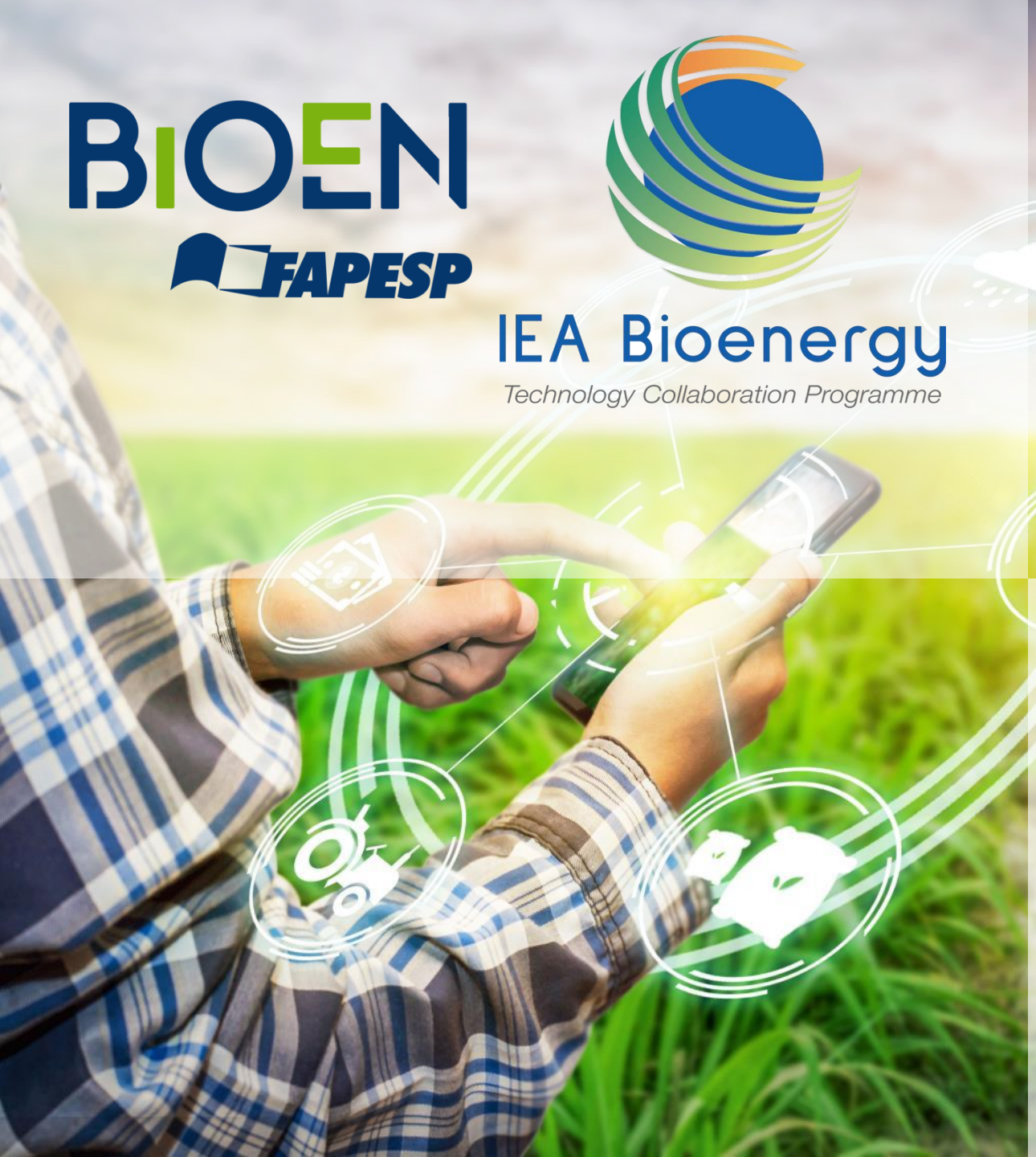


HOW TO IDENTIFY A SUSTAINABLE BIOFUEL FOR THE MARITIME ENERGY TRANSITION

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

BIOEN FACTSHEET

BIOFUELS AS AN IMMEDIATE AND EFFECTIVE SOLUTION FOR DECARBONIZATION OF TRANSPORTATION

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

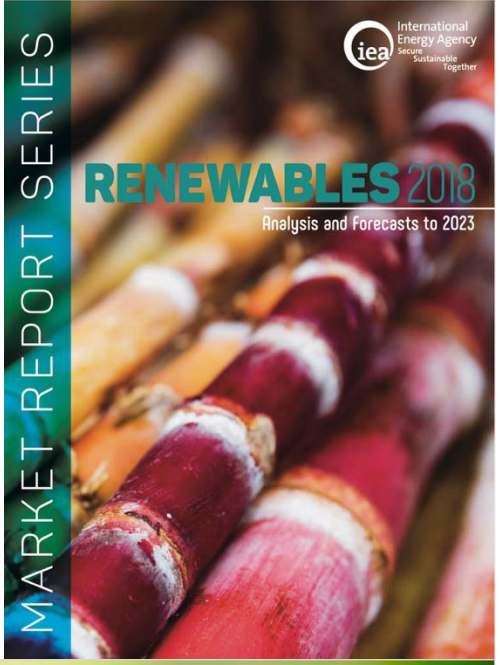
The focus is on biofuels that can be produced sustainably, with sufficient capacity to be relevant for decarbonization of the maritime sector.

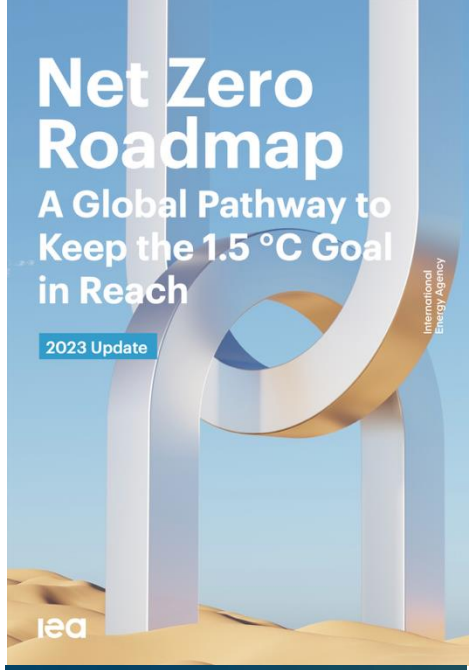
Discuss the Brazilian model of agriculture and its technological developments.

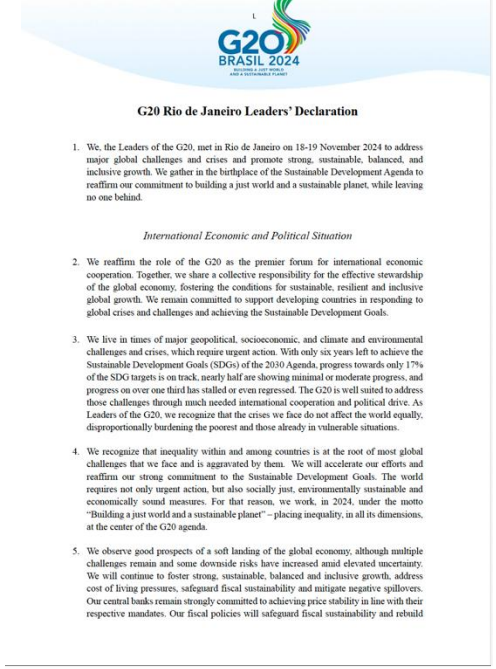
Show how bioenergy is generating social-economic benefits and reducing emissions without the need for extensive land areas.

