Consequential LCA of Biofuels Using GCAM

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What do I mean by CLCA?

Estimating the effect on climate of a biofuel-promoting policy

- Modeling increased production requires a policy
- **Effect** = change in some climate-relevant metric from a baseline scenario without the policy

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Integrated Assessment Models

- Designed to assess climate change policies
- Policy levers (subsidies, taxes, mandates)
- Global scope
- Dynamic, multi-decadal timeframe
- Economic interactions and price feedbacks
- Endogenous energy supply and demand
- GHG accounting and aggregation to radiative forcing
- Crops, forestry, livestock production, unmanaged land
- Land use change

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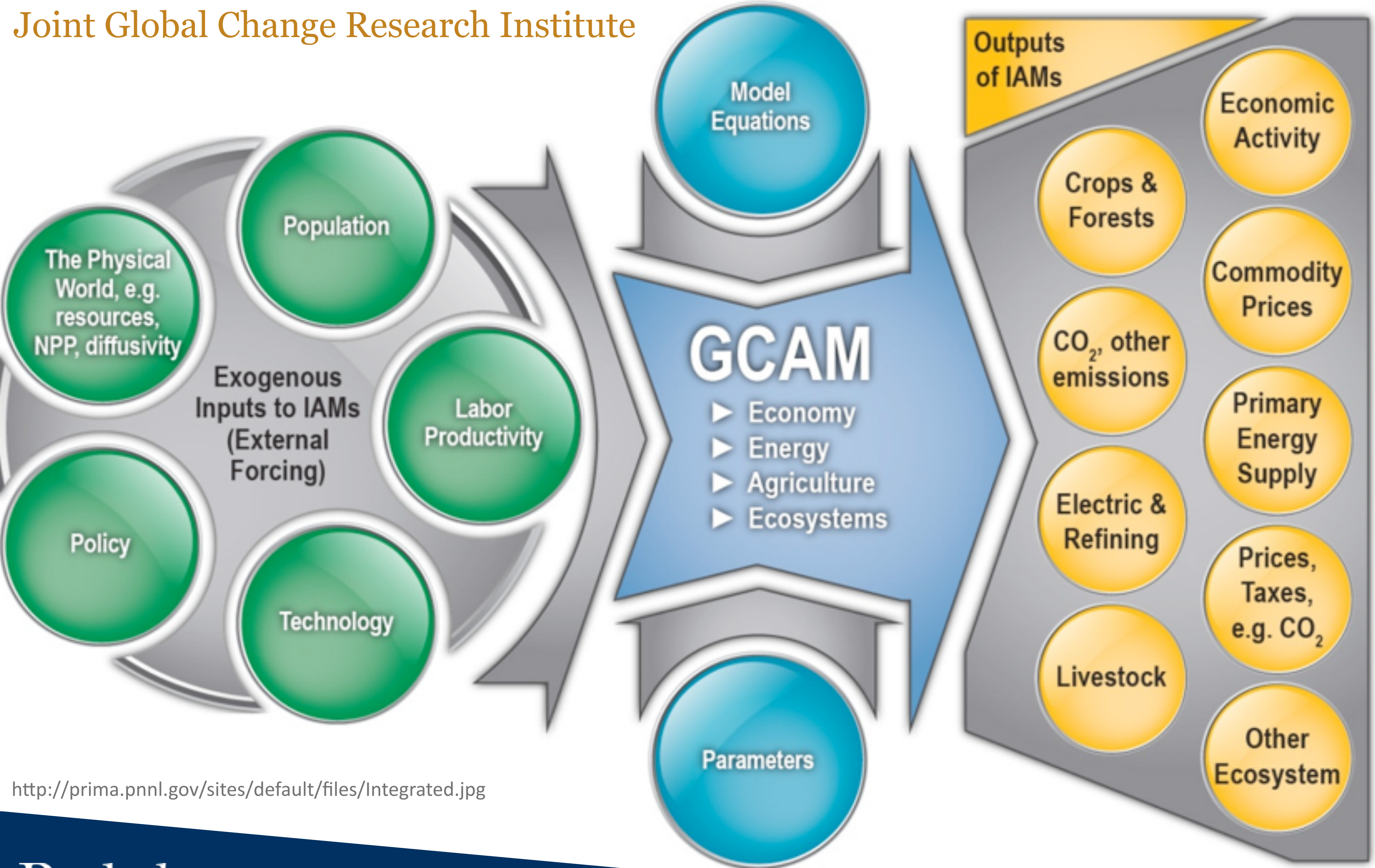
Global Change Assessment Model

Joint Global Change Research Institute



http://prima.pnnl.gov/sites/default/files/Integrated.jpg

Limitations of GCAM for CLCA

- Simpler technology representation than in many LCAs
- No explicit supply chain (only energy and feedstock)
- No distinctions among refined petroleum products
- Trade only in primary commodities
- No (direct) price-induced yield effect

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GCAM	GTAP-BIO-ADV
Partial equilibrium	General equilibrium
Dynamic (5 yr timestep)	Static
Long-term (100 y)	Medium-term (10-15 y)
One world price	Armington elasticities
Several managed & unmanaged land use types	Cropland, forestry, and livestock grazing land
Land can be brought into economic use	All accessible land is effectively in economic use
Internal GHG accounting (All land and energy uses)	External GHG accounting (Generally LUC only)
32 region, 12 crops	19 regions, 7 crops

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Goals of present analysis

- Examine sensitivity of CI of alternative definitions
- Examine effect on CI of uncertainty in key assumptions
- Identify key parameters via global sensitivity analysis

