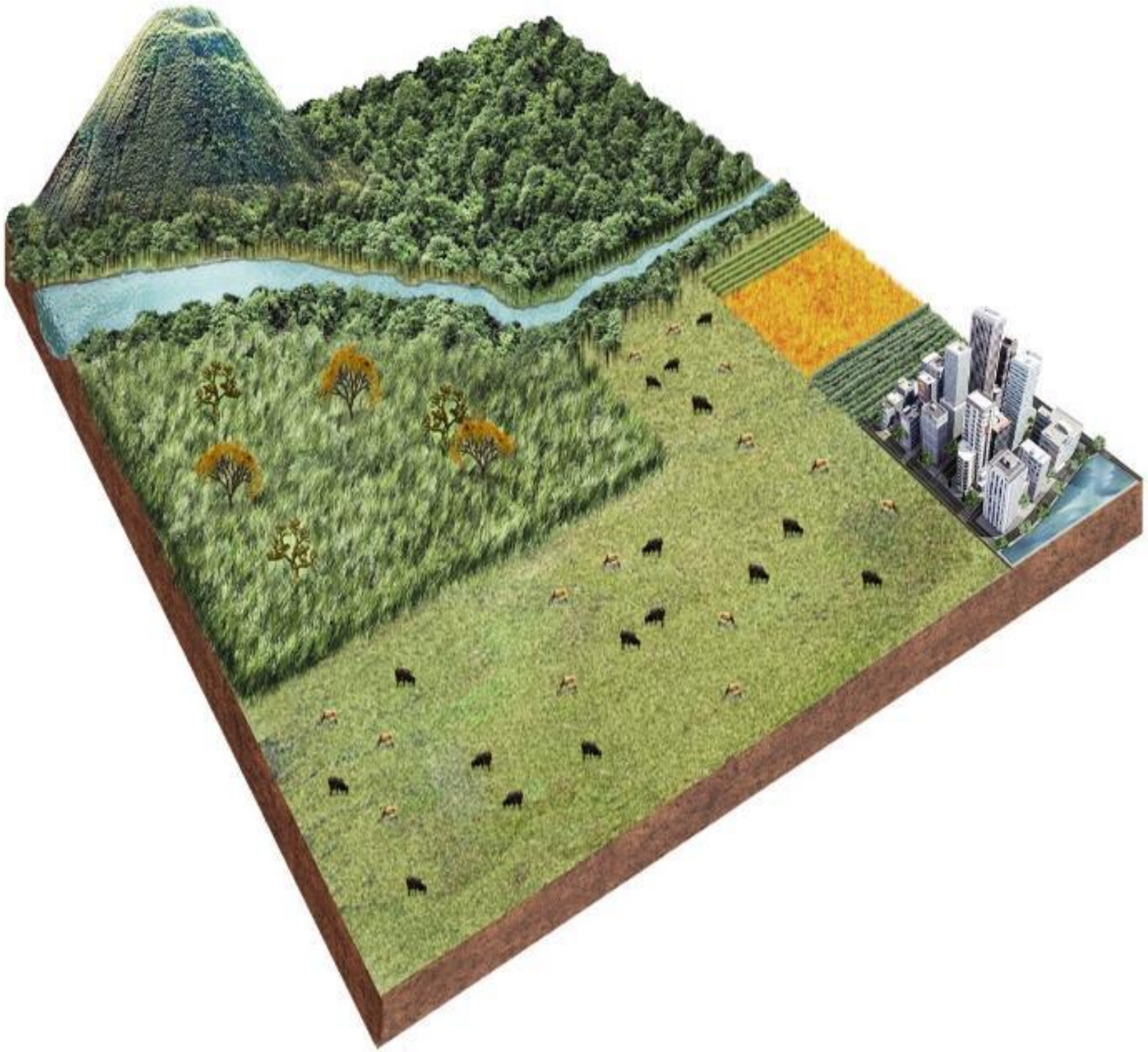
Brazil preserves the largest area in the world in native vegetation

FOREST CODE

Brazilian territory occupies 852 million ha
66% preserved with forests: 33% in rural properties + 33% preserved with integral conservation units, indigenous units and others
Rural producers must maintain at least 20% of their own area with preserved or recovering native vegetation.
In the Amazon, the minimum preservation is 80%.

