Estimation of Land Use Change Emission Values for Aviation Biofuels Production

Project 13-C-AJFE-PU

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Motivation

- ICAO agreed to implement a Global Market-based Measure (GMBM) scheme
  - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (39^{th} Assembly, 2016).
  - Aviation biofuels (biojet) are expected to play an important role.
- We need to know to what extent aviation biofuels can help reduce emissions.
- Induced Land Use Change (ILUC) emissions will be a part of the aviation biofuel emission estimates for the ICAO/CAEP/AFTF process, so we need the best possible estimated values.

Induced Land Use Change Impacts

- Reduced consumption of the feedstock in non-biofuel uses.
- Switching among crops to produce more of the biofuel commodity.
- Changes at the extensive margin to convert pasture and forest to cropland.
- Changes at the intensive margin to increase crop yield, engage in more double cropping, and increase cultivation of unused land.
- Shifts in global production and trade.

Estimating ILUC emissions

- First, estimate the global land use change using an economic equilibrium model
  - CARD–FAPRI (FASOM, US EPA), GTAP-BIO (CARB)
  - MIRAGE-BioF (EU), GLOBIOM (EU)
- Second, calculate emissions using an emission factor/accounting model
  - plant biomass carbon,
  - soil carbon,
  - forgone carbon sequestration
- There are important disparities among models/estimations
  - Modelling theoretical background
  - Baseline assumptions, shock size, simulation approach
  - Emissions calculation (amortization periods, etc.).

Objectives

- Our long term objective is to provide reliable ILUC emission estimates for different types of aviation biofuels produced in any region of the world.
- Our near term objectives are
  - To test simulations for aviation biofuels produced in four regions using GTAP-BIO and AEZ-EF.
  - In collaboration with the GLOBIOM group, validate parameters and address uncertainty associated with ILUC modeling.

GTAP-BIO

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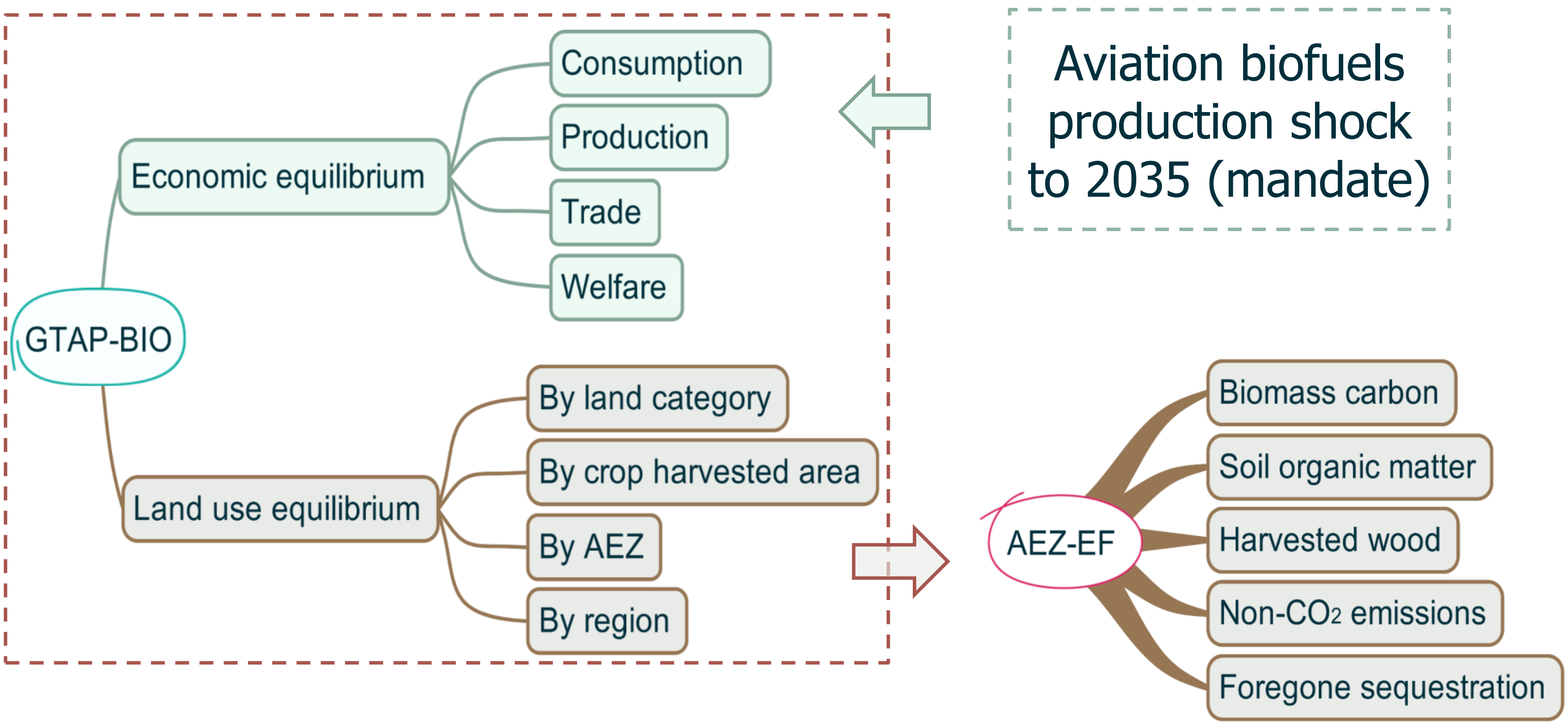
- Computable general equilibrium (CGE) model
- Originally created by incorporating GTAP-AEZ into GTAP-E for biofuels policy analysis.
- Aggregated to 19 regions, disaggregated agricultural, biofuels, and other related sectors.
- Land was disaggregated into up to 18 Agro-Ecological Zones (AEZs) in each region
- GTAP database (2011 base year).
- Land database
  – Cropland, Pasture, Accessible forest
  – Harvested area for all crops

GTAP-BIO and AEZ-EF



Study scope

- Pathways
  - ASTM approved technologies
    - Fischer-Tropsch biojet (FTJ) which represents both FT-SPK and FT-SKA, HEFA, SIP, and ATJ
  - Feedstocks that entail higher risks to induce LUC
  - Agricultural and forestry residues, waste tallow, used cooking oil (UCO), municipal solid waste (MSW), and microalgae are excluded.
- Regions
  - USA, EU, Brazil, Malaysia & Indonesia
  - Major biofuels producing and jet fuel consumption regions
- Shock
  - Biojet production in 2035, CORSIA policy target