Goal was *not* to generate a "best" estimate of CI

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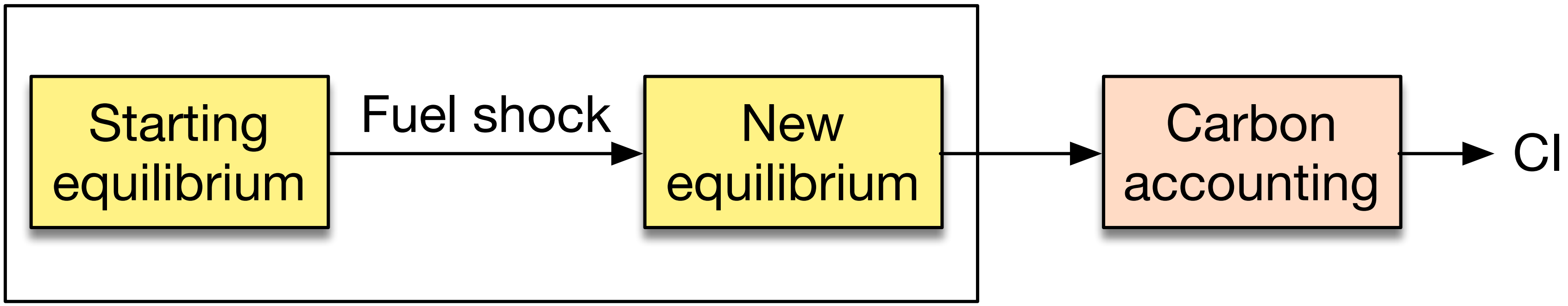
Some decisions affecting CI estimate

Model	Which model(s) to use?
Period of reckoning	Cumulative or instantaneous? Measured when?
Climate forcings	3 GHGs? All GHGs? Aerosols? Albedo change?
Climate policies	Industrial and fossil CO_2? Biogenic CO_2?
Other land demands	Population/GDP/yield changes; bioenergy mandates
Shock method	Tax, subsidy, production or technology mandate, cap?
Food consumption	Prevent reduced food consumption?
Treatment of time	Analytical horizon, production period, discount rate
Post-policy	Maintain production? Allow reversion? New policy?

GTAP-BIO-ADV modeling approach



- Instantaneous change in land use
- Emissions from LUC projected for 30 years
- Assume 30 years times the size of the shock
- Time is not represented

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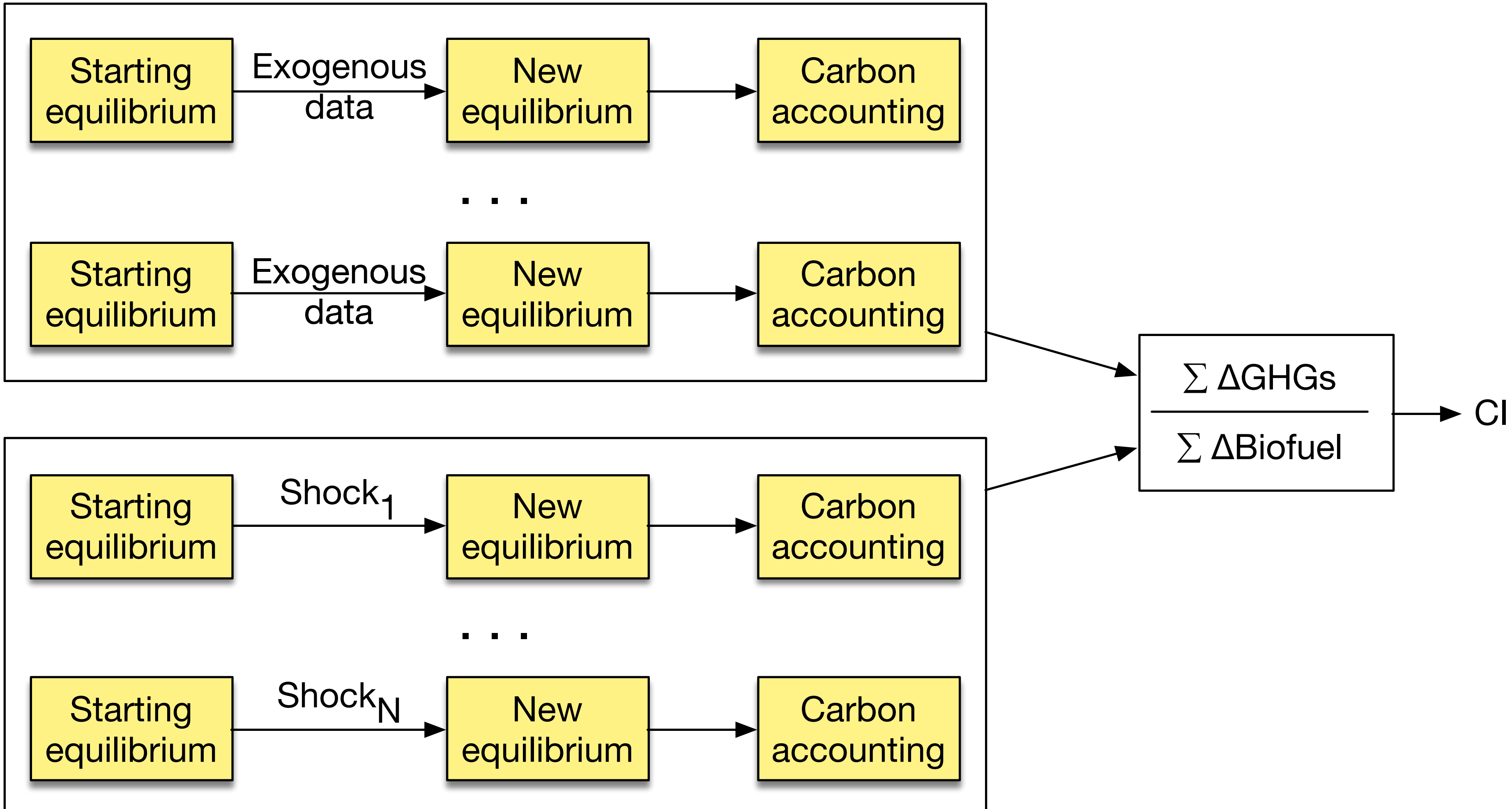
GCAM modeling approach



