Assessing induced economic and environmental impacts of biofuels and their consequential life-cycle analyses in a computable general equilibrium framework: An exercise with GTAP-BIO model

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- Role of GTAP-BIO in biofuel policy analysis
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- An overview of GTAP-BIO
- EPA Model Comparison Exercise
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- Conclusion

Introduction and motivations

- Since the surge in biofuel production in the late 2000s, various efforts have been made to study the economic and environmental impacts of biofuel production and policies
- These efforts have addressed various related topics including but not limited to:
  - 1) Techno-Economic Analysis (TEA) and feasibility studies of alternative biofuel pathways
  - 2) supply chain and Life-Cycle Analysis (LCA) of alternative biofuel technologies
  - 3) assessing the long-run and short-run effects of biofuel production and policy on welfare, agricultural activities, commodity markets, and energy markets at local, national, and global scales
  - 4) evaluating the Induced Land Use Changes (ILUC) due to biofuels and their corresponding greenhouse gas (GHG) emissions
- This paper concentrates on the last two topic

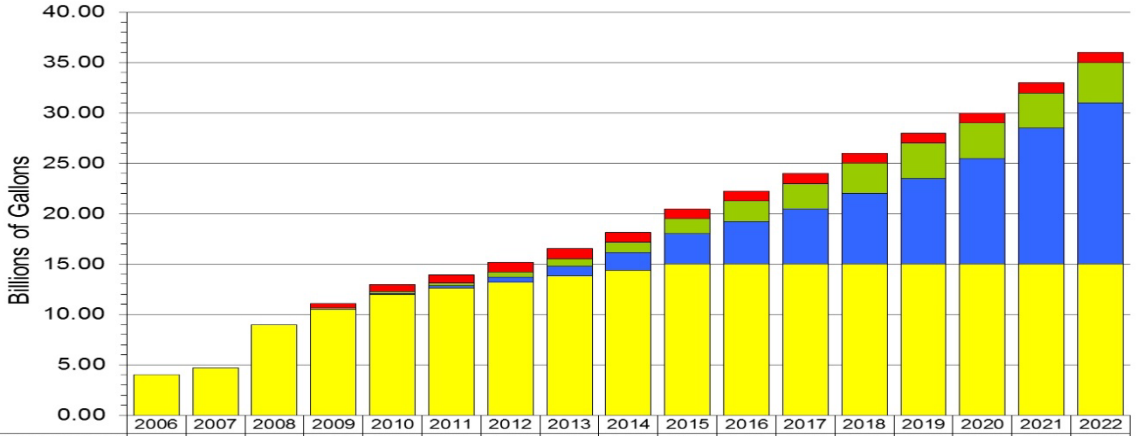
Potential effects of biofuels

- When biofuels are produced at large scale, they could affect many markets and economic activities including but not limited to:
  - Agricultural (crop and livestock) and forestry activities leading to land use changes
  - Food and feed markets and the corresponding industries
  - Energy and fuels markets
  - Other industries and services through forward and backward links
  - Welfare and labor market
  - Theological progress
- The above changes could have positive or negative economic and environmental impacts
- While the existing literature has addresses the above topics, many efforts have been made to better understand land use changes due to biofuels and their corresponding emissions.

Background of US biofuel policy

- The original RFS was enacted by Congress in 2005 and amended in 2007
- Goals of RFS: 1) enhance income rural areas; 2) improve energy security; and 3) Reduce GHG emissions
- RFS defined annual goals for consumption of biofuels from 2006-2022
- To qualify as a renewable fuel under the RFS program:
  - A fuel must be produced from qualifying feedstocks and have lifecycle GHG emissions that are at least 20% less than the baseline petroleum-based gasoline and diesel fuels

RFS biofuel targets

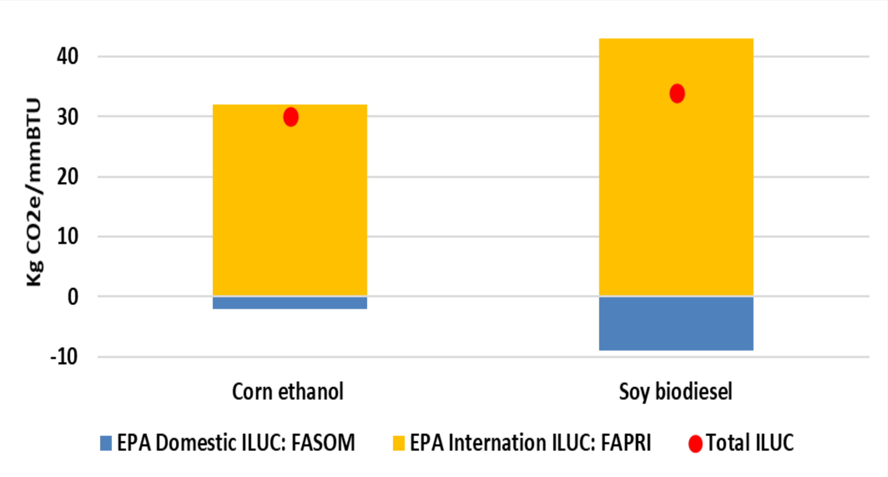


	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biomass-based Diesel				0.50	0.65	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Other Advanced				0.10	0.20	0.30	0.50	0.75	1.00	1.50	2.00	2.50	3.00	3.50	3.50	3.50	4.00
Celulosic Advanced					0.10	0.25	0.50	1.00	1.75	3.00	4.25	5.50	7.00	8.50	10.50	13.50	16.00
Conventional Biofuels	4.00	4.70	9.00	10.50	12.00	12.60	13.20	13.80	14.40	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00

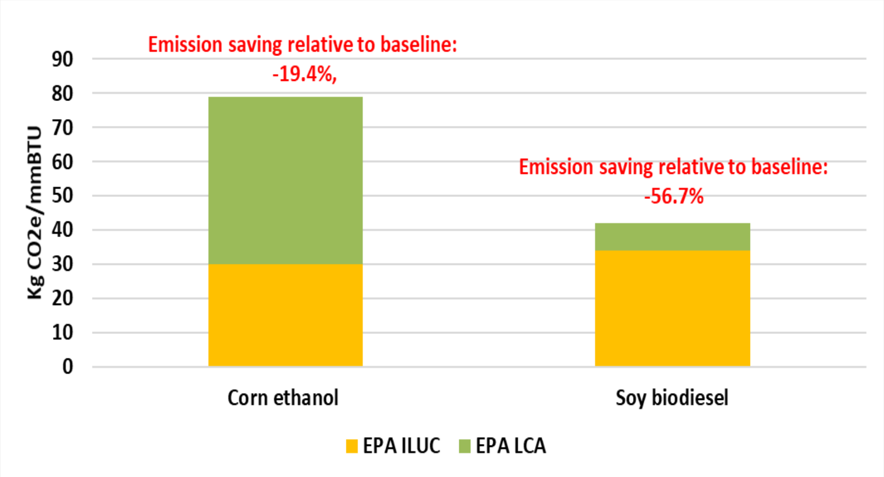
Renewable Fuel Standard (RFS) program, Carbon Intensity (CI), and EPA assessment of CI (1)