Simulations

Pathways

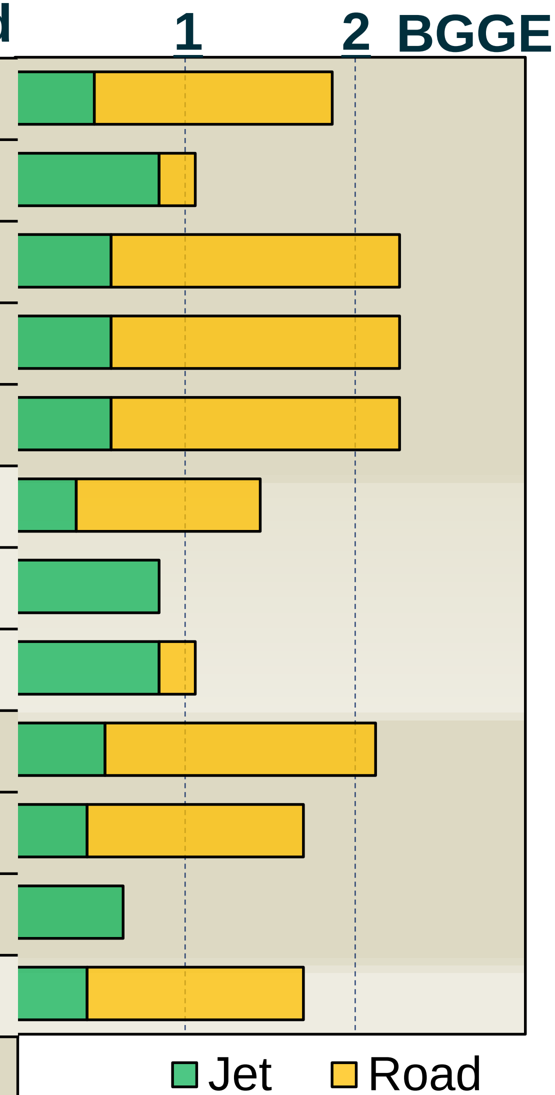
	USA	Brazil	EU	Mala Indo
Soy HEFA	**1**	**6**		
Rapeseed HEFA			**9**	
Palm HEFA				**12**
Sugarcane ATJ		**7**		
Corn ATJ	**2**			
Sugar beet SIP			**10**	
Sugarcane SIP		**8**		
Switchgrass FTJ	**3**			
Miscanthus FTJ	**4**		**11**	
Poplar FTJ	**5**			

- Shock size development
  - IEA 450 scenario
  - 62 Mtoe (21.2 BGGE), 2035

Study scope
Feedstock availability
Economic feasibility
Road biofuels coproducts

Shock size (BGGE)

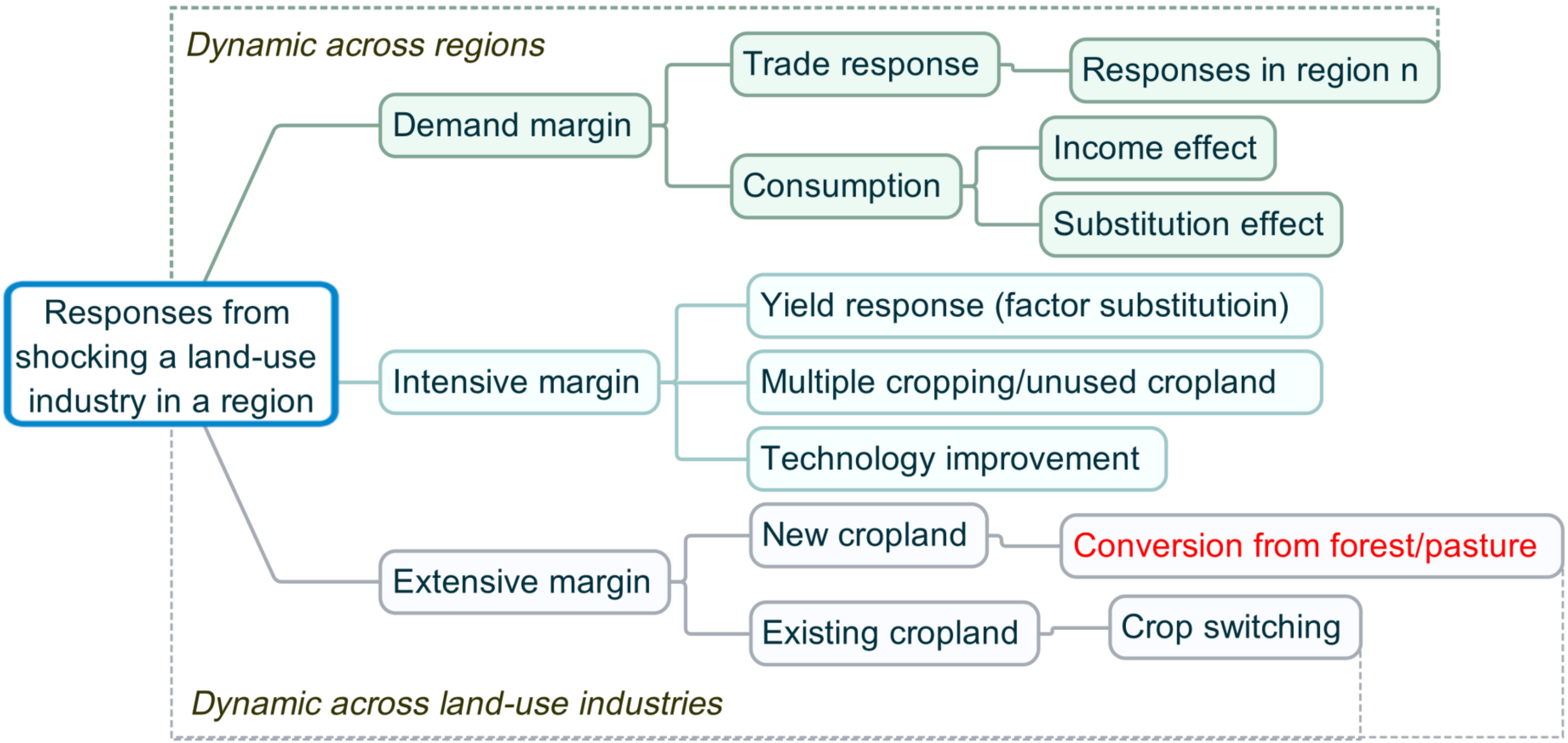
Region	NO.	Pathway	Total	Jet	Road
USA	1	Soy HEFA	1.9	0.5	1.4
	2	Corn ATJ	1.1	0.8	0.2
	3	Miscanthus FTJ	2.3	0.6	1.7
	4	Switchgrass FTJ	2.3	0.6	1.7
	5	Poplar FTJ	2.3	0.6	1.7
Brazil	6	Soy HEFA	1.4	0.4	1.1
	7	Sugarcane SIP	0.8	0.8	0.0
	8	Sugarcane ATJ	1.1	0.8	0.2
EU	9	Rapeseed HEFA	2.1	0.5	1.6
	10	Miscanthus FTJ	1.7	0.4	1.3
	11	Sugar beet SIP	0.6	0.6	0.0
Mala & Indo	12	Palm HEFA	1.7	0.4	1.3
ALL		ALL	19.2	7.1	12.1