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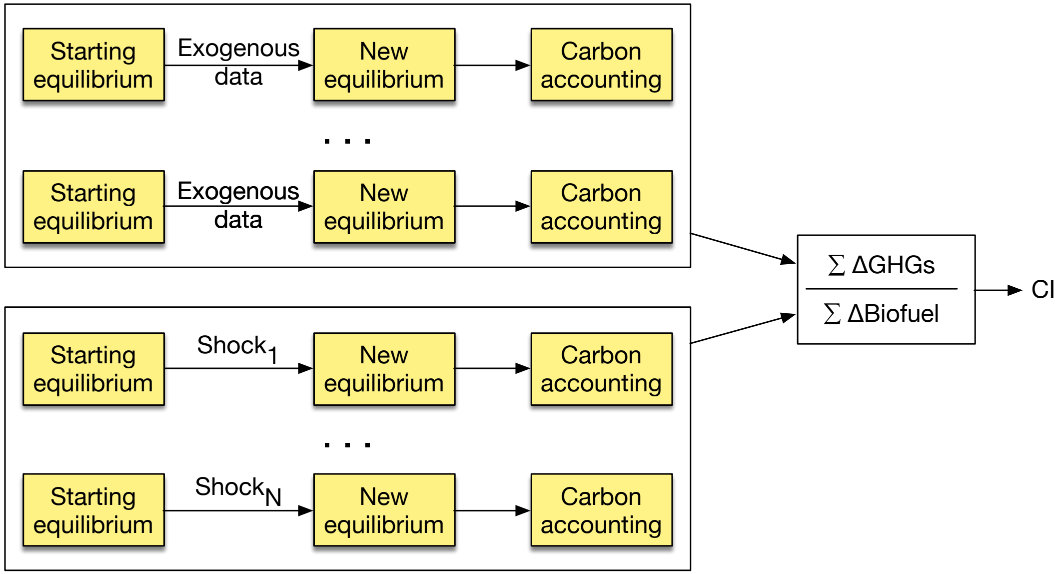
With explicit time dimension...



- Fuel shock need not be constant in each time step
- LUC can be triggered in any time step
- **Shape** of ramp-up curve affects overall CI

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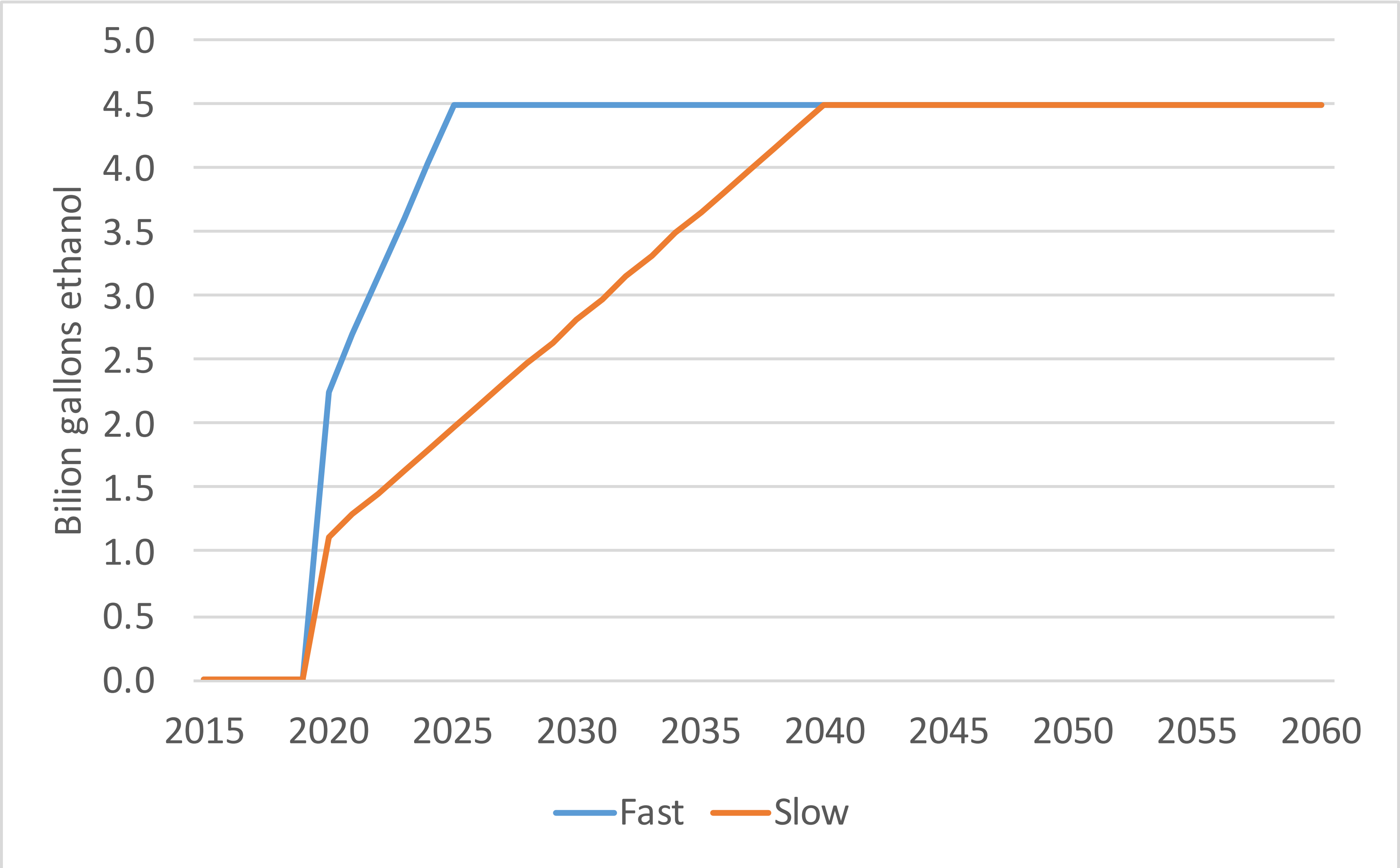
Fuel ramp-up curves (Δ ethanol)