- In 2010, EPA developed a methodology to evaluate the lifecycle GHG emissions of renewable fuels.
- This methodology has considered two items to determine the CI of each renewable fuel:
  - GHG emissions obtained from supply change Life Cycle Analyses, based on the GREET model (v1.8b and V1.8c) results
  - GHG emissions due to direct and indirect land use changes, based on FASOM and FAPRI models.
- 2010 EPA assessment of CI of renewable fuels: Corn ethanol and soy biodiesel
- Since 2010, EPA has not changed its initial CI assessments for renewable fuels

ILUC emissions



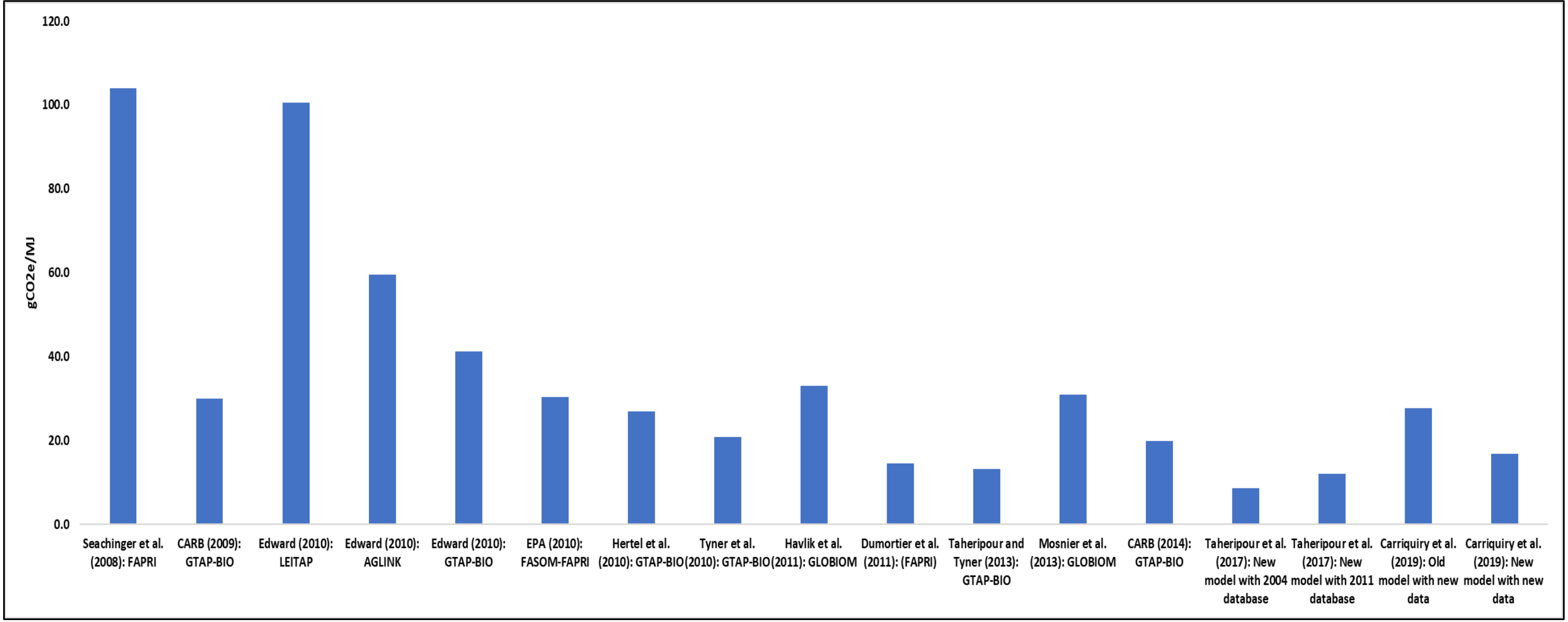
Carbon intensities



Role of GTAP-BIO in biofuel policy analysis

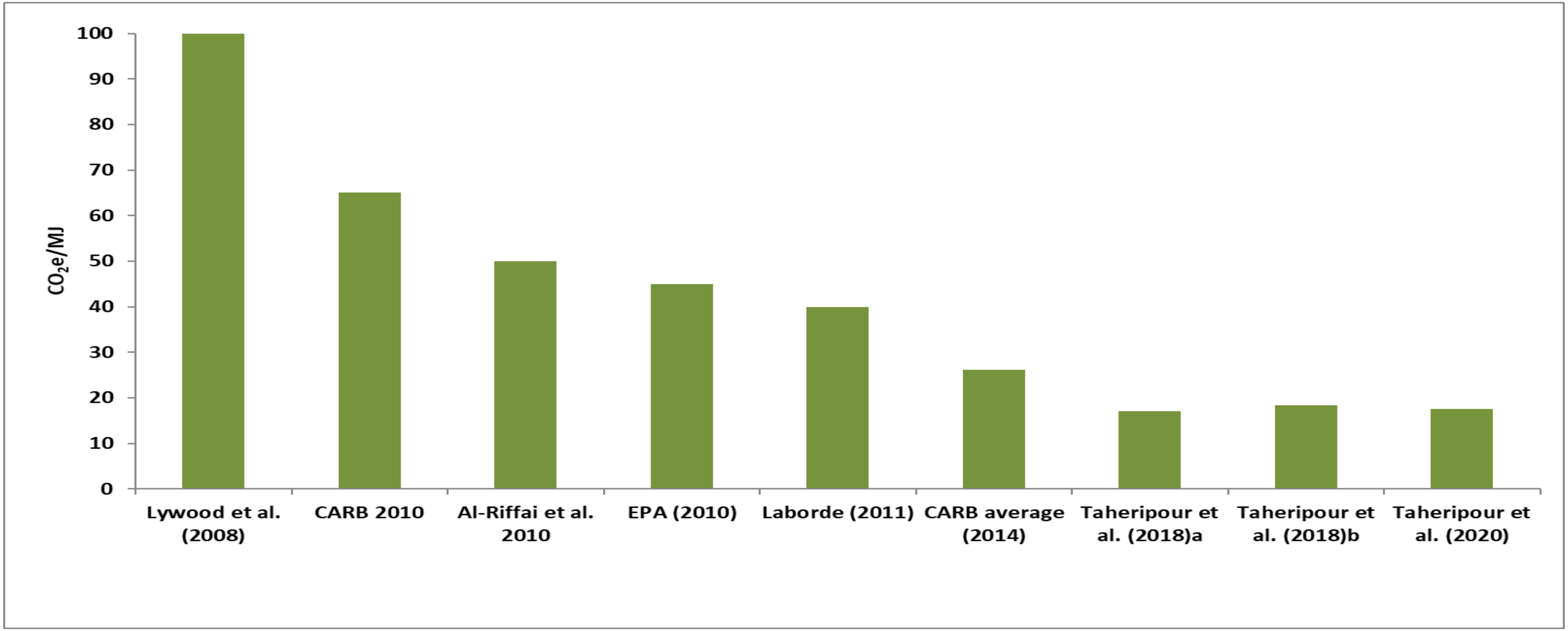
- GTAP-BIO has been developed, frequently revised, and used to evaluate the economic and environmental impacts of biofuel and policy
- The GTAP team has played a leading role in developing new research activities in this field:
  - Market-mediated responses
  - Feed-fuel trade-offs
  - Consequences of biofuel production for livestock
  - Competition among crops (crop switching)
  - Use of marginal land in response to biofuel policy
  - Yield response and yield growth
  - Productivity of new cropland versus existing cropland
  - Harvest frequency and multiple cropping
  - Energy rebound effects of biofuels
  - Assessing ILUC emissions and uncertainties in modeling ILUC
  - Non-CO_2 emissions impacts of biofuels
  - Land use emission factors and their corresponding uncertainties
- GTAP-BIO has played a major role in assessing ILUC emissions in policy analyses: CARB, CORSIA, EPA, and academis publications