Model modifications

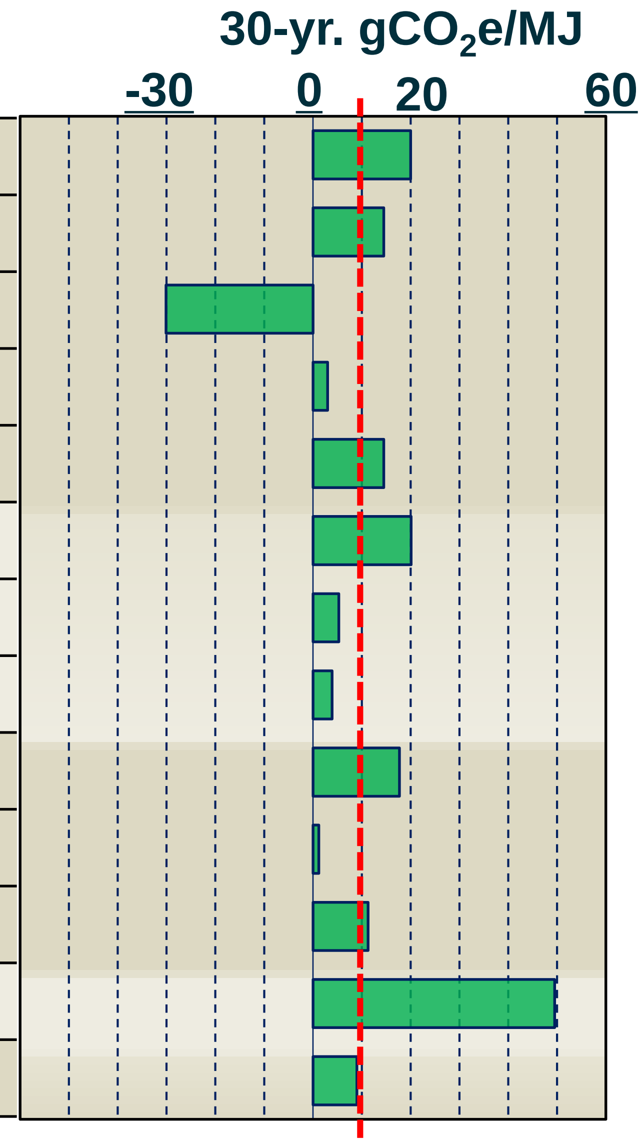
- Introduce the 12 aviation biofuels pathways into GTAP-BIO using literature cost data and technology specifications.
- Introduce miscanthus, switchgrass, and poplar into the GTAP-BIO database and model and the AEZ-EF model. Nest them with cropland pasture in land supply for the US.
- Split coproducts of aviation biofuels. Coproducts may include renewable diesel, naphtha, and others. They will supply road transport.
- Related parameters such as land transformation elasticities have been recalibrated based on updated information.

Market-mediated responses



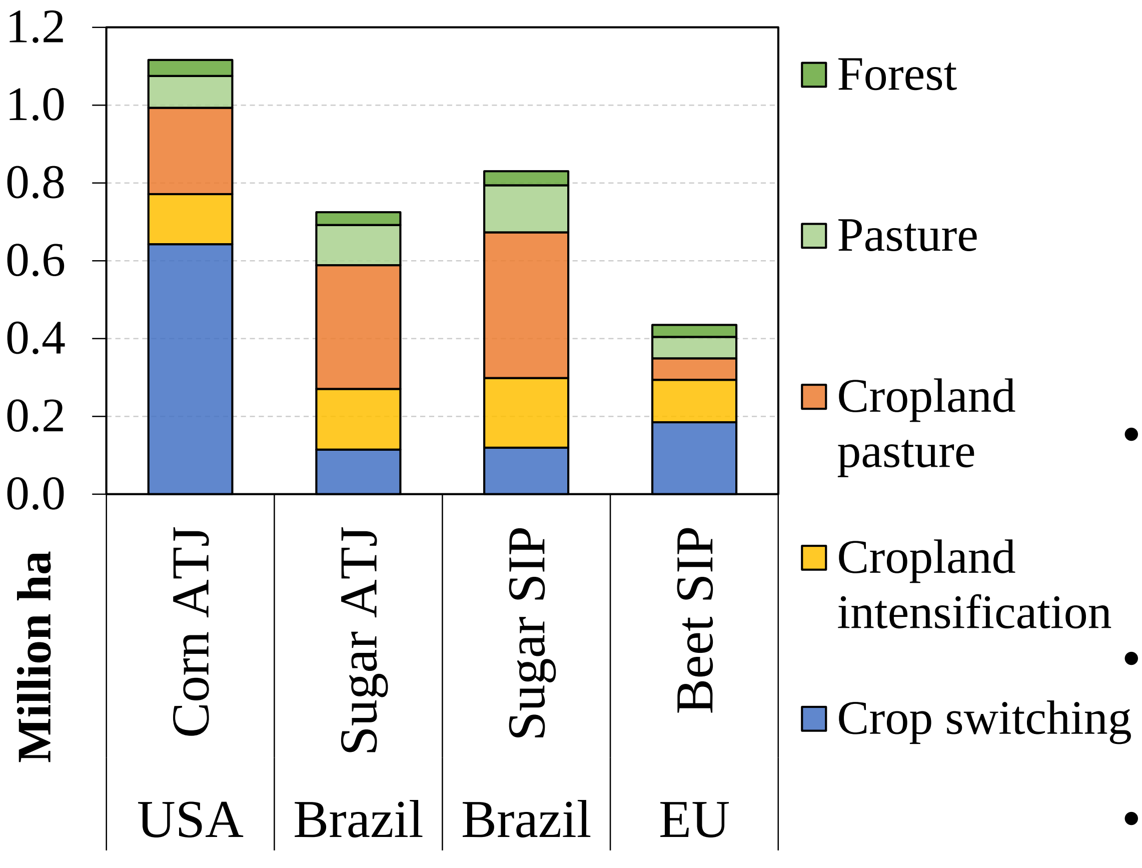
GTAP ILUC CI (gCO_2e/MJ)