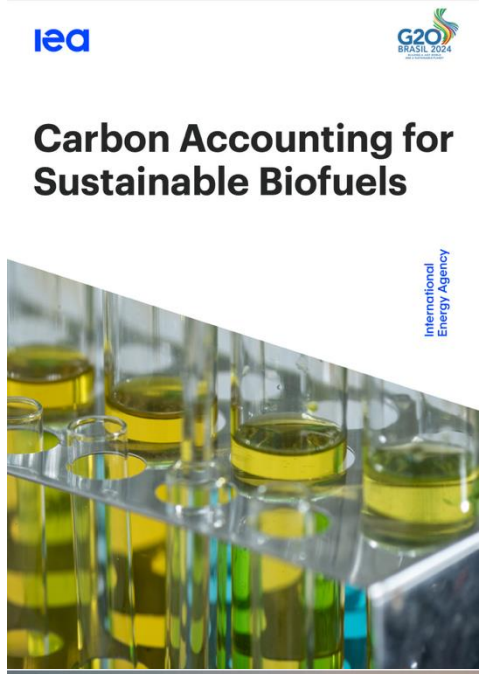
Discuss the potential for biofuel production in the global south.

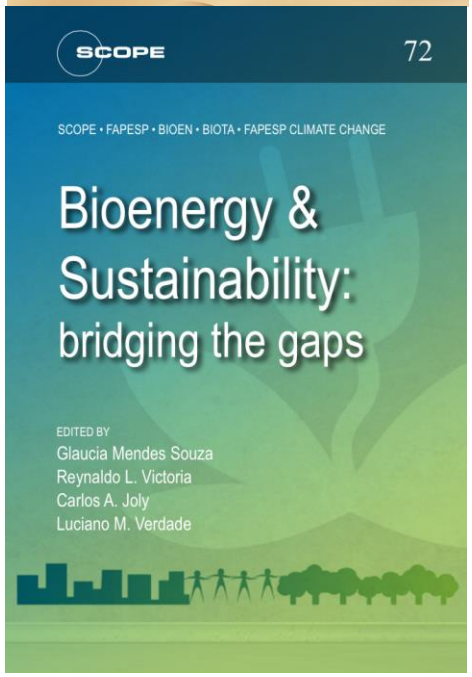
https://bioenfapesp.org/biofuels-as-an-immediate-and-effective-solution-for-decarbonization-of-transportation-factsheet/

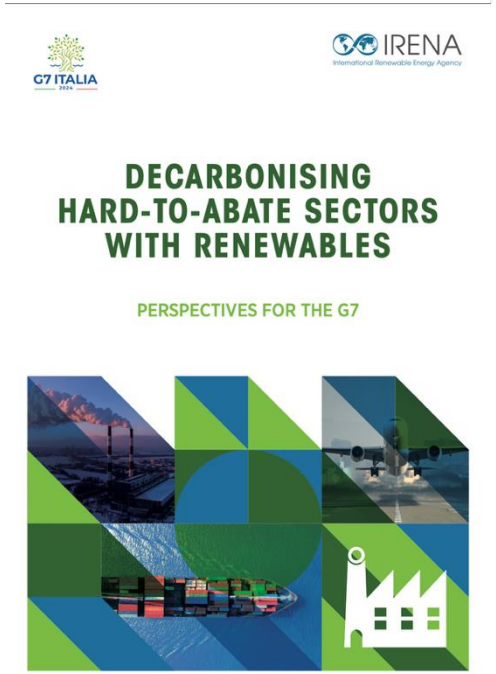


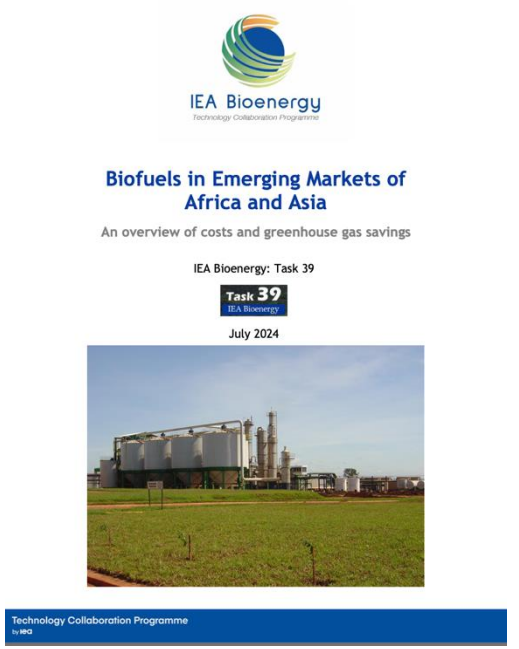












TECHNICAL NOTE

Analysis of Current Biofuels Outlook – Year 2023

AUGUST 2024

MINISTÉRIO DE MINAS E ENERGIA · GOVERNO FEDERAL BRASIL UNIÃO E RECONSTRUÇÃO · epe · cnos

+80 references to major reports and open access high impact scientific articles

Bioenergy is the "Overlooked giant in renewable resources". Bioenergy share in the global renewable resources is 50%, as much as hydro, wind and solar combined (Fatih Birol, IEA, 2018).

The substitution of fossil fuels with biofuels is important to keep global temperatures from rising (IPCC, 2022)

Bioenergy contributes to energy security, food security, environmental security and sustainable development (SCOPE, 2015)

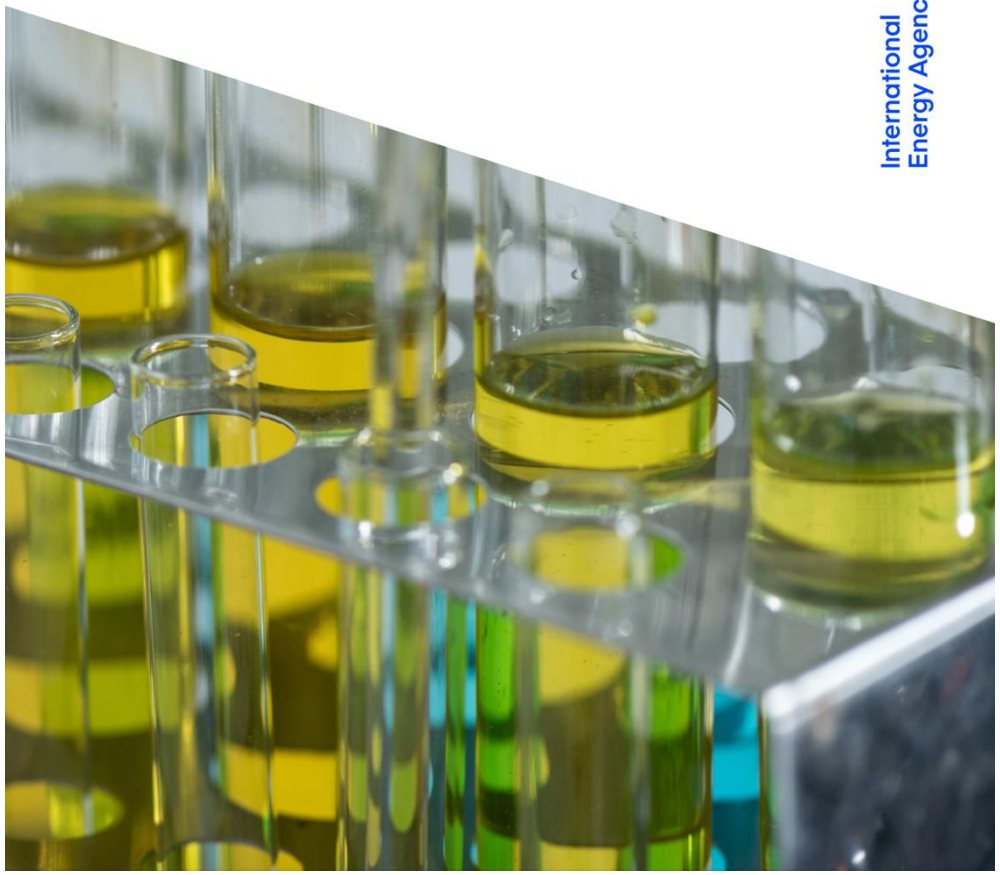
To achieve carbon-neutrality biofuels use need to grow by 2.5 times from today to 2030 (IEA, 2023)

The path to carbon neutrality includes biofuels displacing almost 800 Mt of fossil CO_2, or 10% of today's global transport emissions (IEA, 2023)

In shipping and aviation, bioenergy, hydrogen and hydrogen-based fuels need to ramp up from less than 1% of energy consumed today to almost 15% in 2030 and 80% by 2050 (IEA, 2023)

Carbon Accounting for Sustainable Biofuels

International Energy Agency



The G20 in 2024 moved forward a set of PRINCIPLES FOR JUST AND INCLUSIVE ENERGY TRANSITIONS with the following recommendation:

"We underscore the crucial role of technologically neutral, integrated, and inclusive approaches to develop and deploy a variety of low-emitting energies, sustainable fuels and technologies, including for abatement and removal, carbon management, and emission reduction, with a view to creating scale and global markets to accelerate energy transitions, particularly in hard-to-abate sectors.