Past assessments of ILUC emissions: Corn ethanol



Amortization period: 30 Years

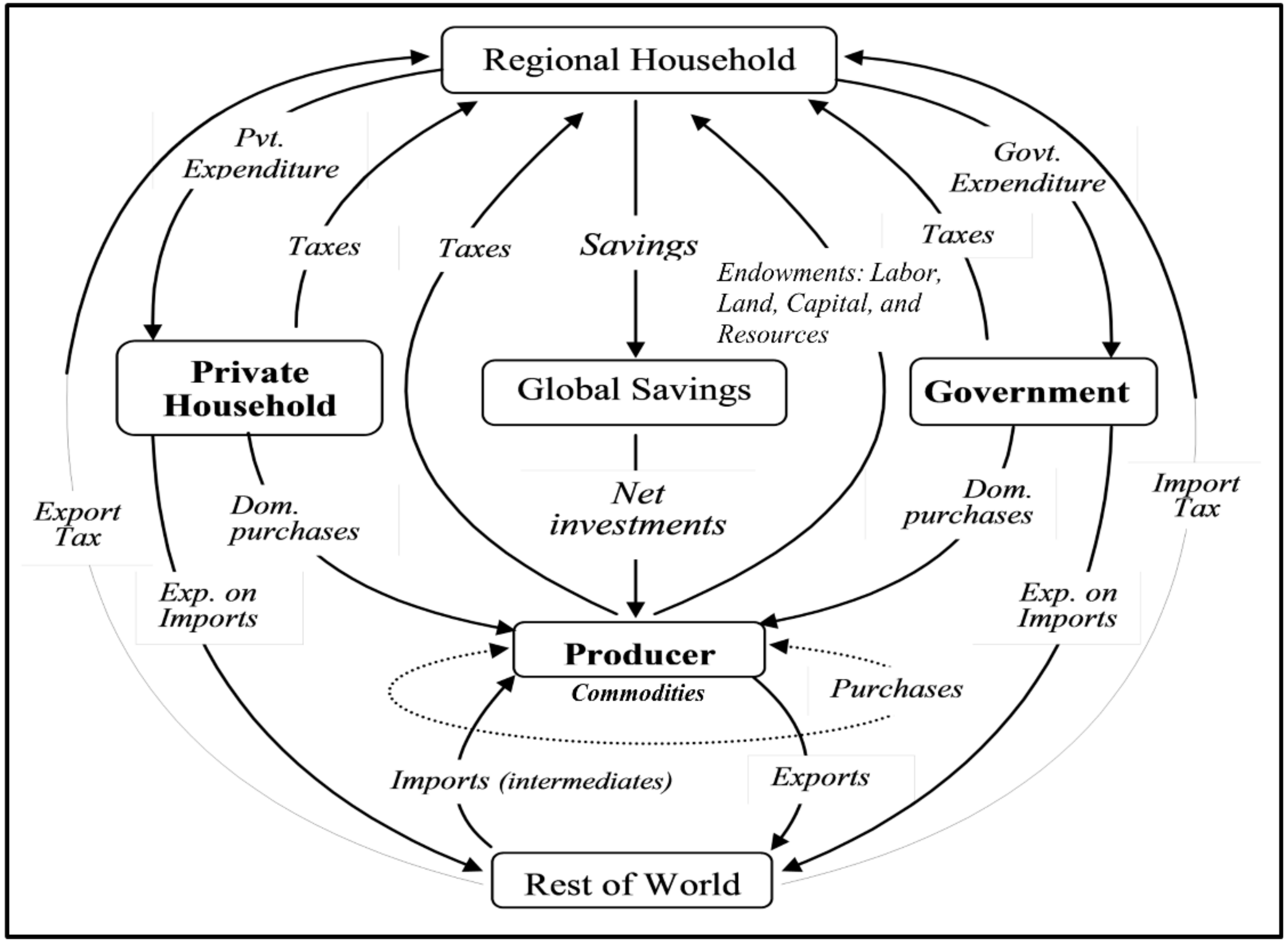
Past assessments of ILUC emissions: US soy oil biodiesel