Region	NO.	Pathway	30-yr
USA	1	Soy HEFA	20
	2	Corn ATJ	15
	3	Miscanthus FTJ	-30
	4	Switchgrass FTJ	3
	5	Poplar FTJ	15
Brazil	6	Soy HEFA	20
	7	Sugarcane SIP	5
	8	Sugarcane ATJ	4
EU	9	Rapeseed HEFA	18
	10	Miscanthus FTJ	1
	11	Sugar beet SIP	11
Mala & Indo	12	Palm HEFA	50
ALL		ALL	9



SIP & ATJ

Global LUC decomposition



- US ATJ and EU SIP
  - Stronger crop switching from soybean, wheat, other feed crops so that export decreases
  - Deforestation in other regions
- CP plays important role in USA and Brazil; CP has a lower EF than pasture.
- Two Brazil sugar pathways are similar in LUC pattern
- 0.2-0.5% feedstock yield growth

SIP & ATJ

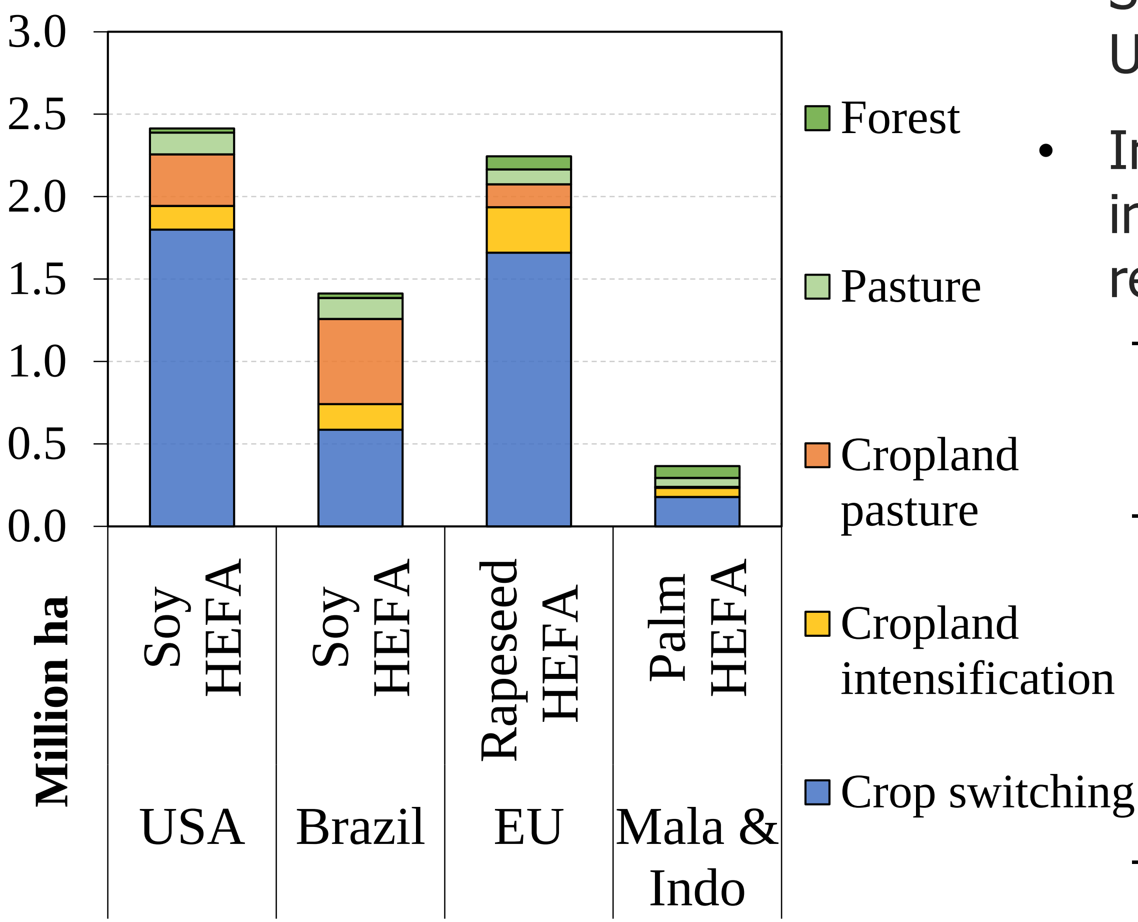
➢ Emissions (CI) decomposition, g CO_2e /MJ

Region	Pathway	Natural Veg.	Foregone	Crop Carbon	SOC	Peat	30-year CI
USA	Corn ATJ	7.0	1.2	-0.2	6.0	0.6	14.5
Brazil	Sugarcane SIP	9.0	1.2	-7.7	2.4	0.3	5.3
	Sugarcane ATJ	6.5	0.9	-5.4	1.7	0.3	3.9
EU	Sugar beet SIP	6.9	1.8	-3.5	5.3	0.8	11.3

- Natural vegetation carbon is the largest carbon source (i.e. carbon in forest, pasture, and CP)
- Three sugar crops have large crop carbon sequestration due to the large dry yield
- Two Brazil sugar pathways have similar distribution; Sugarcane, as a perennial crop has larger SOC;
- Peat oxidation impacts are small.