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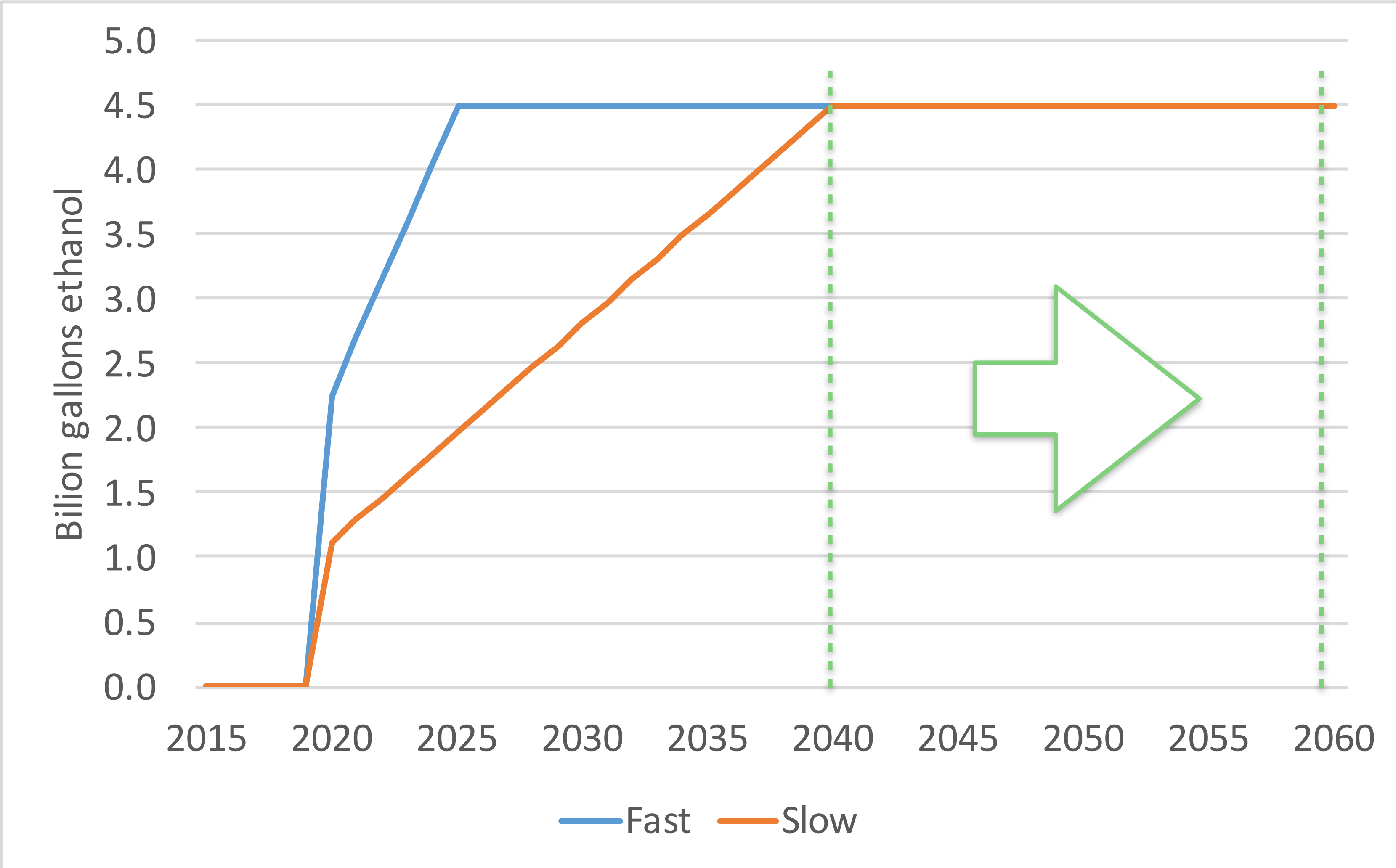
Fuel ramp-up curves (Δ ethanol)



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CI defined here as:

$$\frac{\sum_{t}\sum_{r}\sum_{i}\sum_{g}\Delta E_{g,i,r,t}}{\sum_{t}\Delta F_{t,r=U.S.}}$$

ΔE: Change in CO_2e emissions (just LUC or all GHGs)

ΔF: Change in US production of a single biofuel

t: Analytical time frame, e.g., 2020-2050

r: 32 modeled regions

i: All represented industrial sectors

g: All Kyoto greenhouse gases

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Monte Carlo Simulation

- Parameter = set of related values (e.g., forest C density in all AEZs and regions)
- ~50 parameters perturbed to examine model sensitivity.
- Inputs generated for each trial were used to a baseline and shocks to corn and cellulosic ethanol
- GCAM computed tax / subsidy required to meet designated production level
- 5,000 trials were run on a Linux HPC system
- Results saved in a database and analyzed

Some of the parameters examined

Analytic horizon	20 - 40 years
Biofuel shock scaler	±25%
Biofuel ramp-up pace	add 4.5 B gal by 2025 or 2040
CO_2 tax	\$0–25 per tonne
Fraction of land "protected"	70–90% of unmanaged land
Energy conversion coefficients	±25% or ±30%
Land substitution logit exponents	±25%
Carbon densities by land type	±30%
Yield growth rate	±30%
Food price and income elasticities	various

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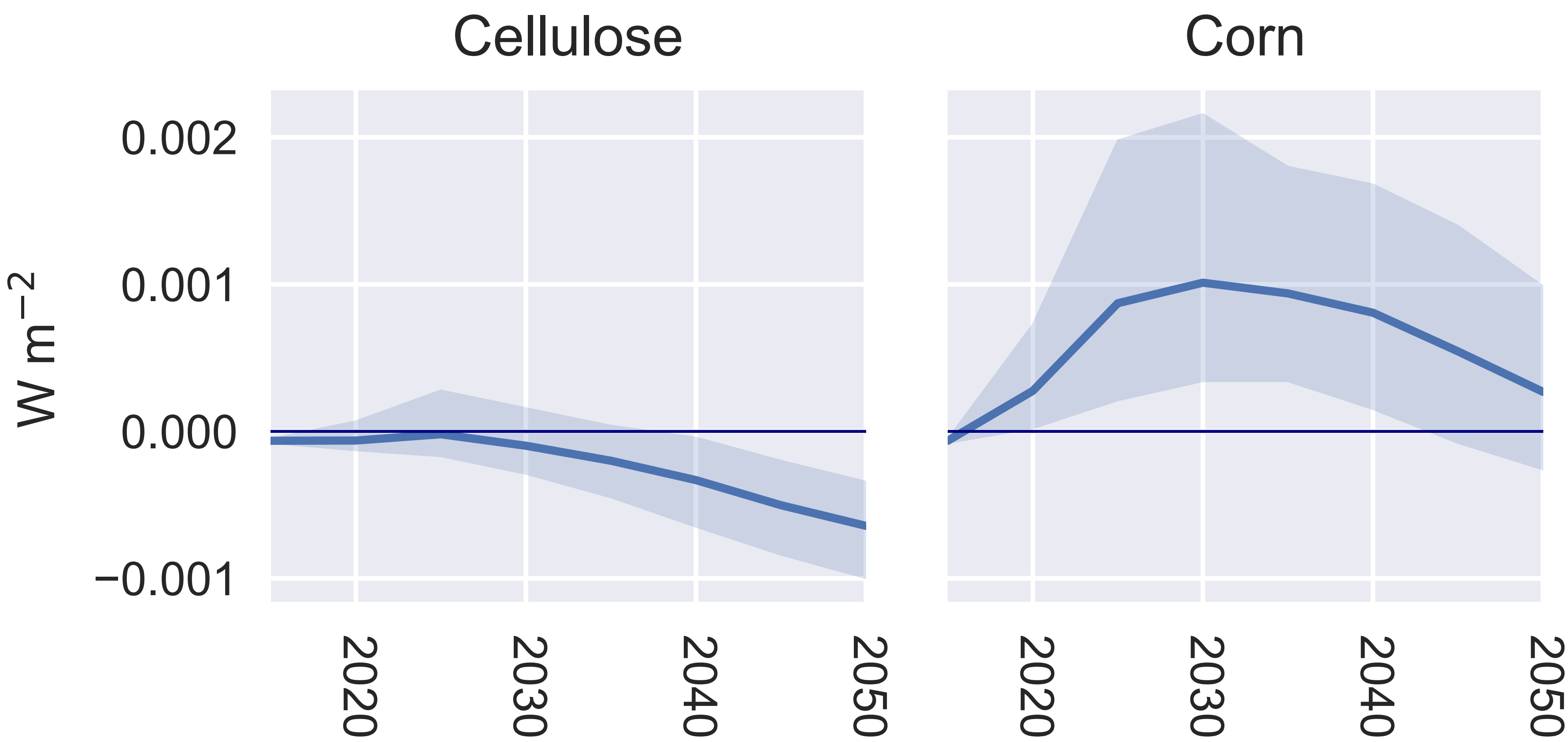
Model outputs tracked