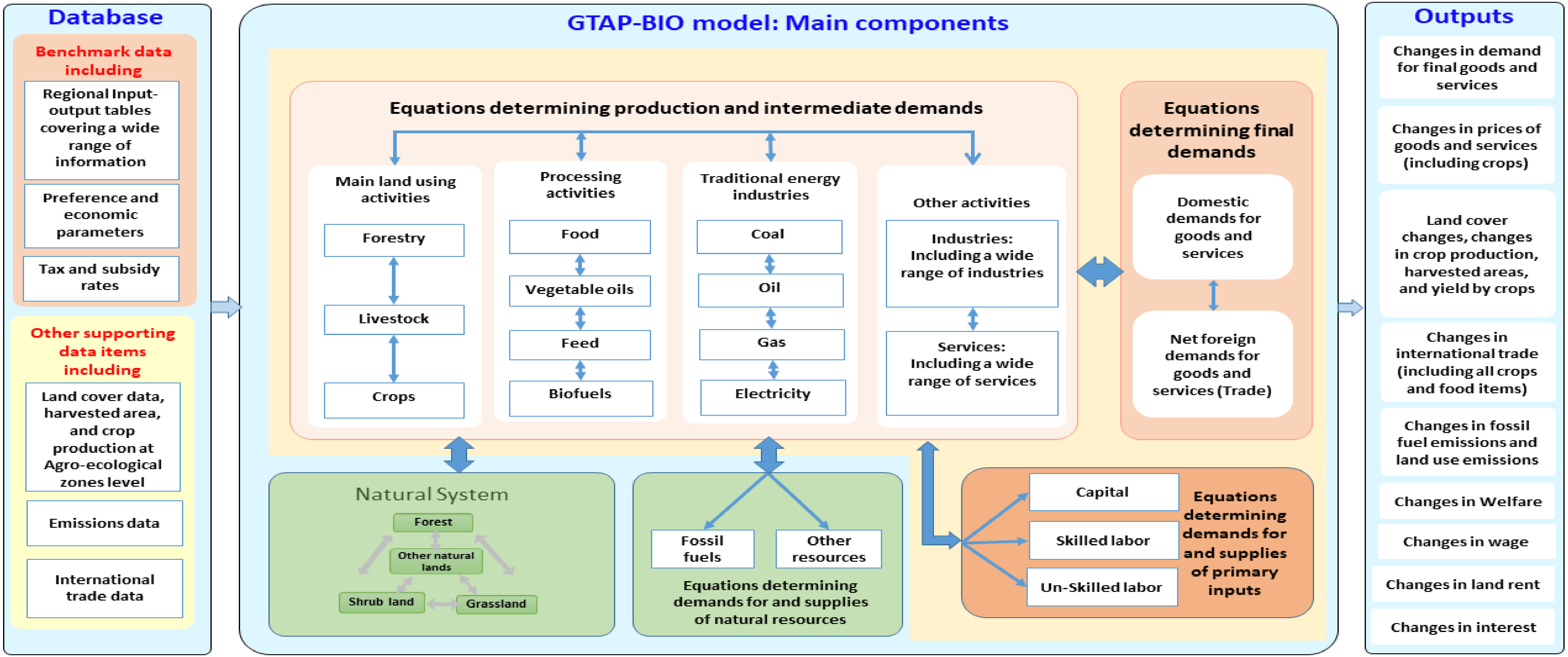
Amortization period: 30 Years

GTAP-BIO is an advanced extension of GTAP model

- An advance extension of the standard Global Trade Analysis Project (GTAP) model documented in Hertel (1997)
- GTAP based models have been used in hundreds peer-reviewed publications examining the economic and environmental consequences of energy-trade-economic-environmental policies and actions
- A global CGE model that represents all goods and services produced across the world
- Economic activities are categorized under 65 groups of economic activities
- Divide the global economy to 160 countries and regions.
- The GTAP center is the focal point of a global network of more than 27,000 researchers, scholars, academic institutions, and policy research entities