HEFA

➢ Global LUC decomposition



- Strong yield responses globally
- Stronger crop switching in the USA and EU
- In Mala & Indo, palm area increase is smaller than net required
  - strong market-mediated responses in palm oil consumption and trade
  - The total palm oil production in Mala & Indo increases by 6.2%. It can be decomposed into an 11.4% increase in domestic consumption and 5.2% decrease in exports.
  - Area expansion in rapeseed (0.18 Mil. ha) and other oilseeds (0.40 Mil.ha)

HEFA

- USA soy HEFA, trade impact
  - Decrease in soybean and soy oil export
    - Soybean export to China decreases by 11%
    - Soybean oil export to Central and Caribbean Americas decrease by 19.8%
    - Export from Brazil and Mala & Indo increases
  - US imports of palm oil, rapeseed oil, and other vegetable oils increase by 1.3%, 0.9%, and 8.1%, respectively.
  - Strong increase in meal export (59%).

HEFA

➢ Emissions (CI) decomposition, g CO_2e /MJ

Region	Pathway	Natural Veg.	Foregone	Crop Carbon	SOC	Peat	30-year CI
USA	Soy HEFA	3.8	0.4	2.1	3.9	9.8	20.0
Brazil	Soy HEFA	7.0	0.6	-1.9	7.7	6.7	20.1
EU	Rapeseed HEFA	5.1	1.1	1.2	3.5	6.8	17.7
Mala & Indo	Palm HEFA	10.3	0.9	-6.6	0.4	44.5	49.5

- Peat oxidation is a major carbon source in all HEFA pathways.
- Brazil HEFA has relatively less crop switching, but more expansion into natural vegetation, so higher emissions from natural vegetation.

Schedule and Status

- We have updated the GTAP data base and model from 2004 to 2011.
- Aviation biofuels and cellulosic crops have been introduced into the data base and the new model.
- We have done test simulations with the new model for 12 aviation biofuels pathways.
- Currently, we are working on comparing results between GTAP-BIO and GLOBIOM.
  - This process helps improve both models.
- We will test the sensitivity of important parameters.

Recent Accomplishments and Contributions

- Presentations to the ICAO/CAEP/AFTF group in February and June in 2017.

Publications

- Taheripour, Farzad, Xin Zhao, and Wallace E. Tyner. "The impact of considering land intensification and updated data on biofuels land use change and emissions estimates." Biotechnology for biofuels 10.1 (2017): 191.

Summary

- Summary statement
  - Producing aviation biofuels using land-based feedstocks will induce global land use change.
  - Our preliminary results show that vegetable oil HEFA pathways will have relatively higher carbon intensity, largely due to the related peat oxidation.
  - Cellulosic crops tend to have small or even negative ILUC emission mainly due to the high soil carbon sequestrations.
- Next steps?
  - Work with the GLOBIOM group to improve both models based on the available information
- Key challenges/barriers
  - Comparisons between GTAP-BIO and GLOBIOM can be challenging given the differences in model design, data base, emissions accounting, etc.

Acknowledgements

- David Cui provided support with some of the model simulations.
- Hugo Valin from IIASA has been collaborating on model comparison activities.