We encourage, as appropriate, the use of mutually recognized methodologies and standards for assessing greenhouse gas emissions."

(G20, OCTOBER 2024)

"Policies should be technology neutral and feedstock agnostic".

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

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

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).

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.

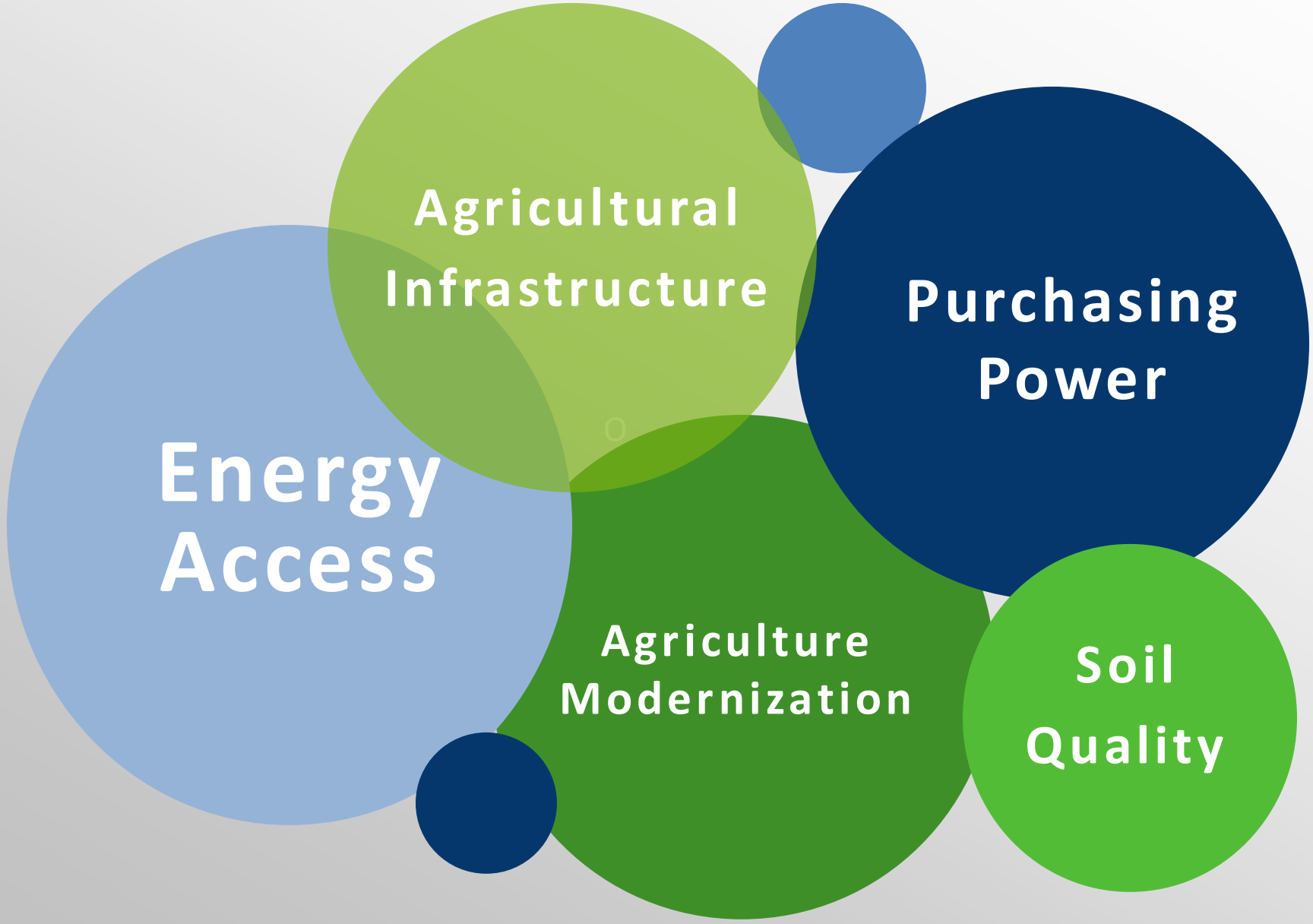
When observed data was used the reporting of negative impacts was lower.

224 papers

There is no correlation 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

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)

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

750 million people do not have electricity in the world (80% in rural areas)

Energy use has a direct correlation to Human Development Index.

Food security increases with energy access.