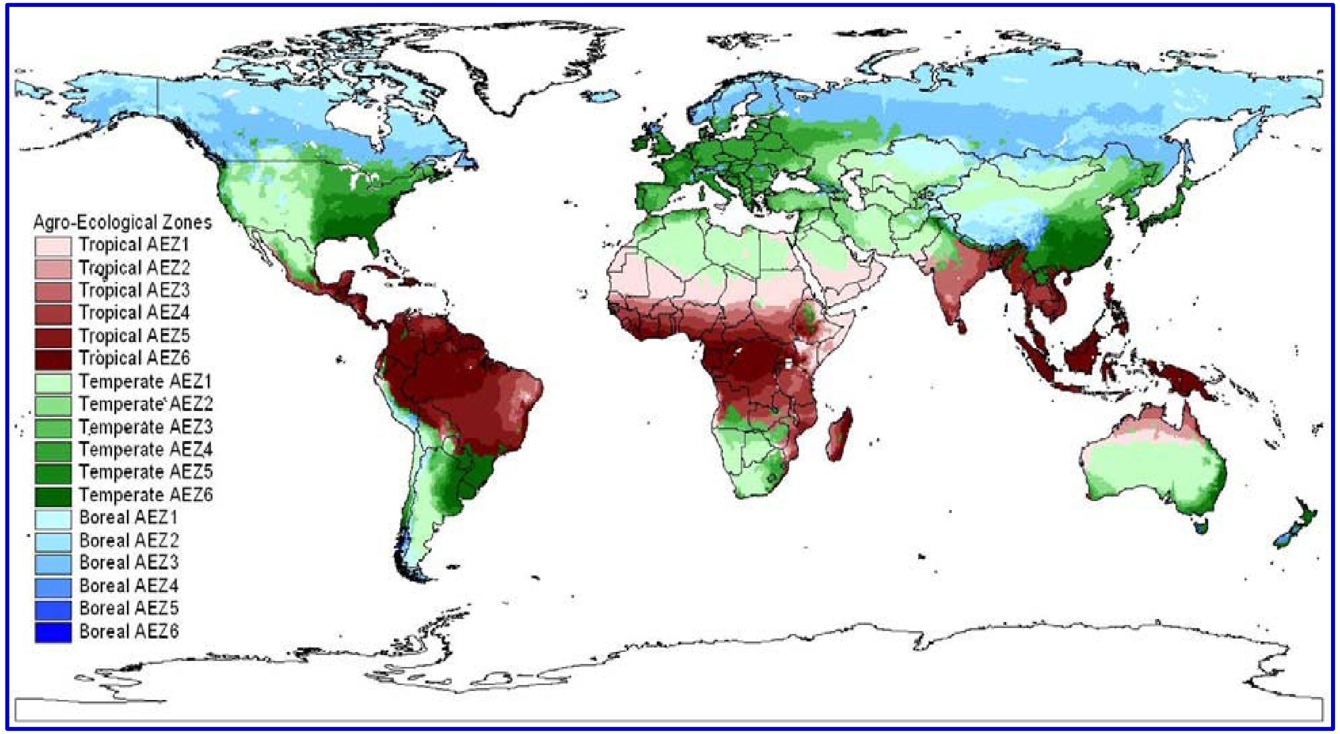


GTAP-BIO: An economic model to assess the effect of biofuels

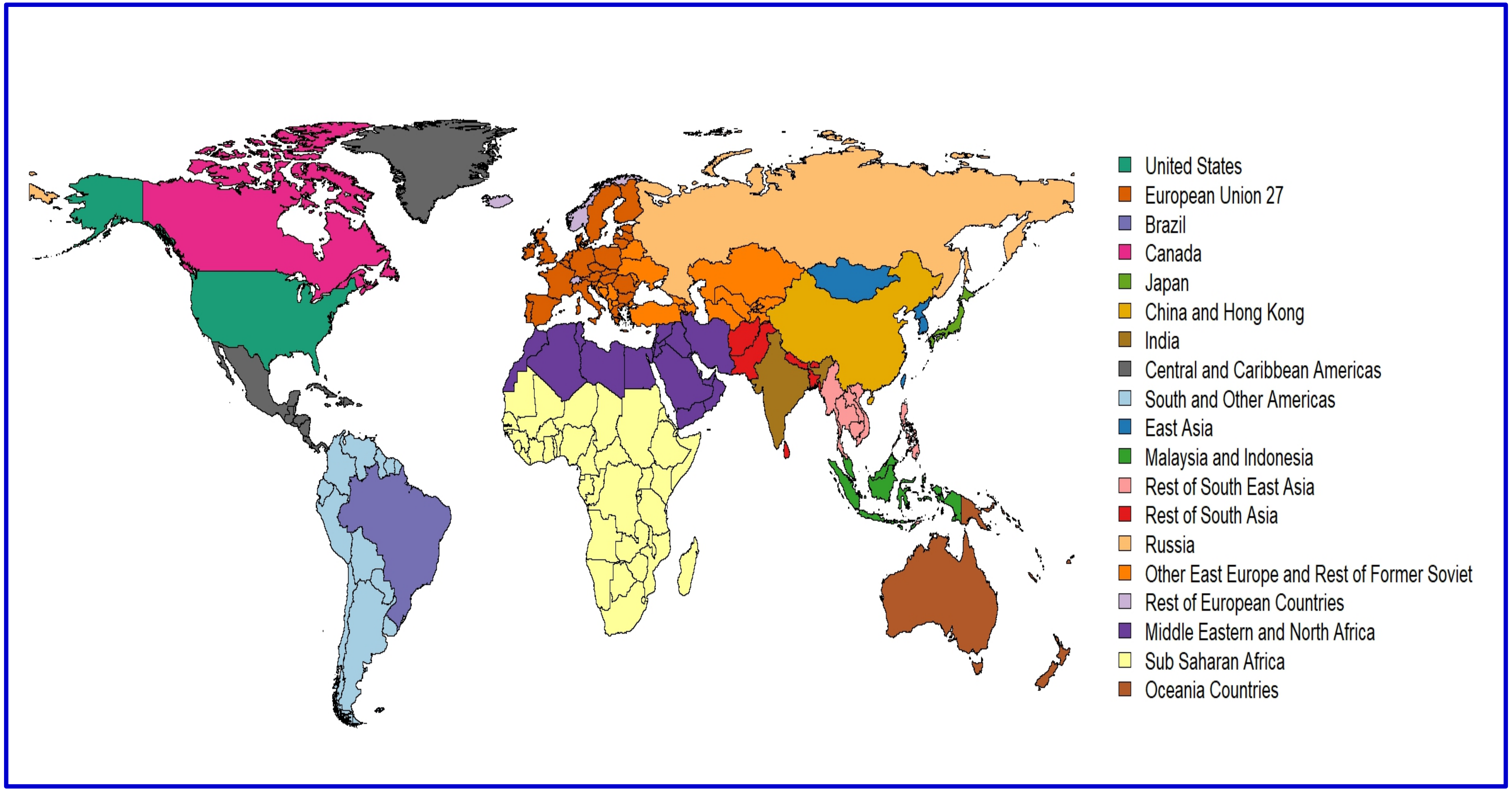


Land in GTAP-BIO model

- GTAP-BIO represents land variables at an Agro-Ecological Zone (AEZ) level and traces their changes across the world
- Managed land cover in this model is divided to: Forest, Pasture, and cropland
- Harvested areas are aggregated to: Rice, wheat, corn, Other coarse grains, soybeans, palm oil, rapeseed, other oilseeds, sugar crops, other crops
- Cellulosic crops are also included
- Marginal cropland can return to crop production
- Double cropping is included in this model



Regional aggregation of GTAP-BIO model (19 regions)



EPA model comparison exercise (MCE)

- Since 2010, EPA has not changed its initial CI assessments for renewable fuels
- More recently EPA has acknowledged that: **“*our previous framework is comparatively old, and that a better understanding of these newer models and data is needed* ” (EPA, 2023)**
- A model comparison exercise has been developed by EPA in 2022 and 2023
- Goals of MCE:
  - Advance the science in the area of analyzing the lifecycle GHG emissions of biofuels
  - Identify and understand differences across models’ projections regarding biofuel impacts
- Models participated in MCE:
  - **GREET:** Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies Model
  - **GLOBIOM:** Global Biosphere Management Model
  - **GCAM:** Global Change Analysis Model
  - **GTAP-BIO: Global Trade Project Model- An extension for biofuels**
  - **ADAGE:** Applied Dynamic Analysis of the Global Economy
- This paper highlight some key results of GTAP-BIO for this exercise.

Examined experiments in MCE

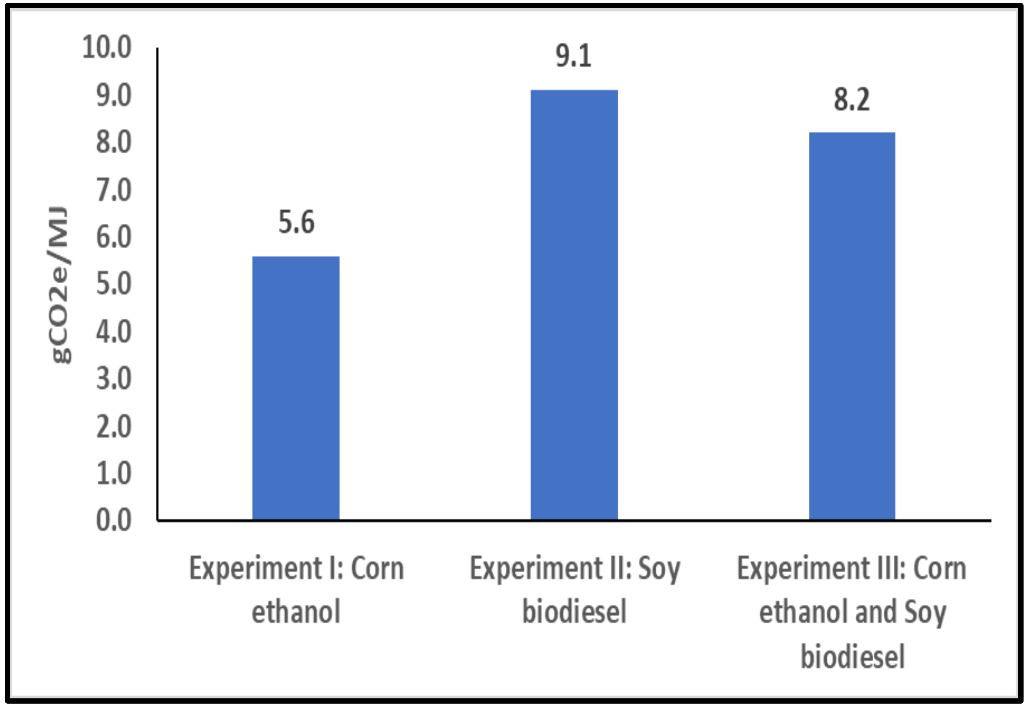
- **Experiment I:** Isolate the global consequential economic and environmental effects of producing one billion gallons of additional corn ethanol in the US from all other drives that might affect the global economy.