- Carbon intensity (ΔGHG / cumulative fuel shock)
- Rebound effect on global fuel use
- Change in radiative forcing over time

Change in radiative forcing over time



(Median and 95% interval shown)

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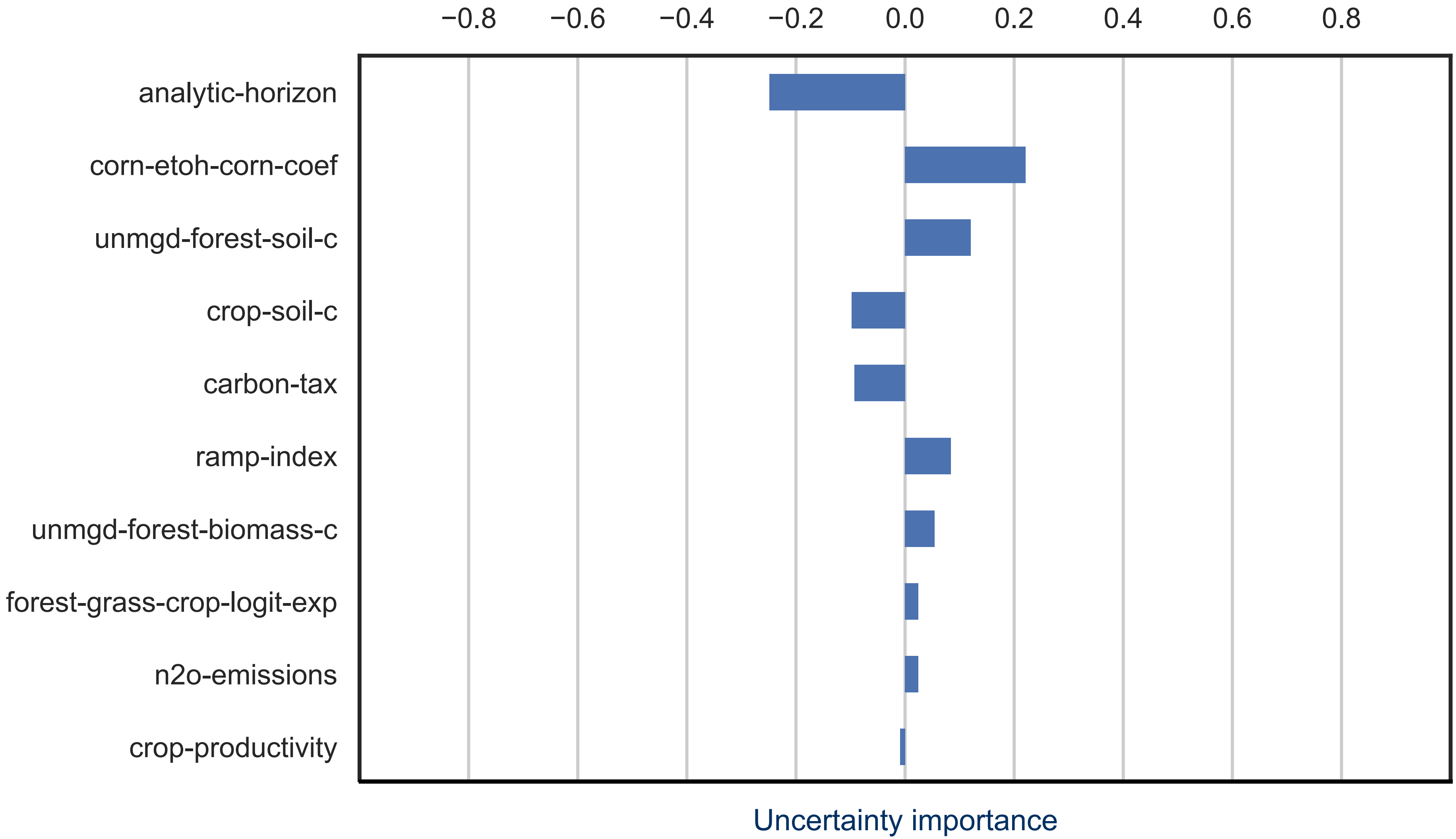
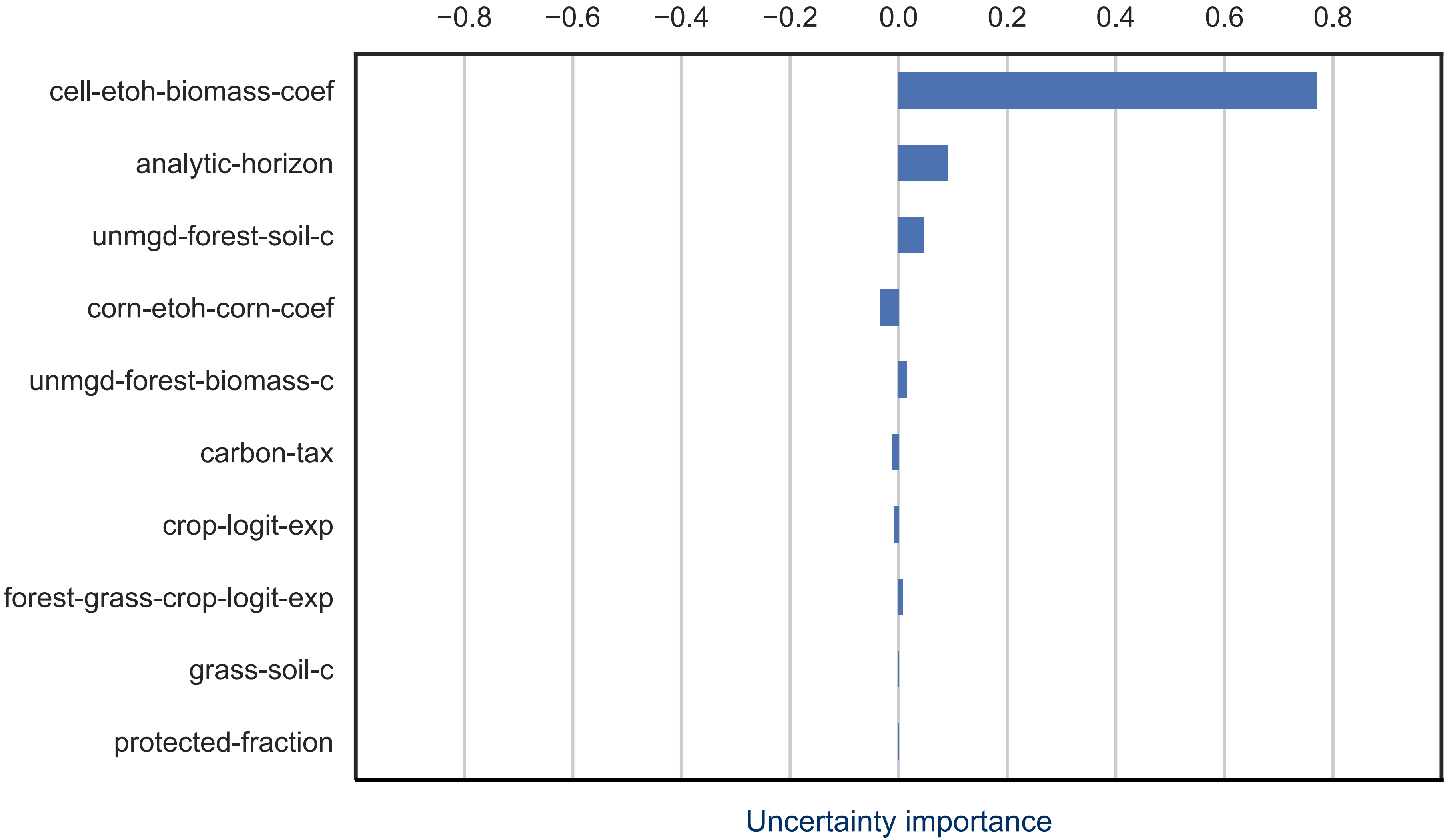
Corn ethanol - All GHGs