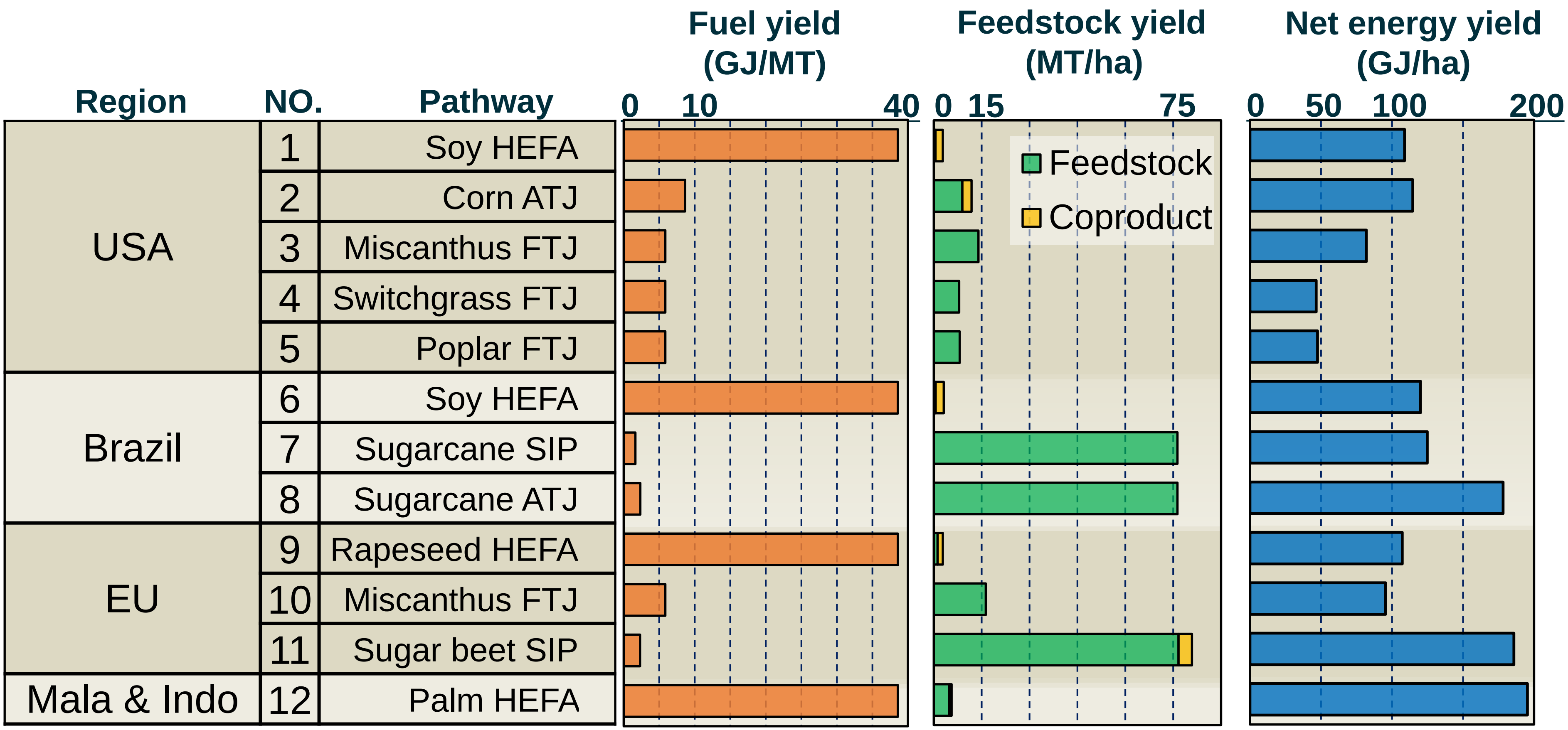
Participants

- Farzad Taheripour, Research Associate Professor, Purdue University
- Xin Zhao, PhD student, Purdue University

Thanks

Questions and Comments

Yield Data


Fuel yield (GJ/MT)
Feedstock yield (MT/ha)
Net energy yield (GJ/ha)
Region
NO.
Pathway
0
10
40
0
15
75
0
50
100
200
Feedstock
Coproduct
USA
1 Soy HEFA
2 Corn ATJ
3 Miscanthus FTJ
4 Switchgrass FTJ
5 Poplar FTJ
Brazil
6 Soy HEFA
7 Sugarcane SIP
8 Sugarcane ATJ
EU
9 Rapeseed HEFA
10 Miscanthus FTJ
11 Sugar beet SIP
Mala & Indo
12 Palm HEFA

Carbon intensity

$$\text{CI} = \frac{\sum_{i,j,k,r} CO_2e_{i,j,k,r}}{Years \times Biofuels\ production} = \frac{g\ CO_2e}{MJ}$$

i : Carbon source/sink

j : Land transitions (forest, pasture, CP, cellulosic, etc.)

k : Argo-ecological zones

r : Regions

$Years$: 20-year or 30-year

$Biofuels\ production$: Shock size

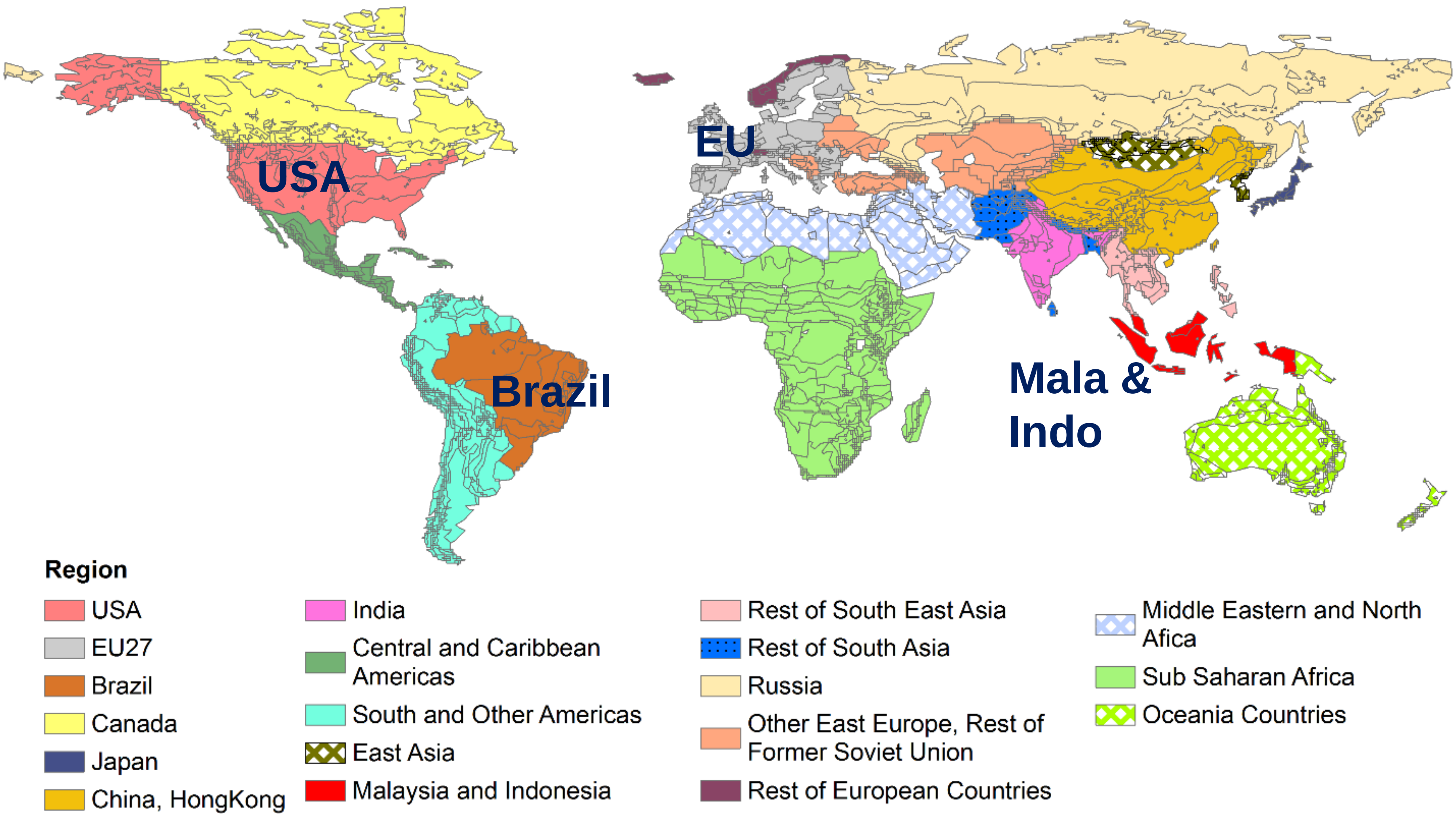
20-year or 30-year

$$\text{CI} = \frac{\sum_{i,j,k,r} CO_2e_{i,j,k,r}}{Years\ \times Biofuels\ production} = \frac{g\ CO_2e}{MJ}$$