- **Experiment II:** Isolate the global consequential economic and environmental effects of producing one billion gallons of additional soy oil biodiesel in the US from all other drives that might affect the global economy.

- **Experiment III:** Isolate the joint effects of an increase in corn ethanol by one billion gallons and an increase in soy oil biodiesel by 1 billion gallons in the US from all other drives that might affect the global economy

Results: ILUC emissions and the corresponding land use changes

ILUC emissions

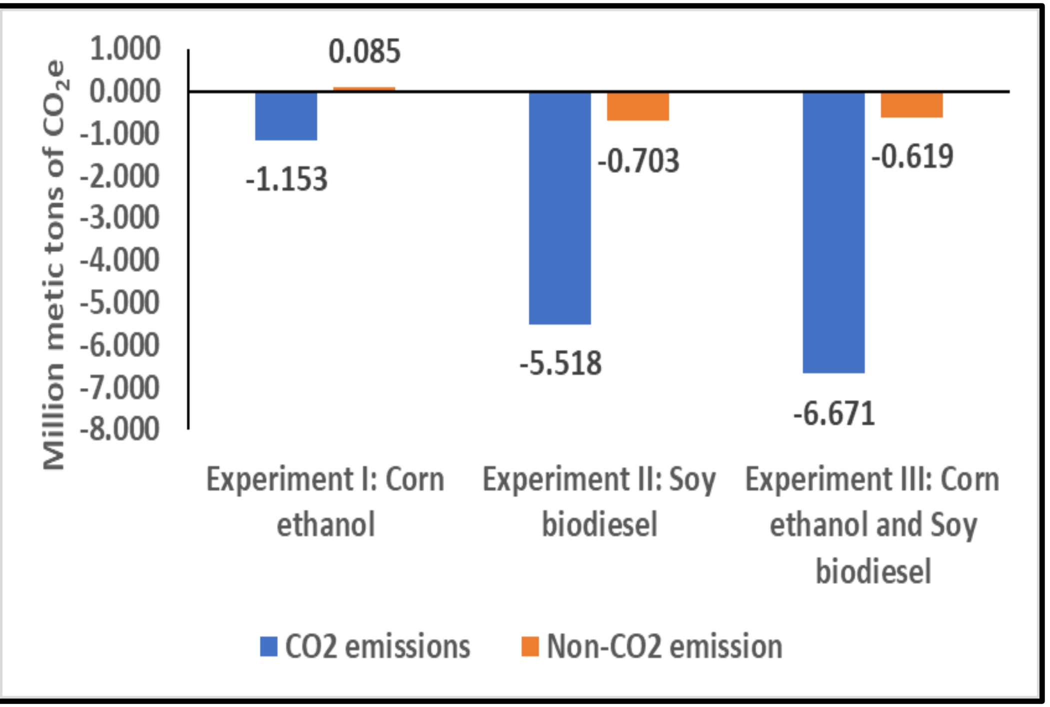


Induced land use changes (1000 ha)

Description	Experiment I: Corn ethanol			Experiment II: Soy biodiesel			Experiment III: Corn ethanol and Soy biodiesel		
	USA	Non-USA	Total	USA	Non-USA	Total	USA	Non-USA	Total
Change in H area of crops	43.5	112.6	156.2	34.5	140.7	175.3	77.5	253.7	331.3
Change in cropland pasture	-32.7	-60.3	-93.0	-24.5	-75.2	-99.7	-56.9	-135.7	-192.5
Change in unused land	-6.9	-13.9	-20.8	-6.4	-15.1	-21.6	-13.3	-29.1	-42.3
Change in multiple cropping	-1.7	-6.5	-8.2	-1.6	-7.1	-8.7	-3.3	-13.6	-16.9
Change in forest	0.6	-8.4	-7.8	-2.8	-1.2	-4.0	-2.2	-9.6	-11.8
Change in pasture	-2.8	-23.5	-26.3	0.8	-42.0	-41.1	-2.0	-65.7	-67.7