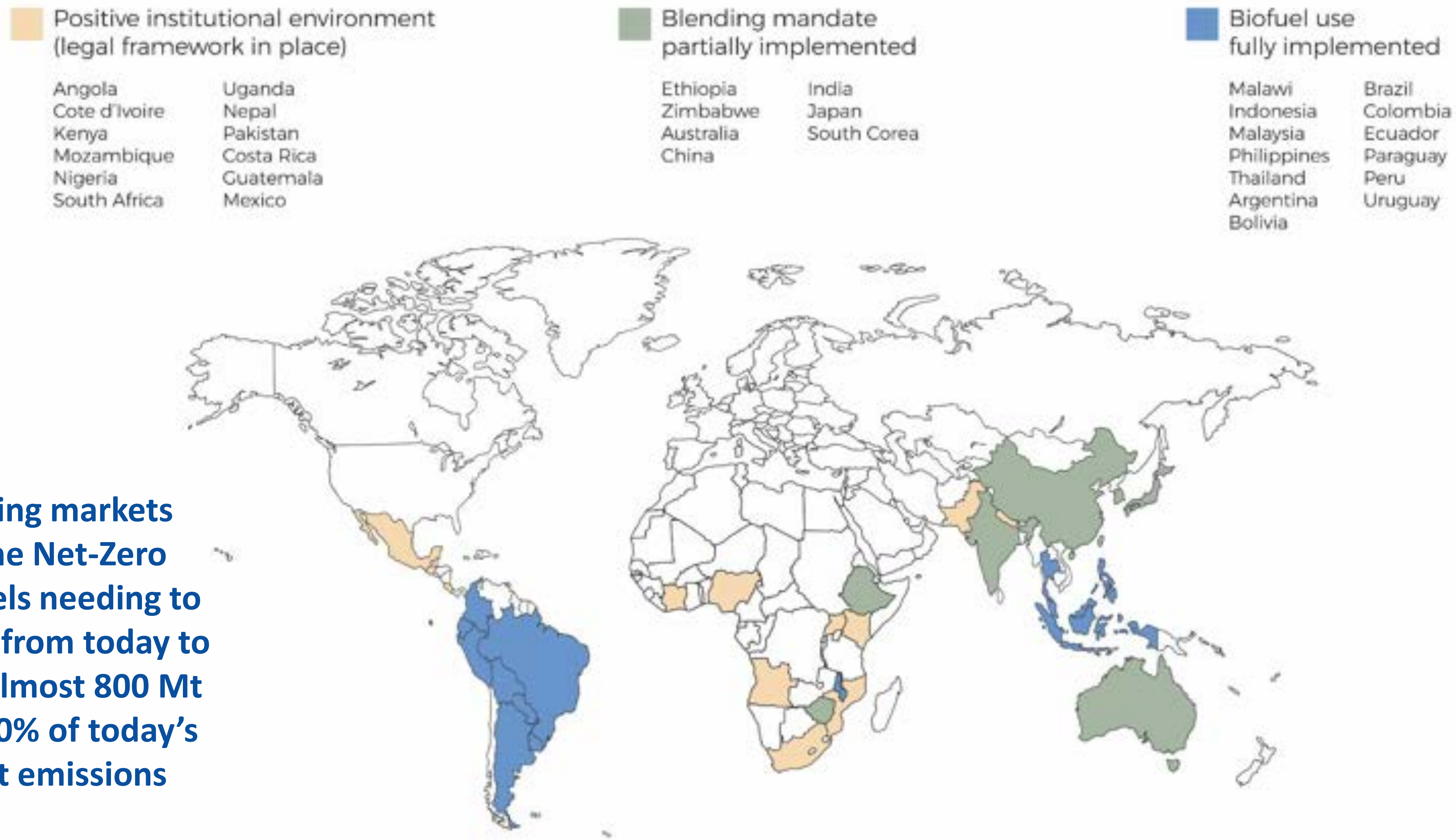
RENOVABIO

Cradle-to-wheel life cycle analysis + Elegibility Criteria:
Traceability of feedstock, a ban on conversion of native vegetation, fullfilment of the environmental legislation and compliance with the agroecological zoning
Compliance verified at plant level



Agroicone, based on LAPIG (2022) for pasture; Mapbiomas (2023) 9th collection; Mapbiomas (2022) for protected areas (8th collection); *Observatório do Código Florestal* (2024) for vegetation on farms. Note*: Calculations for all categories are considered the best in 2024 since the Brazilian government does not provide official data. *Includes undesignated public areas, public forests, settlements and quilombola area; **Includes forestry, mosaics, etc.