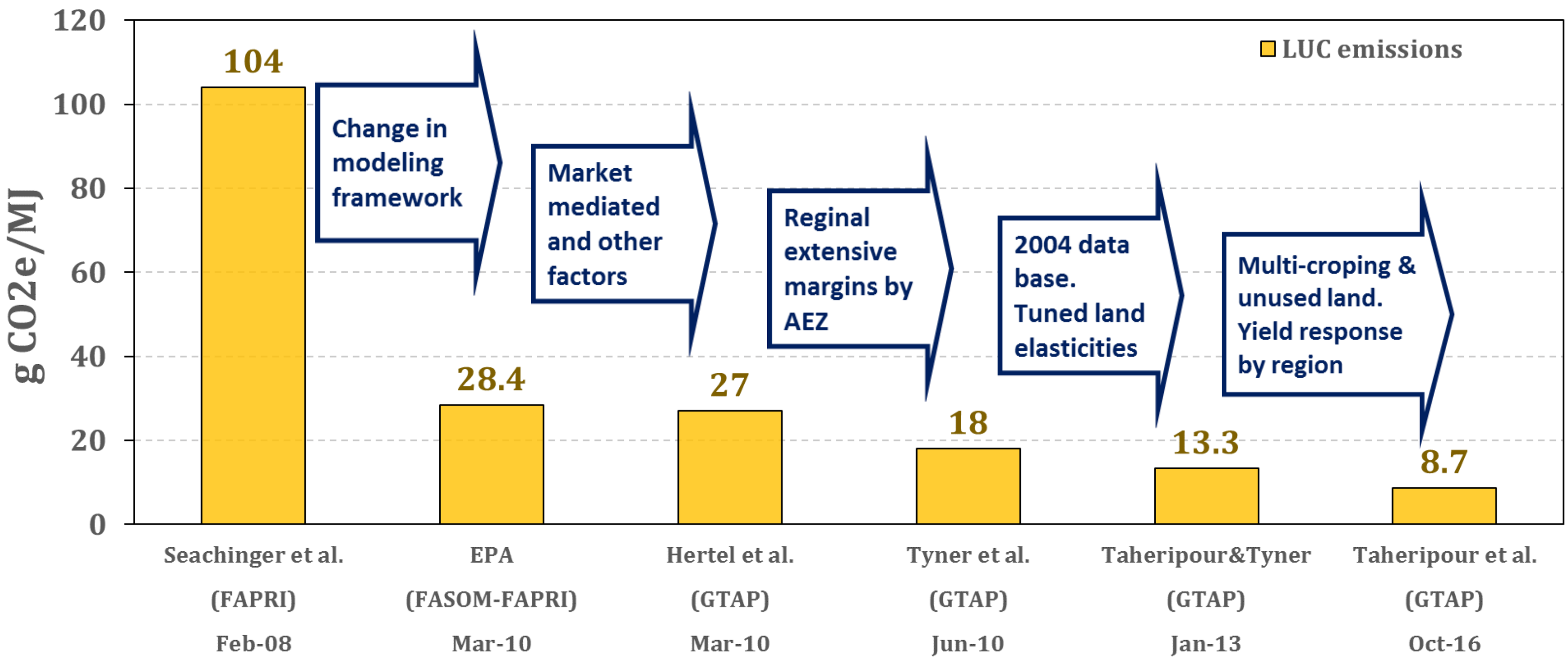
Factor	$g\ CO_2e$					MJ
	Natural vegetation	Foregone sequestration	Agricultural biomass	Soil organic carbon	Peatland oxidation	Production years
Variable		✓			✓	✓

Brief History of GTAP

- This week GTAP celebrates its 25th anniversary, having been founded in 1992.
- We are now using the 9th version of the data base (2011) and developing the 10th (2014).
- The data base contains 140 countries and regions and 57 economic sectors plus all the biofuel sectors
- Land is divided into 18 agro-ecological zones (AEZs)
- The GTAP model and data base are publically available.


USA
EU
Brazil
Mala &
Indo
Region
USA
EU27
Brazil
Canada
Japan
China, HongKong
India
Central and Caribbean Americas
South and Other Americas
East Asia
Malaysia and Indonesia
Rest of South East Asia
Rest of South Asia
Russia
Other East Europe, Rest of Former Soviet Union
Rest of European Countries
Middle Eastern and North Afica
Sub Saharan Africa
Oceania Countries

ILUC from the US RFS mandates (corn ethanol)