Results: Impacts on GHG emissions excluding ILUC emissions

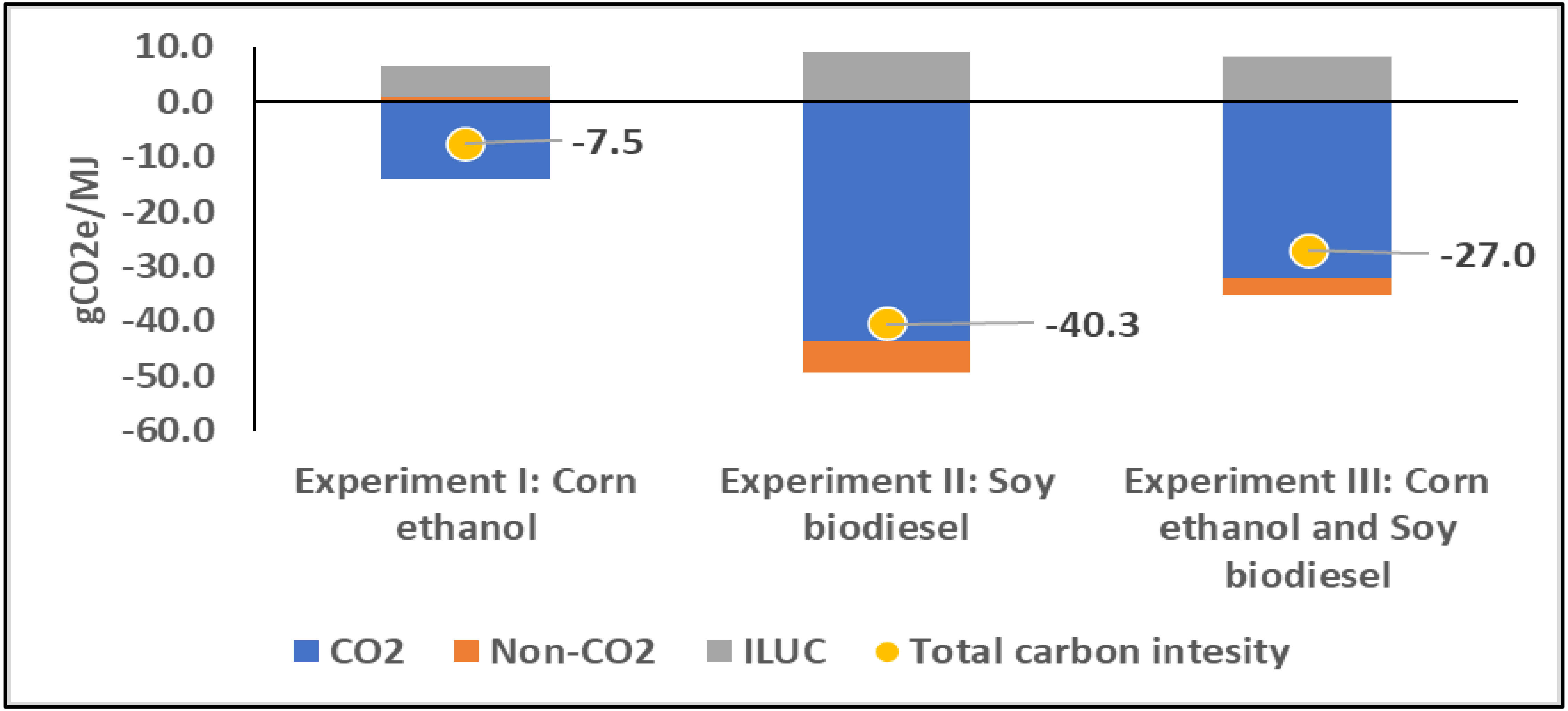
GHG emissions



GHG emissions by type (Million metric tons of CO_2e)

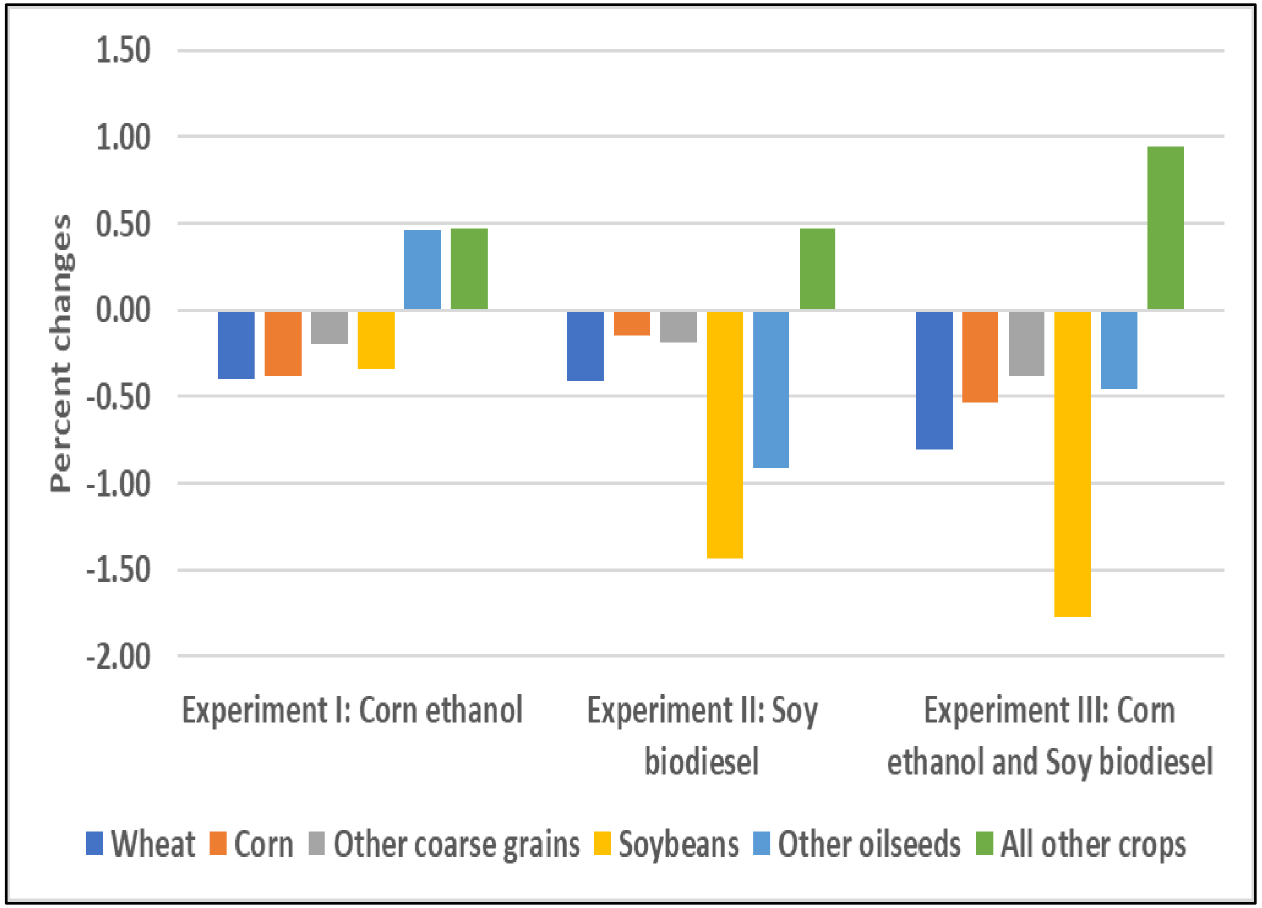
Description	Experiment I: Corn ethanol			Experiment II: Soy biodiesel			Experiment III: Corn ethanol and Soy biodiesel		
	USA	Non-USA	Total	USA	Non-USA	Total	USA	Non-USA	Total
Combustion CO_2	-1.705	0.552	-1.153	-6.853	1.336	-5.518	-8.560	1.889	-6.671
N_2O	0.290	0.120	0.410	0.087	0.043	0.130	0.375	0.164	0.539
CH_4	-0.210	-0.070	-0.280	-0.303	-0.415	-0.717	-0.513	-0.485	-0.998
F-gases	-0.010	0.011	0.001	-0.012	0.025	0.014	-0.022	0.037	0.015
Non-combustion CO_2	-0.106	0.061	-0.045	-0.256	0.126	-0.130	-0.362	0.187	-0.175
Total	-1.742	0.674	-1.068	-7.337	1.116	-6.221	-9.082	1.792	-7.290