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

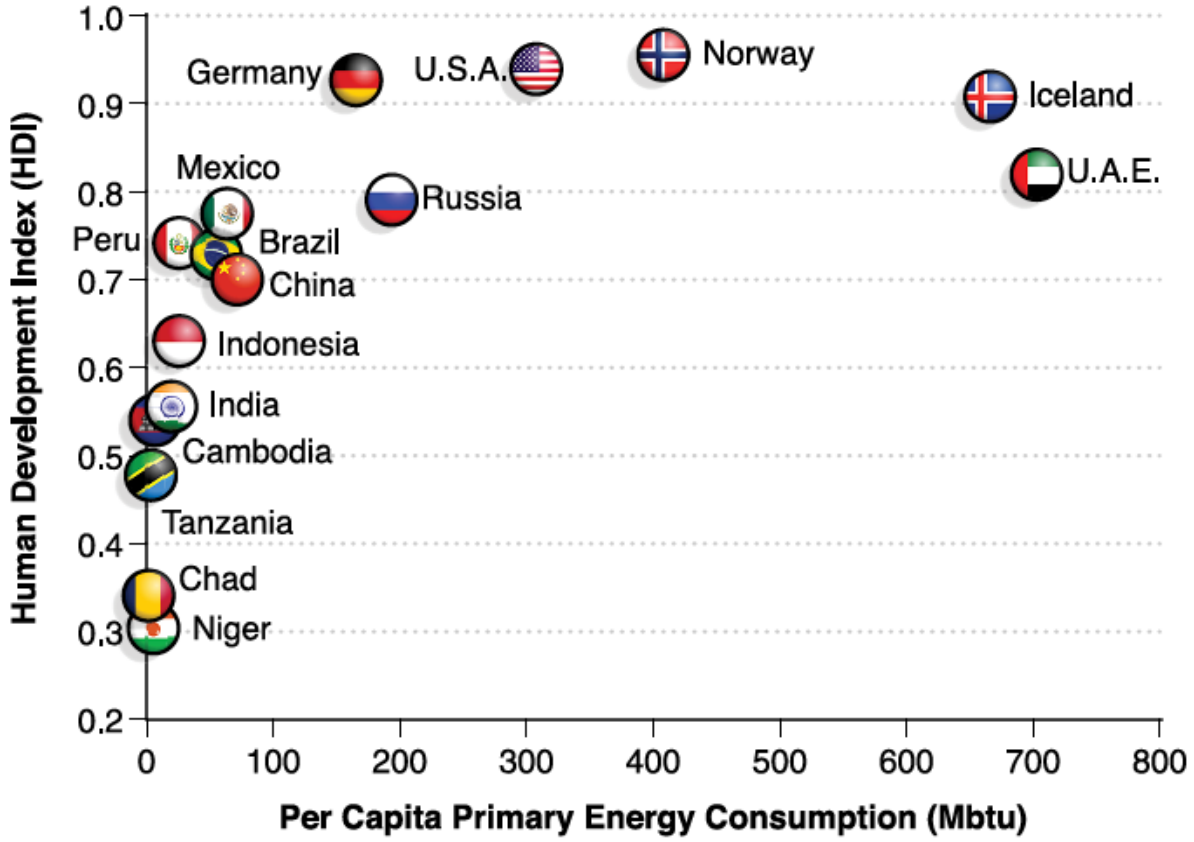


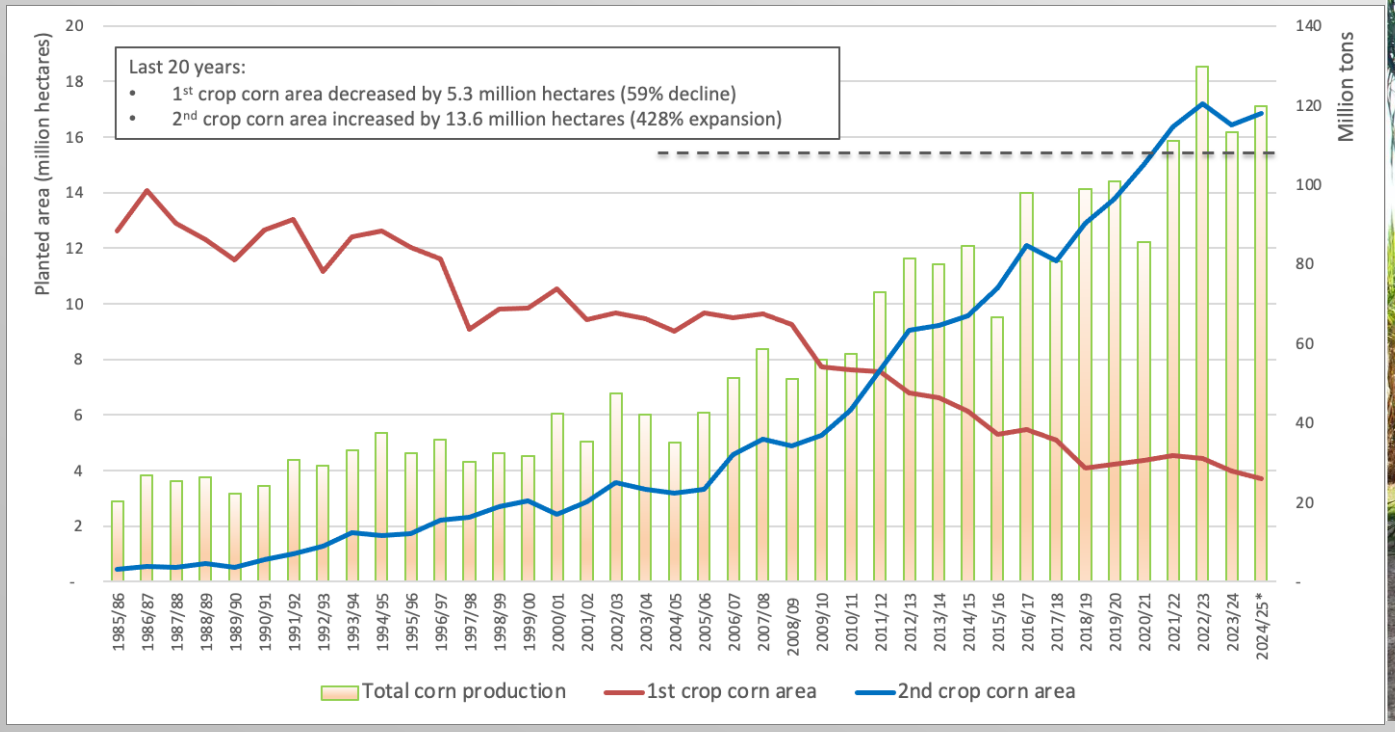
Figure 3.1. Human Development Index versus Per Capita Primary Energy Consumption (EIA 2014; UNDP 2014).

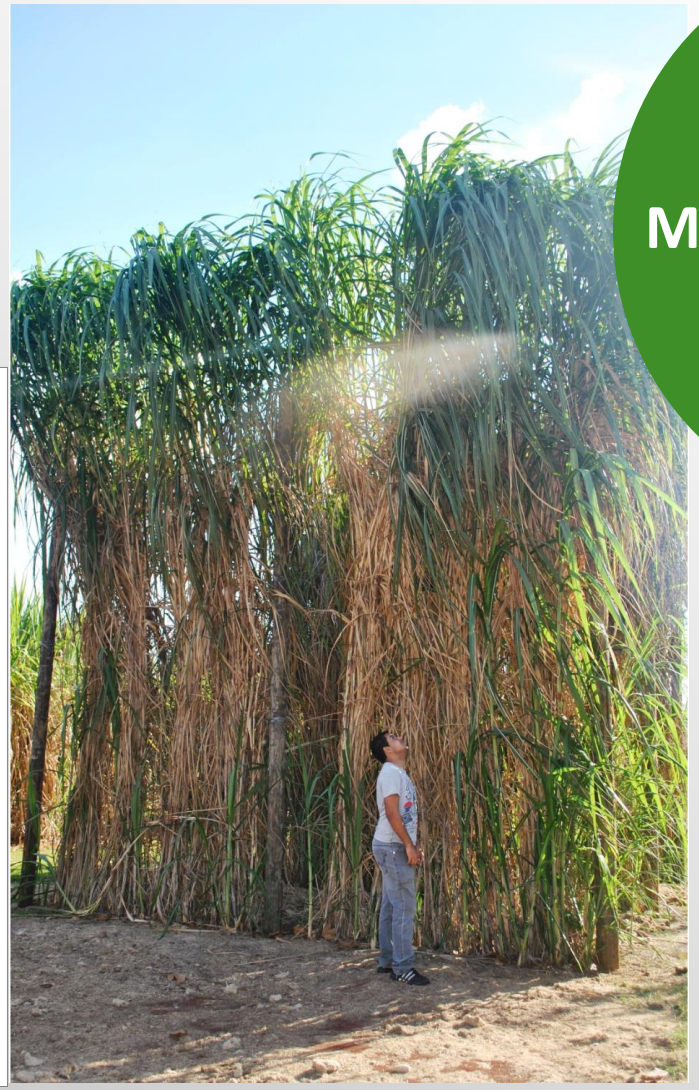
Energy Access

Observed changes brought by bioenergy that contribute to food security: adding value to agriculture increased yields and production with best management practices using very little land