Cellulosic ethanol - All GHGs



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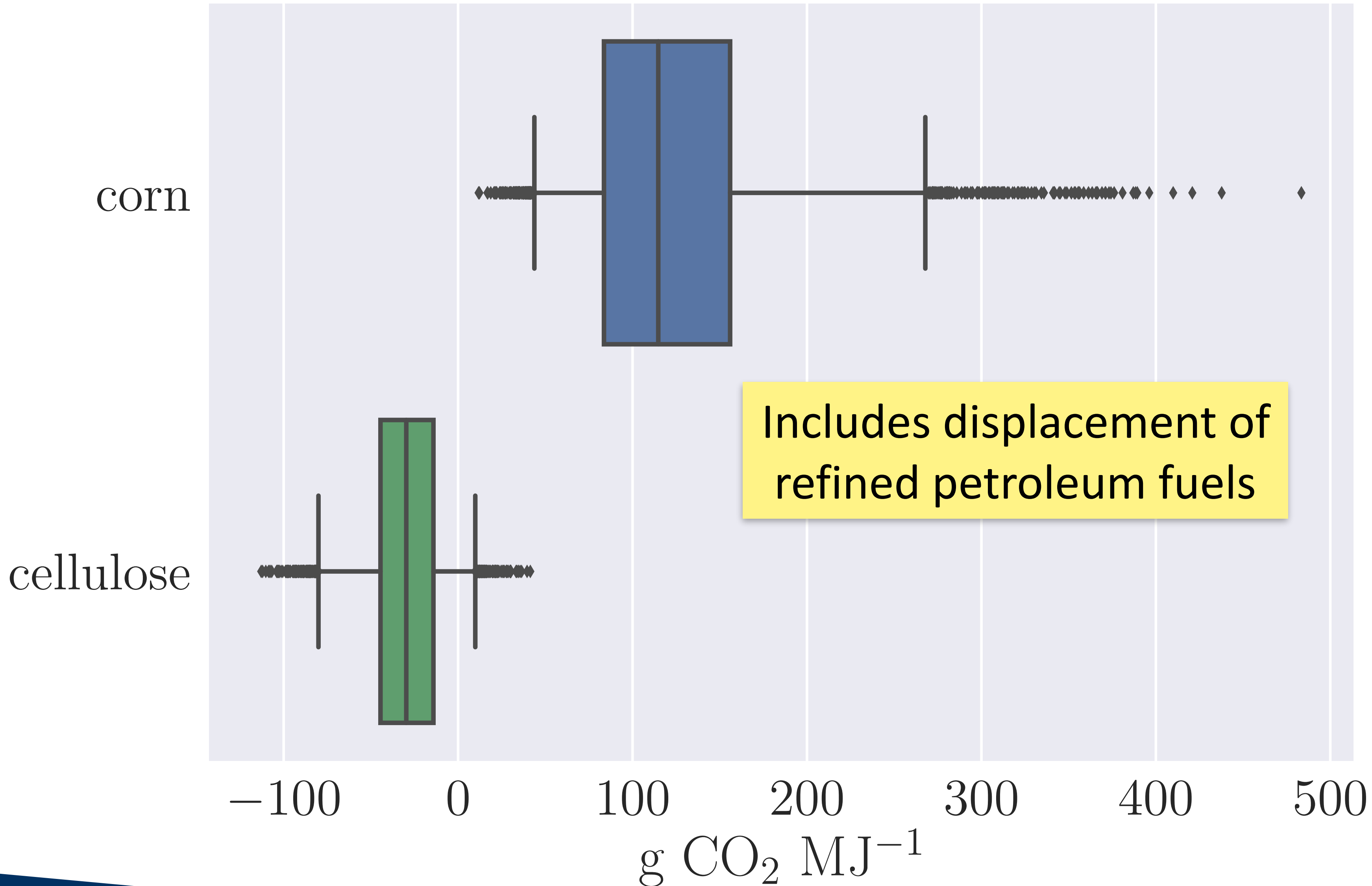
Carbon intensity: ΔCO_2e in *all* sectors