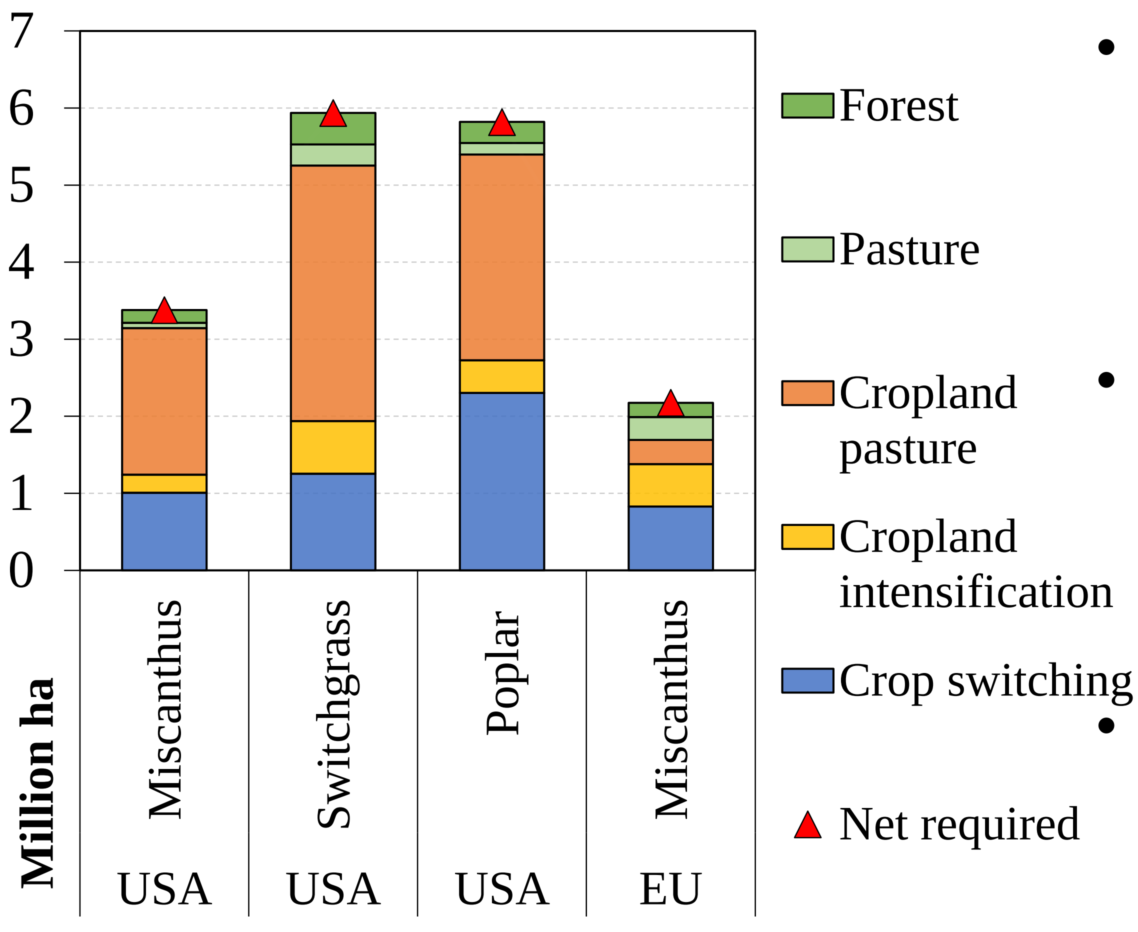


History of GTAP-BIO Model

GTAP-E (2002), first model of the energy-economy-environment-trade linkages.
GTAP-AEZ (2005), land use model designed based on 18 Agro-Ecological Zones for agricultural production including crops, livestock, and forestry.
Initial GTAP-BIO (2008), combing GTAP-E and GTAP-AEZ, highlighting interactions among biofuel, livestock, and forestry, ignoring by-products
Improved GTAP-BIO-ADV (2010), ILUC emissions due to first-generation biofuels, considering biofuel by-products and crop yield response (YDEL), variation in global extensive margin (ETA), and cropland pasture.
GTAP-BIO-ADVFUEL (2011), modelling ILUC emissions due to second-generation biofuels, i.e. switchgrass-gasoline, miscanthus-gasoline etc.
Latest GTAP-BIO, improvements on the intensive margin (double cropping).

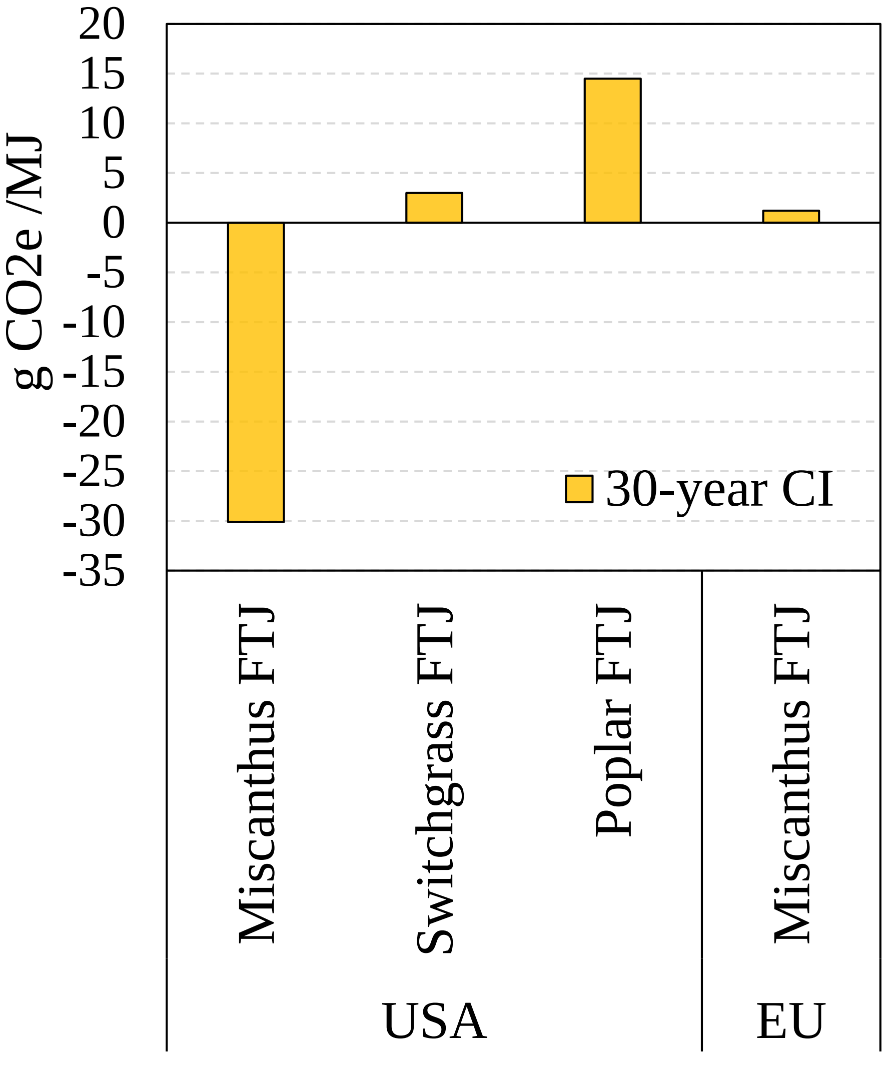
FTJ

➢ Global LUC decomposition



- Net land required is equal to feedstock area expansion.
  - Driven by net energy yield
- In the USA, cropland pasture is the major source for cellulosic crop expansion.
- There is no CP in EU
  - More impact on trade
  - More emissions in ROW

FTJ



- As perennial crops, cellulosic crops entail high sequestration in soil and biomass
  - Miscanthus has the highest sequestration due to the high yield
  - Poplar has relatively lower sequestration in soil
- For EU miscanthus
  - Relatively more global deforestation compared with the US miscanthus FTJ