Crop rotation
Straw layer
Use of residues
New varieties

Planting in beds
Soil amendments
Vinasse fertirrigation
2nd cropping



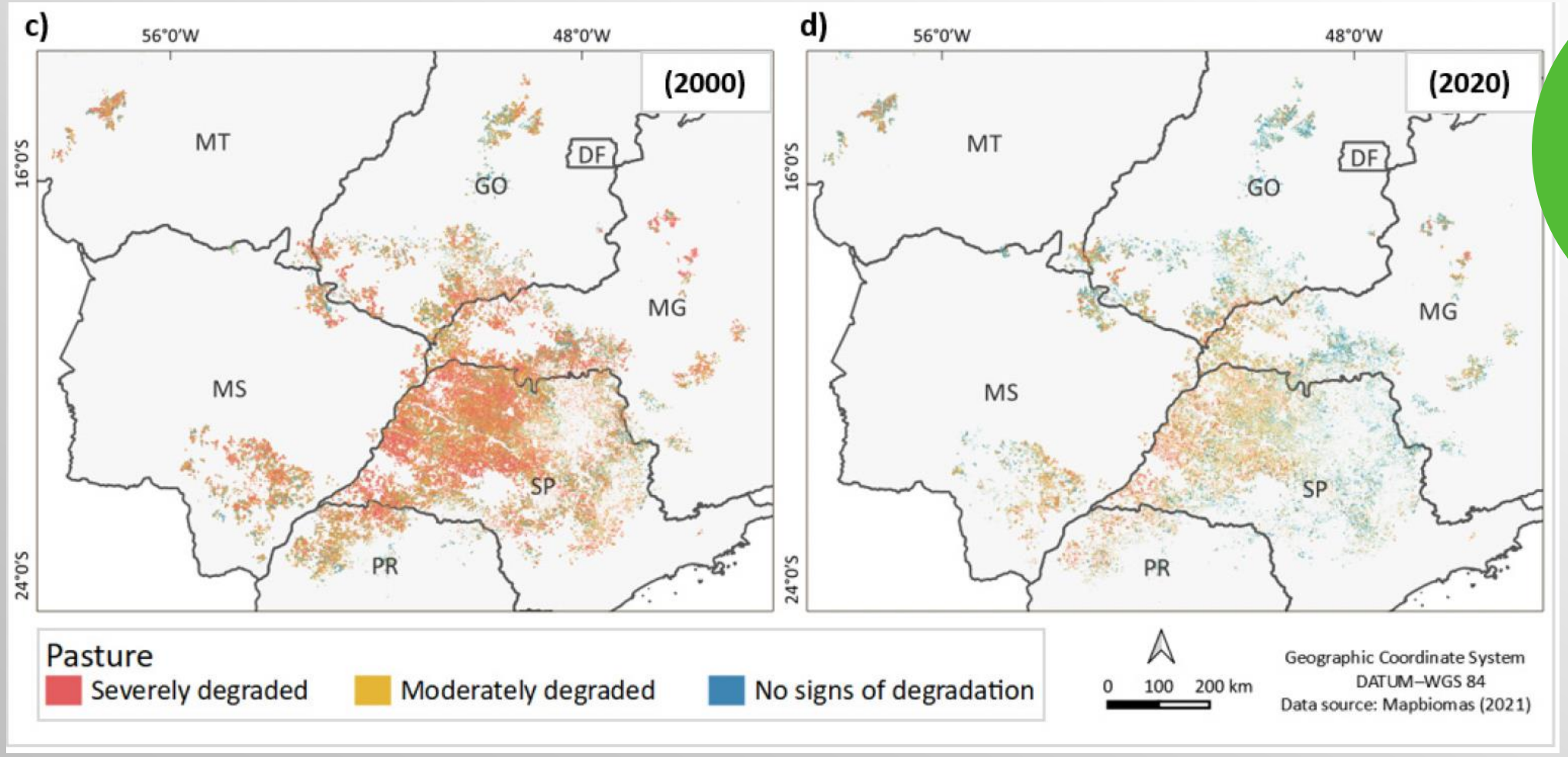


Agriculture Modernization

The three main energy crops (soybean, corn and sugar cane) have not yet reached their theoretical productivity limits!

Cherubin, M. R.; Carvalho, J. L. N.; Cerri, C. E. P.; Nogueira, L. A. H.; Souza, G. M.; Cantarella, H. (2021). Land Use and Management Effects on Sustainable Sugarcane-Derived Bioenergy. Land, 10,72.; Potential in Land Saving Techniques production in Brazil, EPE, 2024; Waclawovsky, A. J., Sato, P. M., Lembke, C. G., Moore, P. H., Souza, G. M. (2010). Sugarcane for bioenergy production: an assessment of yield and regulation of sucrose content. Plant Biotechnology Journal 8 (3), 263-276.

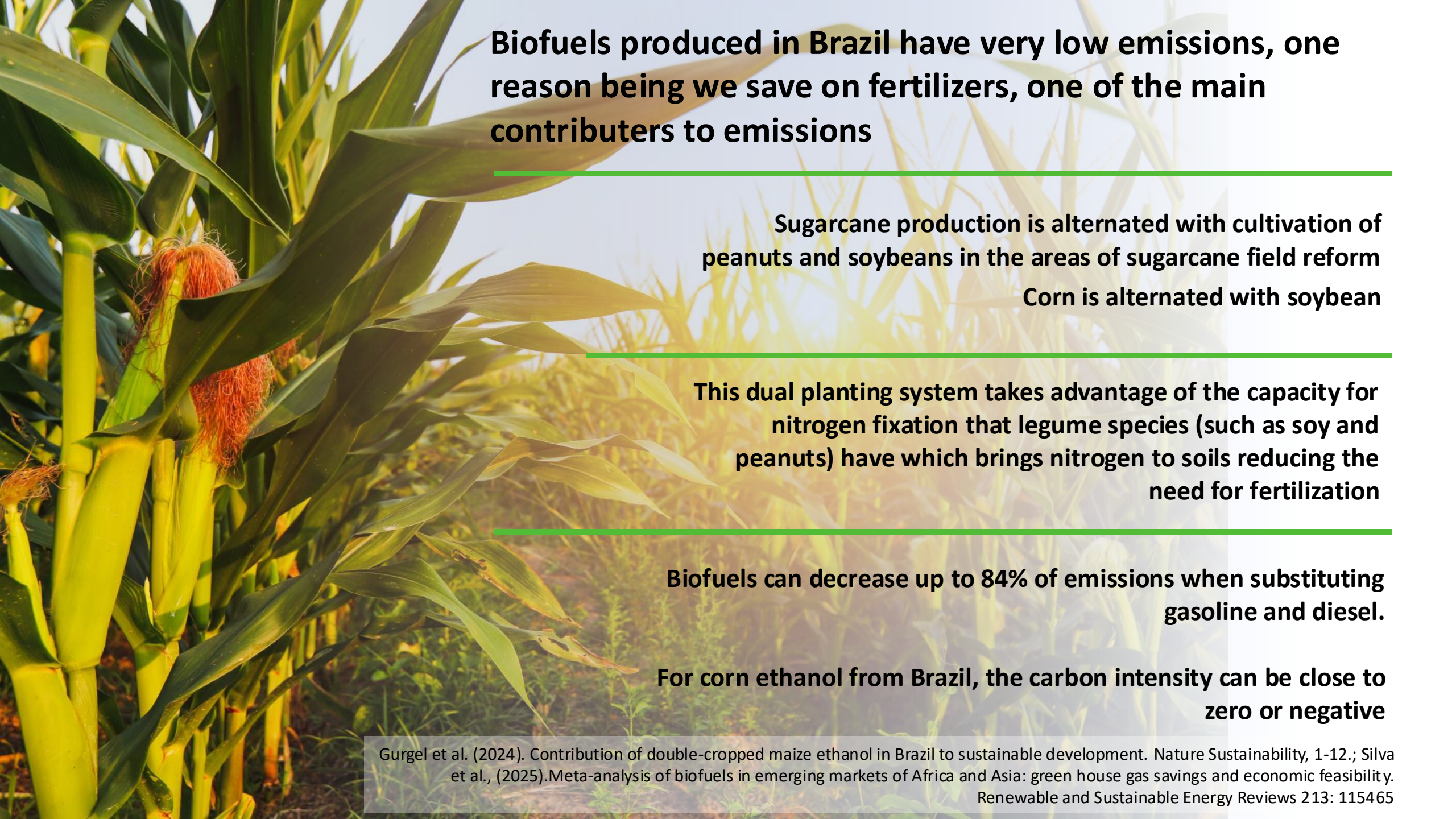
Observed changes brought by bioenergy that contribute to food security: recuperating degraded land and increasing soil carbon



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



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 is alternated with soybean

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

Biofuels can decrease up to 84% of emissions when substituting gasoline and diesel.