Includes displacement of refined petroleum fuels

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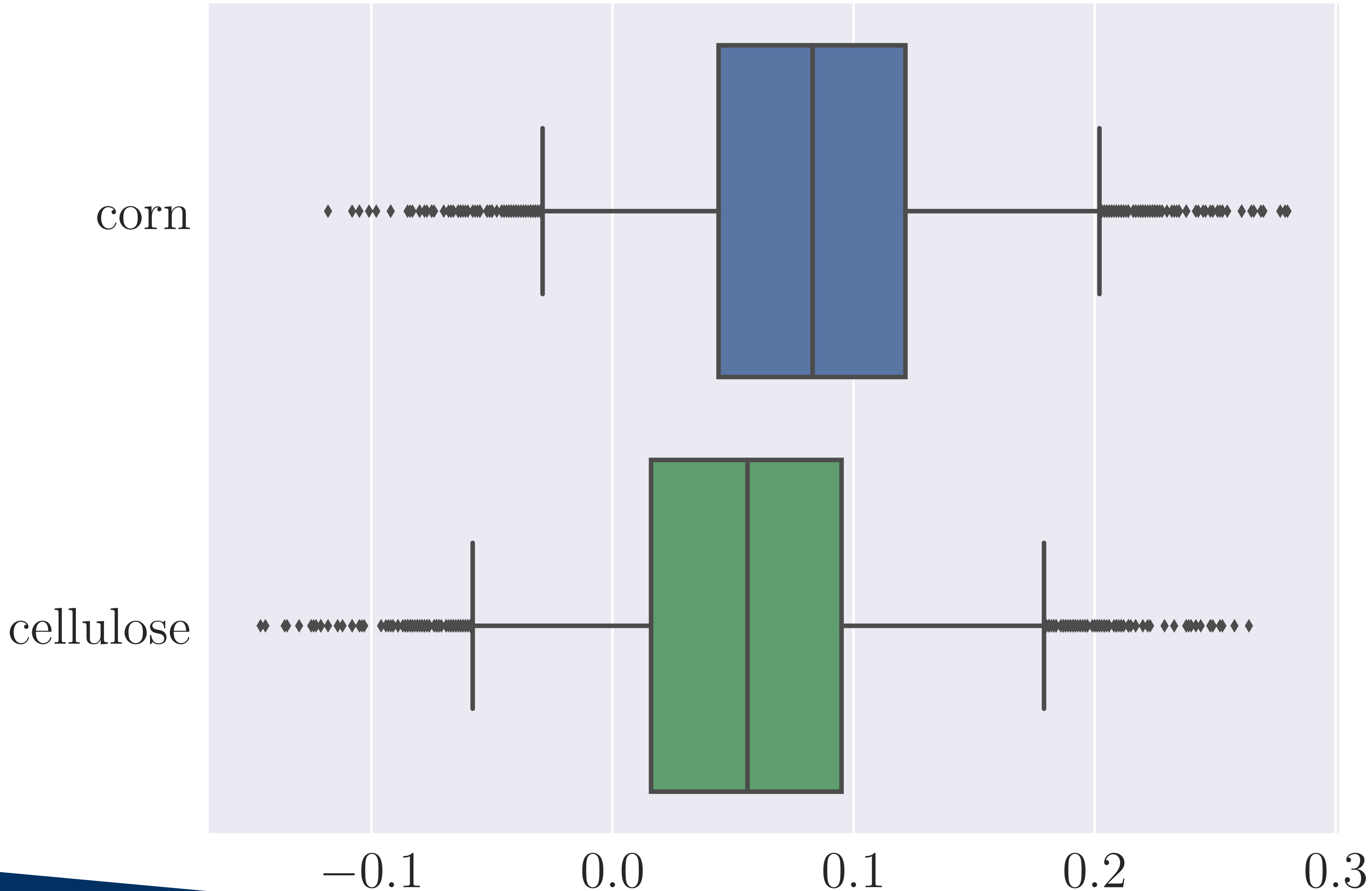
Global fuel rebound effect