BIOFUELS BLENDING MANDATES ACROSS THE GLOBAL SOUTH



How can emerging markets contribute to the Net-Zero Scenario of biofuels needing to grow by 2.5 times from today to 2030, displacing almost 800 Mt of fossil CO_2, or 10% of today's global transport emissions

Souza et al., 2023. Biofuels in Emerging Markets. Potential for sustainable production and consumption. IEA Bioenergy Task 39.
Canabarro, N.I.; Silva-Ortiz, P.; Nogueira, L.A.H.; Cantarella, H.; Maciel Filho, R.; Souza, G.M. (2023). Sustainability assessment of ethanol and biodiesel production in Argentina, Brazil, Colombia, and Guatemala. Renewable & Sustainable Energy Reviews. 171: 113019.

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Biofuels potential and sustainability in emerging markets

Additional biofuel production

45.7 bi liters of biodiesel

64.7 bi liters of etanol

Required conversion of pastureland: 0.1% to 10.7%

Potential GHG savings > 300 Mt CO_2e per year

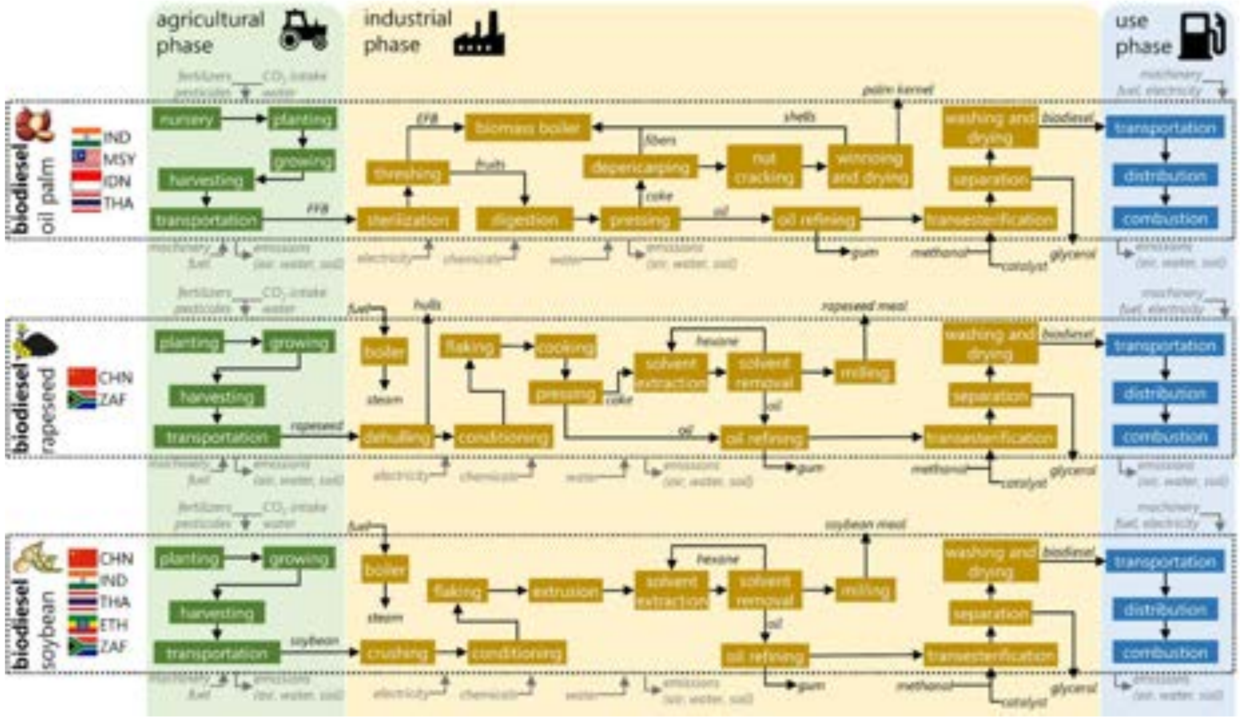
Developing countries with large populations and potential for high energy demand
Argentina, Brazil, China, Colombia, Ethiopia, Guatemala, India, Indonesia, Malaysia, South Africa, Thailand