For corn ethanol from Brazil, the carbon intensity can be close to zero or negative

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

Observed changes brought by bioenergy that contribute to food security: biofuels is integrated into food production

Brazil is the world's largest producer of
Soybeans
Coffee
Orange juice
Sugar
Brazil is the second largest producer
Chicken meat
Beef
Brazil is world's largest exporter of
Soybeans
Coffee
Orange juice
Sugar
Chicken meat
Beef
Corn

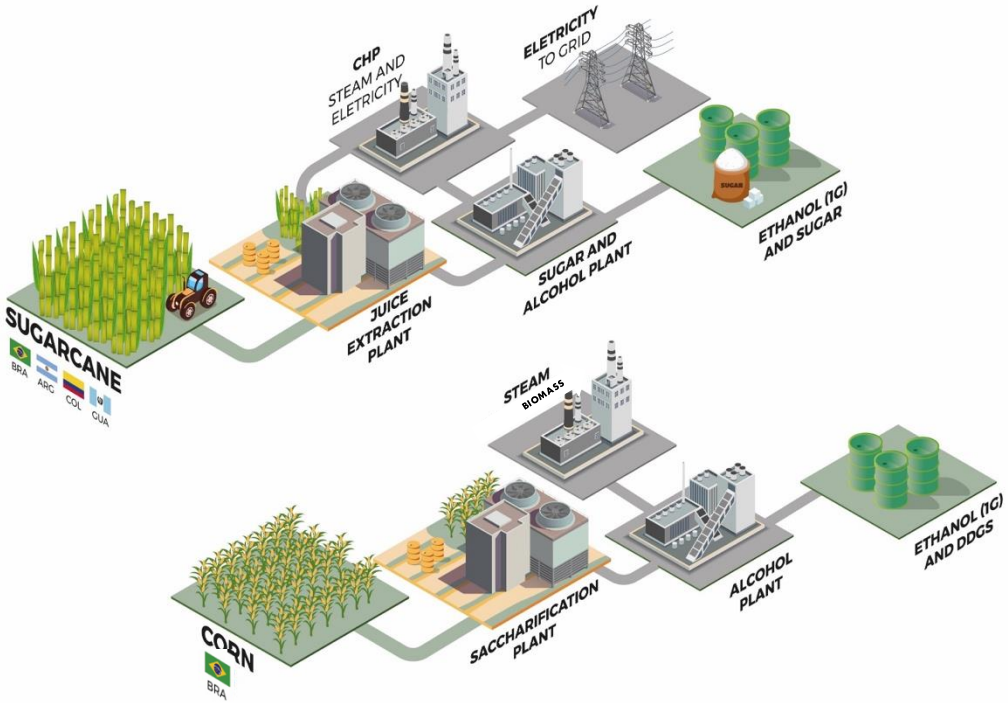
Soybeans and corn produced in Brazil are the basis for the production of animal products, such as meat, milk, eggs, in several countries.

In 2024 Brazilian food items fed 900 million people
(11% of the world's population)

Agricultural Infrastructure

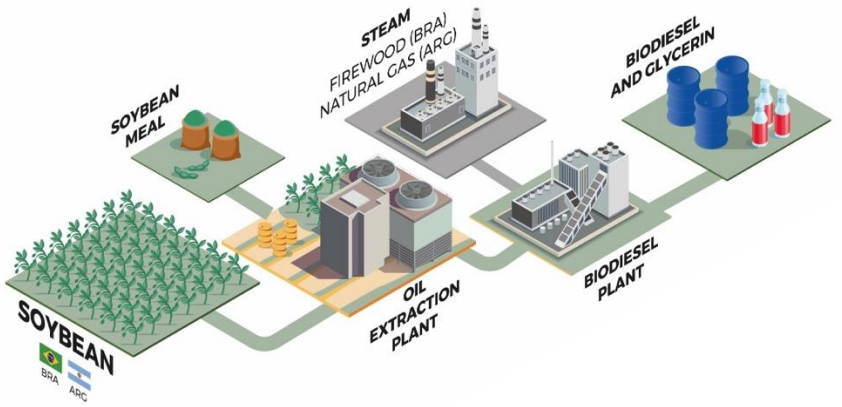
Food AND Feed AND Fuels AND Power produced in parallel

PATHWAYS FOR ETHANOL PRODUCTION



Sugar, DDGS for Feed, Oil
Bioethanol, Bioelectricity, Residues recycled

PATHWAYS FOR BIODIESEL PRODUCTION



Protein for Food, Protein for Feed, Oil
Biodiesel, Bioelectricity, Residues recycled

Biodiesel production in Brazil uses only ~3% of the country's total soybean production

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.

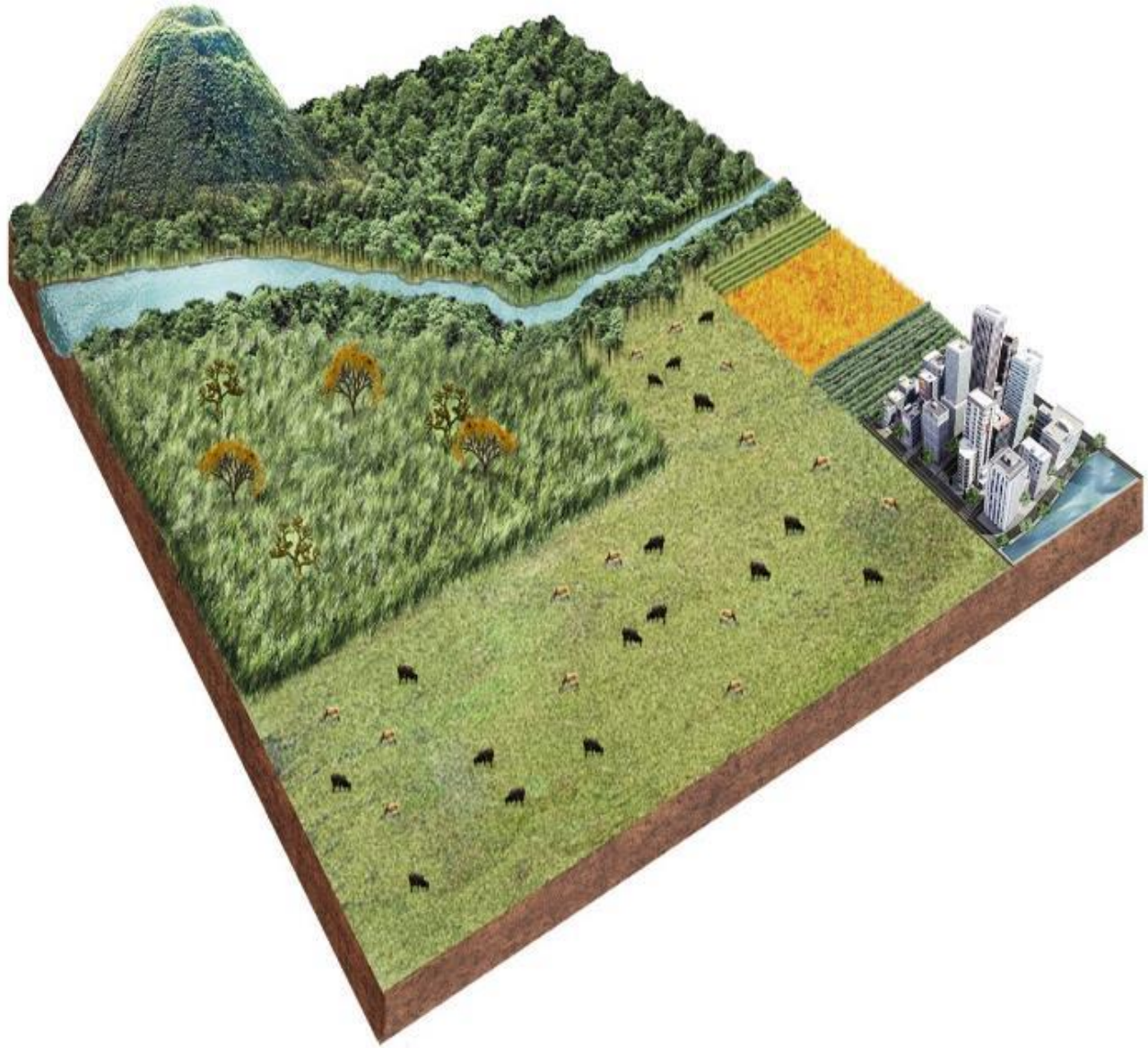
Brazil preserves the largest area in the world in native vegetation