Results: Overall carbon intensity

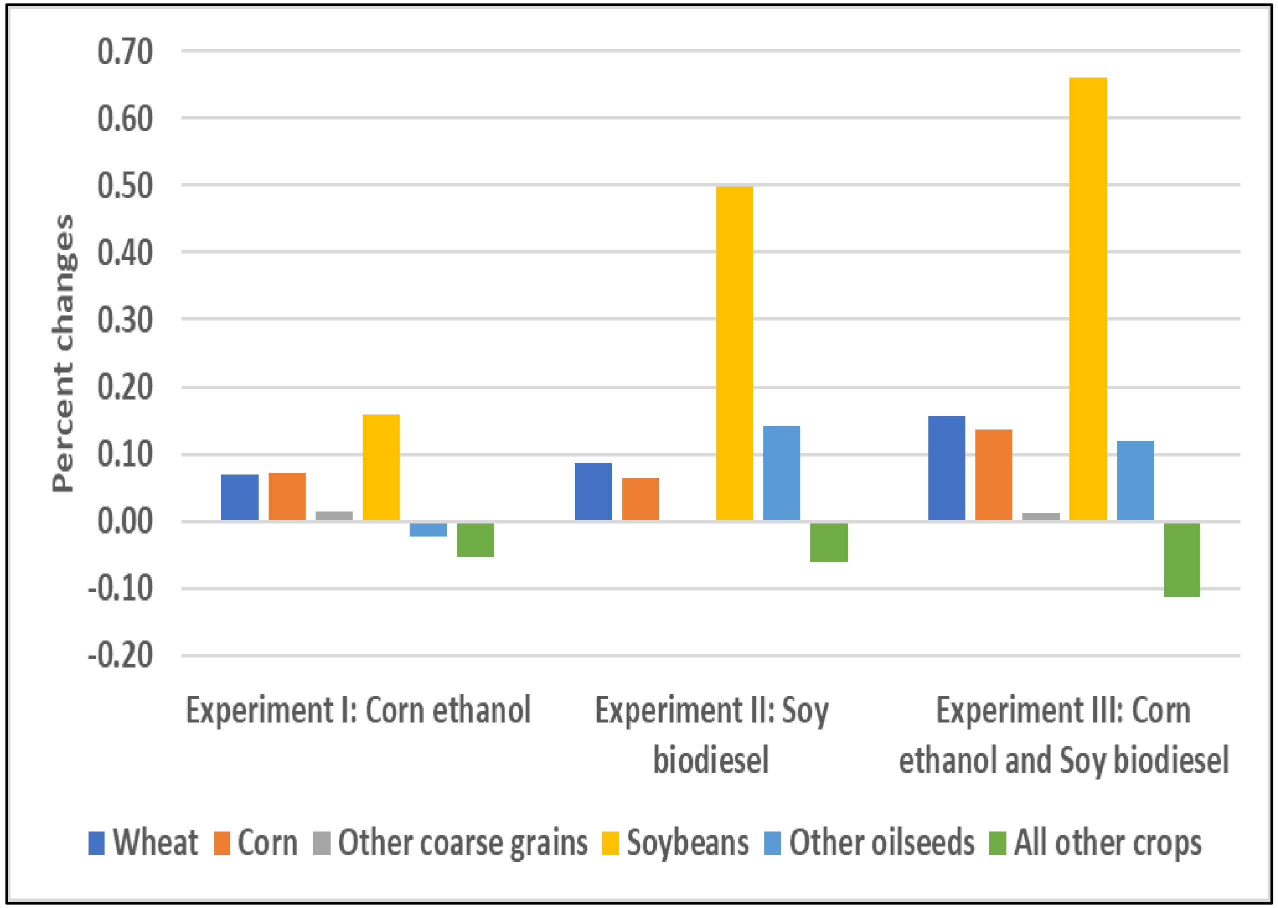


Results: Crops trade effects

Percent changes in US exports



Percent changes in exports of other countries



Results: Crops trade effects (1000 metric tons)

Description	US exports			Non-US exports		
	Exp. I: Corn ethanol	Exp. II: Soy biodiesel	Exp. III: Corn ethanol and Soy biodiesel	Exp. I: Corn ethanol	Exp. II: Soy biodiesel	Exp. III: Corn ethanol and Soy biodiesel
Wheat	-102.5	-104.1	-206.2	103.4	127.6	231.3
Corn	-190.6	-75.2	-266.8	65.1	58.7	124.4
Other coarse grains	-14.8	-14.1	-29.0	6.2	-1.5	4.7
Soybeans	-167.5	-711.2	-880.1	109.8	343.1	455.3
Other oilseeds	2.6	-5.2	-2.6	-7.9	47.1	39.5
All other crops	68.8	68.4	136.9	-86.8	-98.6	-185.3

Carbon intensity: EPA model comparison exercise (kgCO2e/MMBTU)

Description	Experiment I: Corn ethanol				Experiment II: Soy Biodiesel			
	ADAGE	GCAM	GTAP-BIO	GLOBIOM	ADAGE	GCAM	GTAP-BIO	GLOBIOM
Energy sector	-15	-65	-15	X	-28	-40	-46	X
ILUC	-1	31	6	13	295	62	10	23
Ag & forestry	15.1	15.3	1	X	8.7	19.7	-6	X
Total	-.9	-18.7	-8	X	275.7	41.7	-42	X

Conclusions

- **GTAP-BIO Results:**
  - Producing more corn ethanol generates positive ILUC
  - Producing more soy oil biodiesel generates positive ILUC
  - Producing more corn ethanol reduces overall GHG emissions
  - Producing more soy oil biodiesel reduces overall GHG emissions
- EPA MCE practice:
  - Models project reductions in GHG emissions due to substitution between fossil fuels and ethanol
  - Models project reductions in GHG emissions due to substitution between fossil fuels soy oil biodiesel
  - With one exception, models estimate positive ILUC emissions for corn ethanol and soy biodiesel
  - Models project reductions in overall GHG emissions for corn ethanol
  - GTAP-BIO projects reductions in GHG emissions for soy oil biodiesel but ADAGE and GCAM project increases in GHG emissions for this biofule

Thanks for your attention

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