47.0% of the world's population
27.0% of the CO_2 emissions of the transportation sector

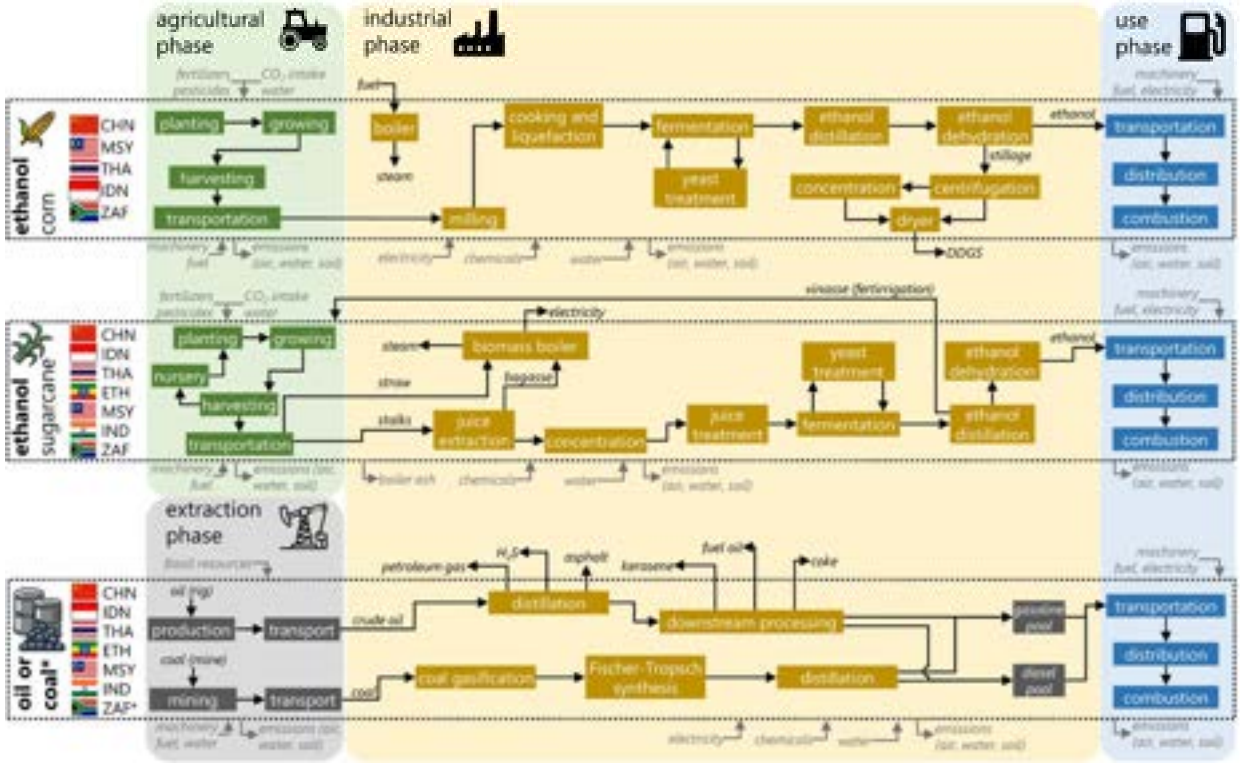
If this group of emerging economies were to achieve the same per capita carbon intensity of the transportation sector as the OECD average, worldwide emissions of the transportation sector would more than double.

SILVA et al. (2025). Meta-data analysis of biofuels in emerging markets of Africa and Asia: Greenhouse gas savings and economic feasibility. RENEWABLE & SUSTAINABLE ENERGY REVIEWS, v. 213, p. 115465. Souza et al. 2023. Biofuels in Emerging Markets. Potential for sustainable production and consumption. IEA Bioenergy Task 39.; Silva et al., (2024). Biofuels in Emerging Markets of Africa and Asia. IEA Bioenergy, 2024.

Fuel production models



Biodiesel (oil palm, rapeseed, and soybean)



Ethanol (corn and sugarcane) and fossil fuels

SILVA et al. (2025). Meta-data analysis of biofuels in emerging markets of Africa and Asia: Greenhouse gas savings and economic feasibility. RENEWABLE & SUSTAINABLE ENERGY REVIEWS, v. 213, p. 115465.