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



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

Positive institutional environment (legal framework in place)

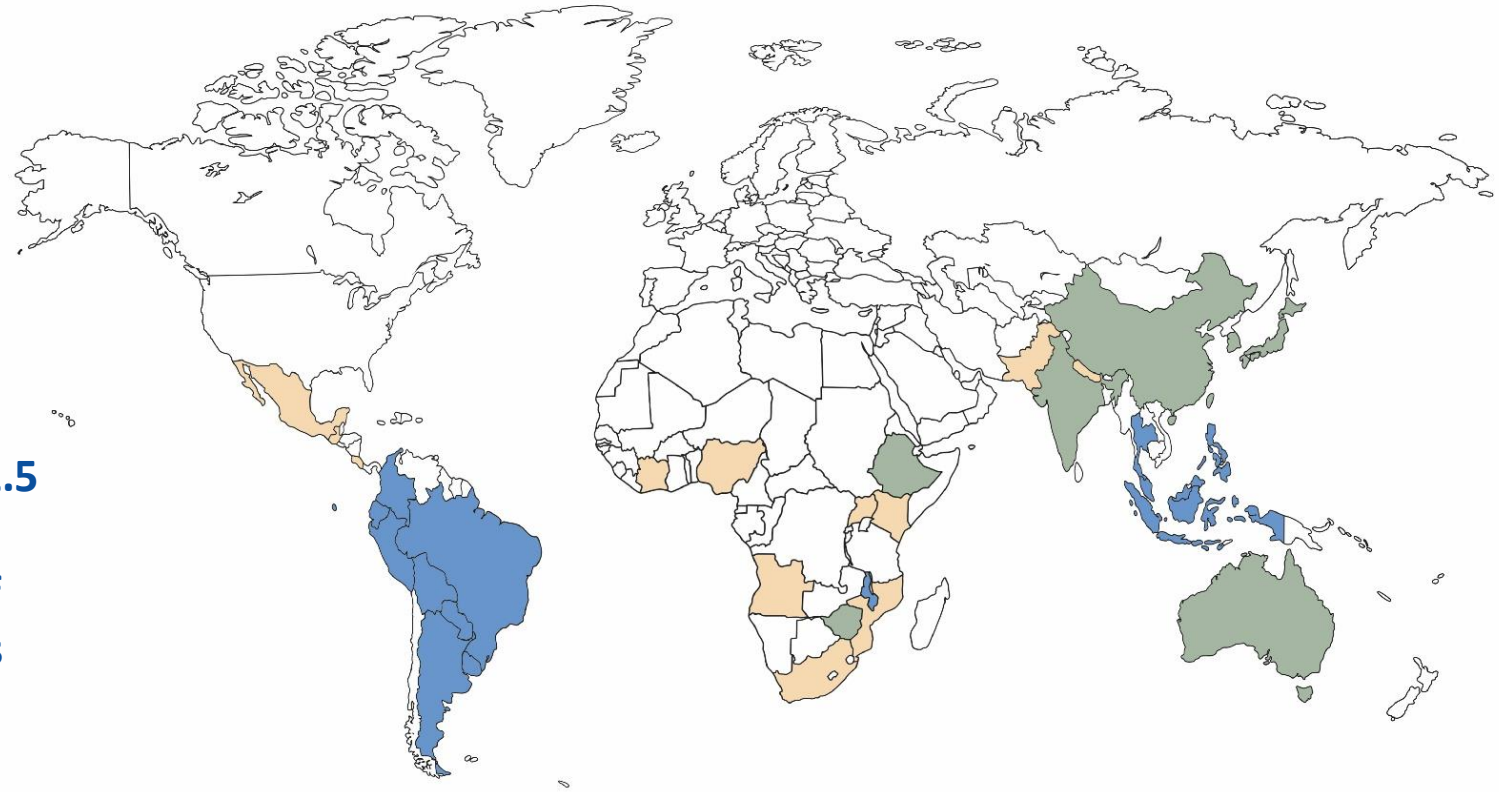
Angola
Cote d'Ivoire
Kenya
Mozambique
Nigeria
South Africa
Uganda
Nepal
Pakistan
Costa Rica
Guatemala
Mexico

Blending mandate partially implemented

Ethiopia
Zimbabwe
Australia
China
India
Japan
South Corea

Biofuel use fully implemented

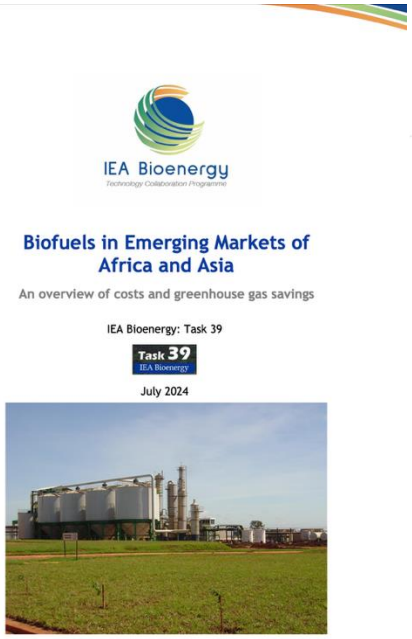
Malawi
Indonesia
Malaysia
Philippines
Thailand
Argentina
Bolivia
Brazil
Colombia
Ecuador
Paraguay
Peru
Uruguay

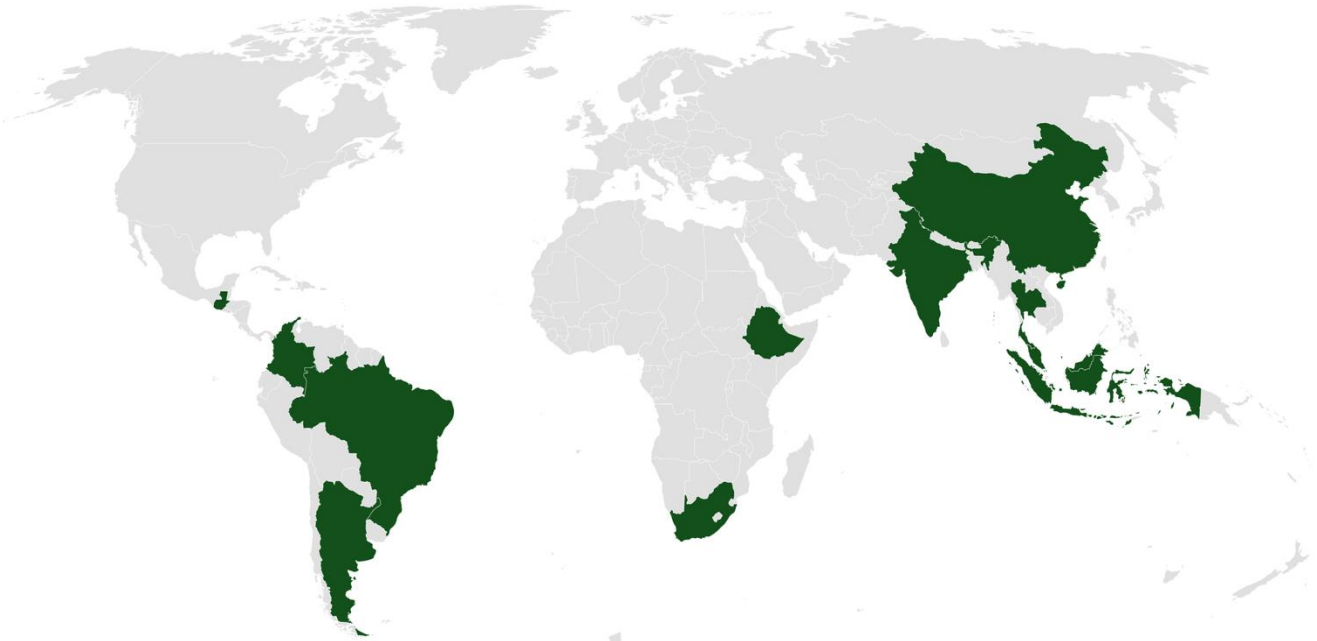


How can emerging markets contribute to the effort of biofuels needing to grow by 2.5 times from today to 2030, displacing almost 800 Mt of fossil CO_2, or 10% of today's global transport emissions