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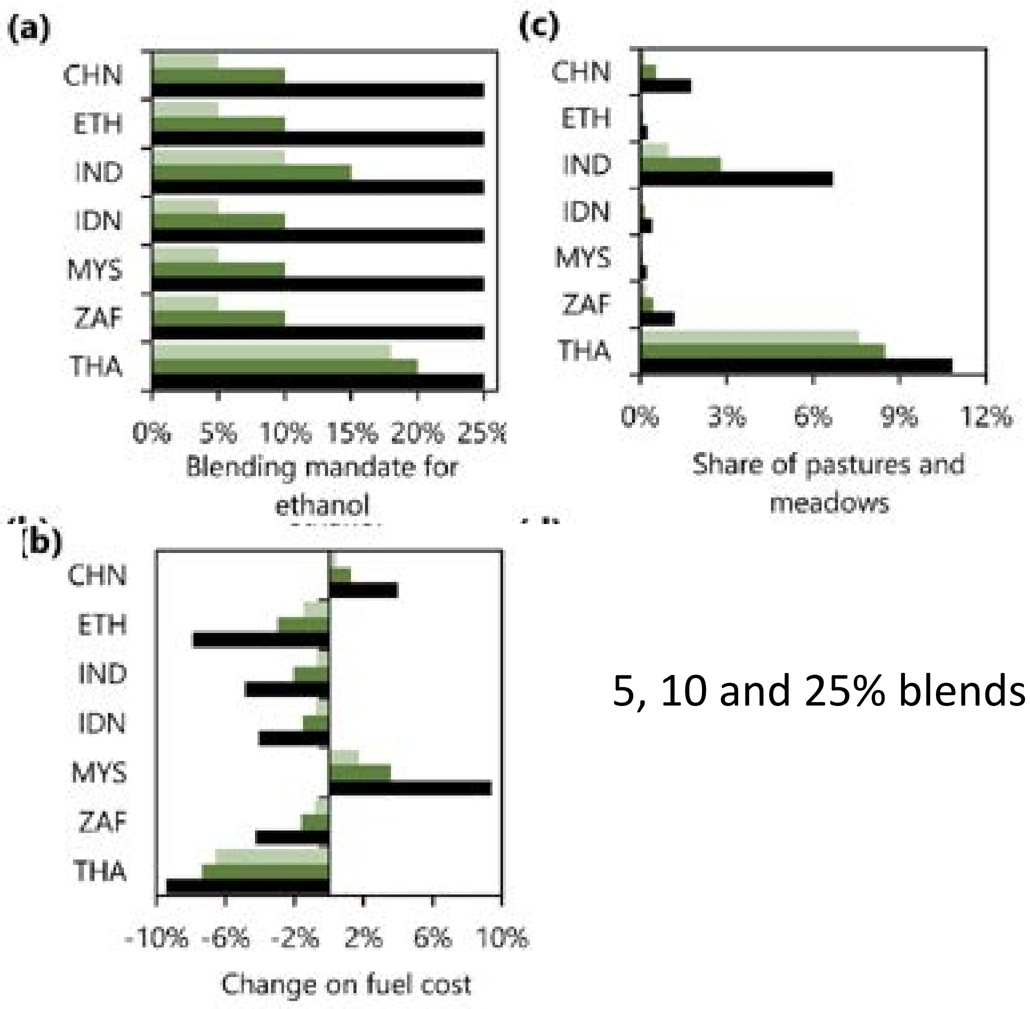
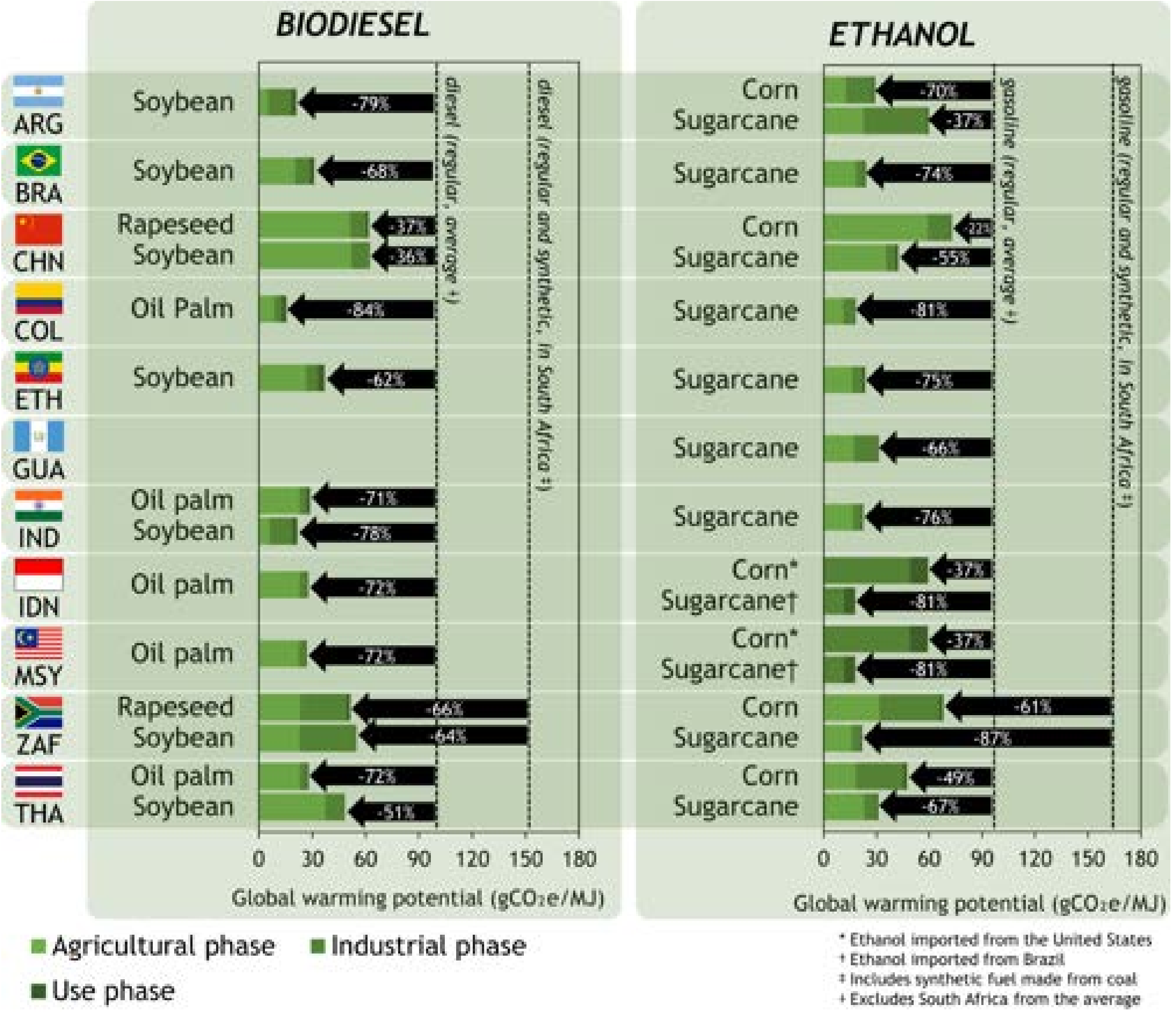
Using very little land...

Avoided emissions of 211 MtCO2eq/yr (moderate scenario)



5, 10 and 25% blends



SILVA et al. (2025). RENEWABLE & SUSTAINABLE ENERGY REVIEWS, v. 213, p. 115465.

IS IT A FRIEND OR A FOE BIOFUEL?

Type of biofuel?

It helps if the technology is mature, economically competitive, commercially available in the scales needed and adapted to local conditions.

Type of feedstock?

Use of best management practices, high yields, with consolidated supply chains.

Available infrastructure?

The urgency of climate change and the high costs of abatement require immediately deployable biofuels that can use available infrastructure whenever possible.

Food versus Fuel?

There is ample evidence that biofuels are not associated to fluctuations on food prices and that food insecurity is not correlated to the feedstock being edible versus non-edible.

Sustainability guardrails?

Proven GHG emissions reduction, compliance with agroecological zoning, no deforestation, good governance on ecosystem services preservation, improved socioeconomical indicators

THANK YOU!

IMO
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Glaucia Mendes Souza
University of São Paulo (USP)
glmsouza@iq.usp.br