Souza et al., 2023. Biofuels in Emerging Markets. Potential for sustainable production and consumption. IEA Bioenergy Task 39.

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.

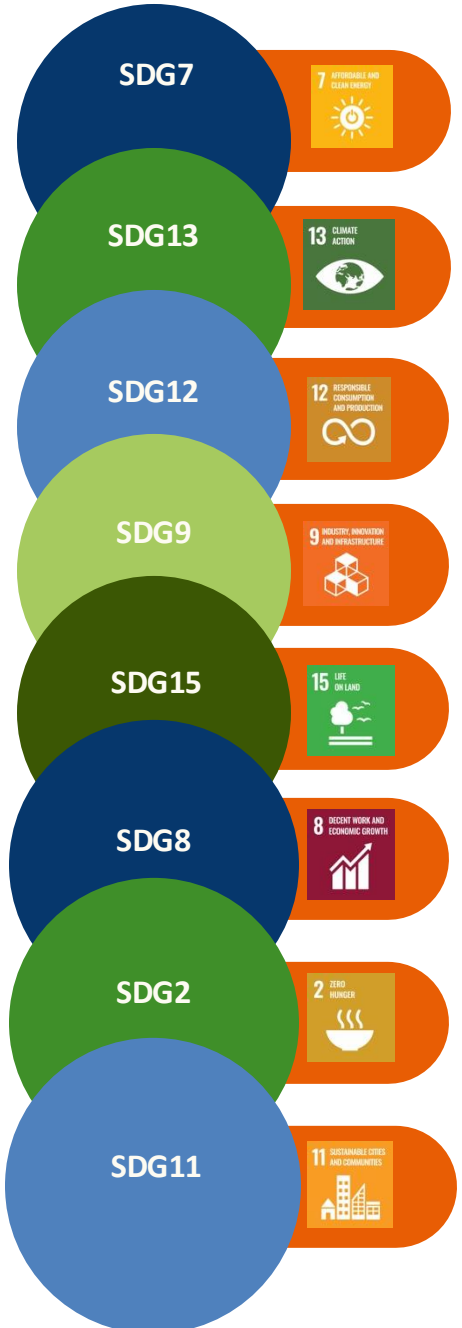
IEA Bioenergy

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

Task 39 IEA Bioenergy

11,439 publications AI study

Contributions of biofuels, biomass, and bioenergy to Sustainable Development Goals



Affordable and Clean Energy

Expanding the share of renewables in the energy mix is one of the clearest outcomes of bioenergy development. Bioenergy is central to the global energy transition. Biofuels provide renewable, high-energy-density alternatives to fossil fuels, especially in transport.

Climate Action

Biofuels and biomass play a major role in greenhouse gas mitigation. Life cycle analysis demonstrates their ability to lower emissions across supply chains, while advanced managing practices reduce land needed.

Responsible Consumption and Production

Biofuels embody circular economy principles by converting agricultural residues, municipal waste, and other biomass into energy and bioproducts. Innovations in supply chain optimization and biorefinery integration minimize environmental impacts, supporting resource efficiency and waste reduction.

Industry, Innovation and Infrastructure

Bioenergy fosters systemic innovation in conversion technologies, supply chains, and industrial scaling. Investments in biorefineries, transport networks, upgrading and pipelines, demonstrate how infrastructure supports scaling and competitiveness of biofuels.

Life on land

Sustainable biomass cultivation can increase land productivity, enhance resilience to climate variability, and restore degraded areas. These practices ensure that biofuel expansion does not compromise biodiversity and ecosystem services.

Decent work and Economic Growth

Biofuels contribute to economic growth and job creation, particularly in rural regions bridging yield gaps into higher productivities through technological upgrading and positioning biofuels as engines of employment and inclusive growth, especially in developing countries.

Zero Hunger

Balancing food and fuel production with modern agricultural practices support resilient agricultural systems. These practices enhance food security while enabling energy production.

Sustainable Cities and Communities

Bioenergy is increasingly integrated into urban sustainability plans, contributing to low-carbon transport and decentralized energy supply. This supports cities in reducing their environmental footprint, pollution and meeting climate targets.

Raman et al., (2025). Analyzing the contributions of biofuels, biomass, and bioenergy to sustainable development goals. iScience 28: 112157.

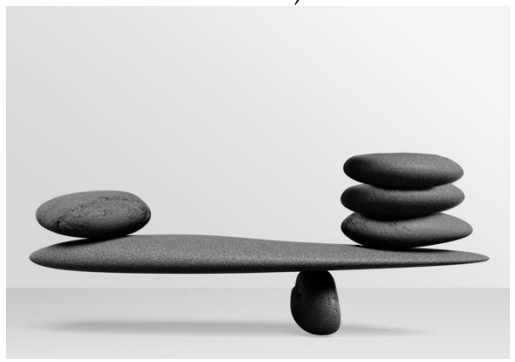
HOW TO PICK A BIOFUEL

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?

You might want to consider best management practices, yields, consolidated supply chains.



Sustainability

GHG emessions, compliance with agroecological zoning, no deforestation, good governance on ecosystem services preservation, socioeconomical indicators

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.

Available infrastructure?

This definitely helps, with the urgency of climate change and the high costs of abatement we need to immediately deploy using the available infrastructure whenever possible.


Canada


Co-operative Republic of Guyana


Democratic Socialist Republic of Sri Lanka


Federative Republic Of Brazil


Hungary


Iceland


Japan


Kingdom of Cambodia


People's Republic of Bangladesh


Republic of Argentina


Republic of Burundi


Republic of Fiji


Republic of India


Republic of Italy


Republic of Kenya


Republic of Mauritius


Republic of Madagascar


Republic of Panama


Republic of Paraguay


Republic of Seychelles


Republic of Singapore


Republic of South Africa


Republic of the Philippines


Republic of Uganda


United Arab Emirates (UAE)


United Republic of Tanzania


United States of America (USA)

Foundational Document on the Global Biofuels Alliance (GBA)

GLOBAL BIOFUELS ALLIANCE

"Recognize that biofuels are proven renewable, low carbon fuels that reduce greenhouse gas emissions, mitigate the effects of climate change, can be produced at scale, are commercially available and can spur domestic growth and develop trade opportunities"

ADB ASIAN DEVELOPMENT BANK

biofuture platform

ICAO · OACI · ИКАО

International Energy Agency

IEF INTERNATIONAL ENERGY FORUM

IRENA International Renewable Energy Agency

SUSTAINABLE ENERGY FOR ALL

UNIDO

THE WORLD BANK

WORLD BIOGAS ASSOCIATION

WORLD ECONOMIC FORUM

WLGA

THANK YOU!

IEA Bioenergy ExCo Workshop
Oslo - Nov 2025

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