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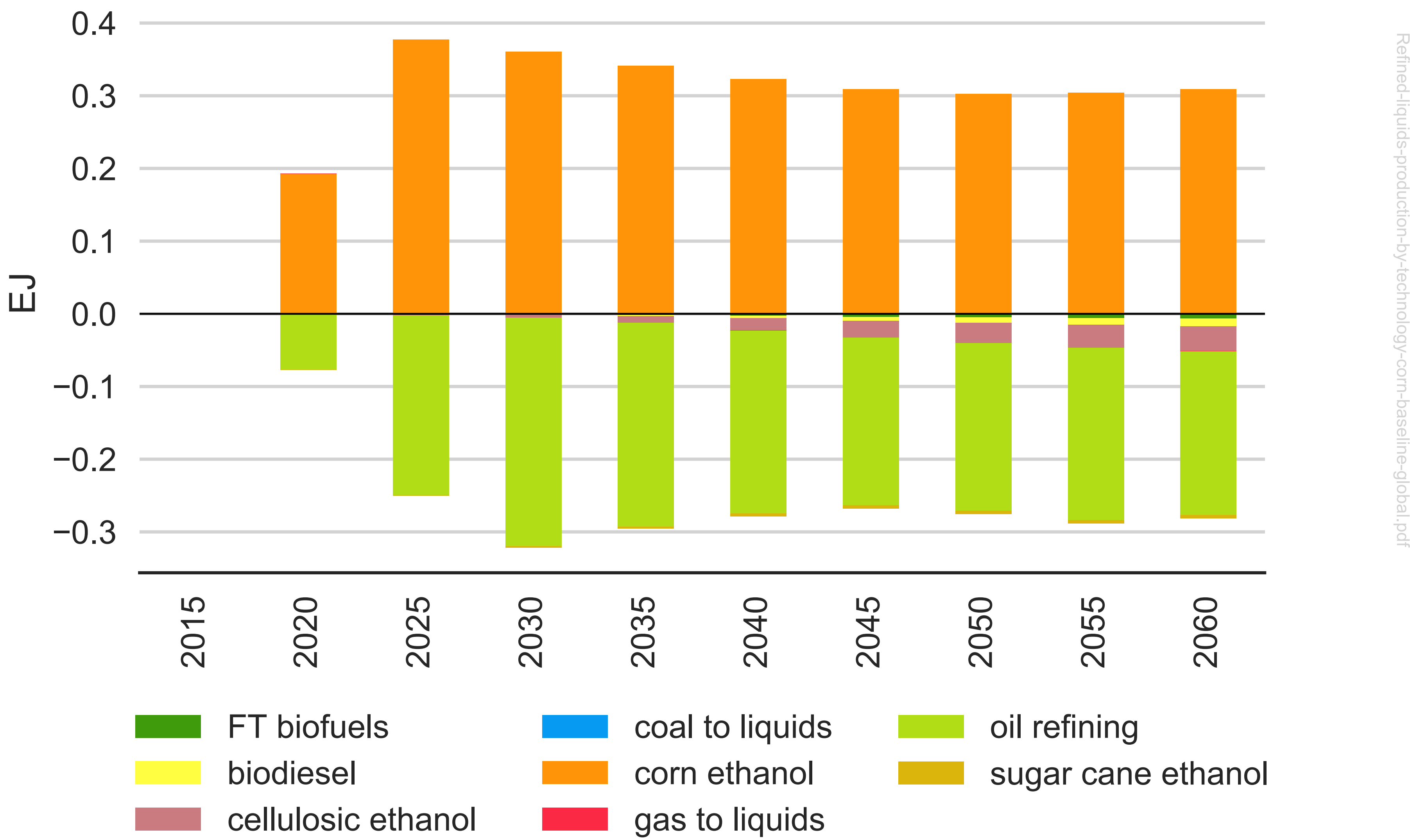
Rebound effect: less than MJ:MJ replacement



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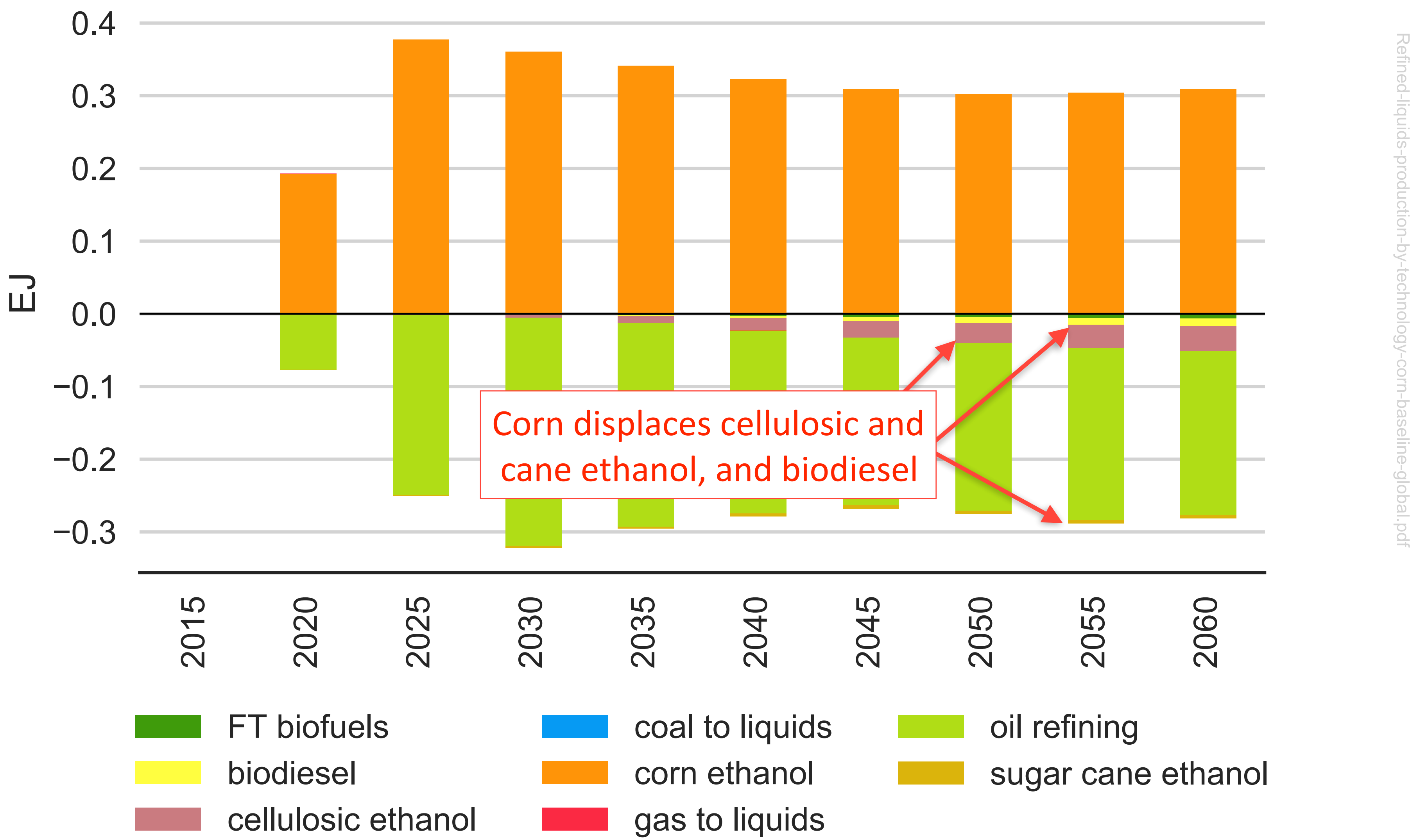
Rebound effect: less than MJ:MJ replacement



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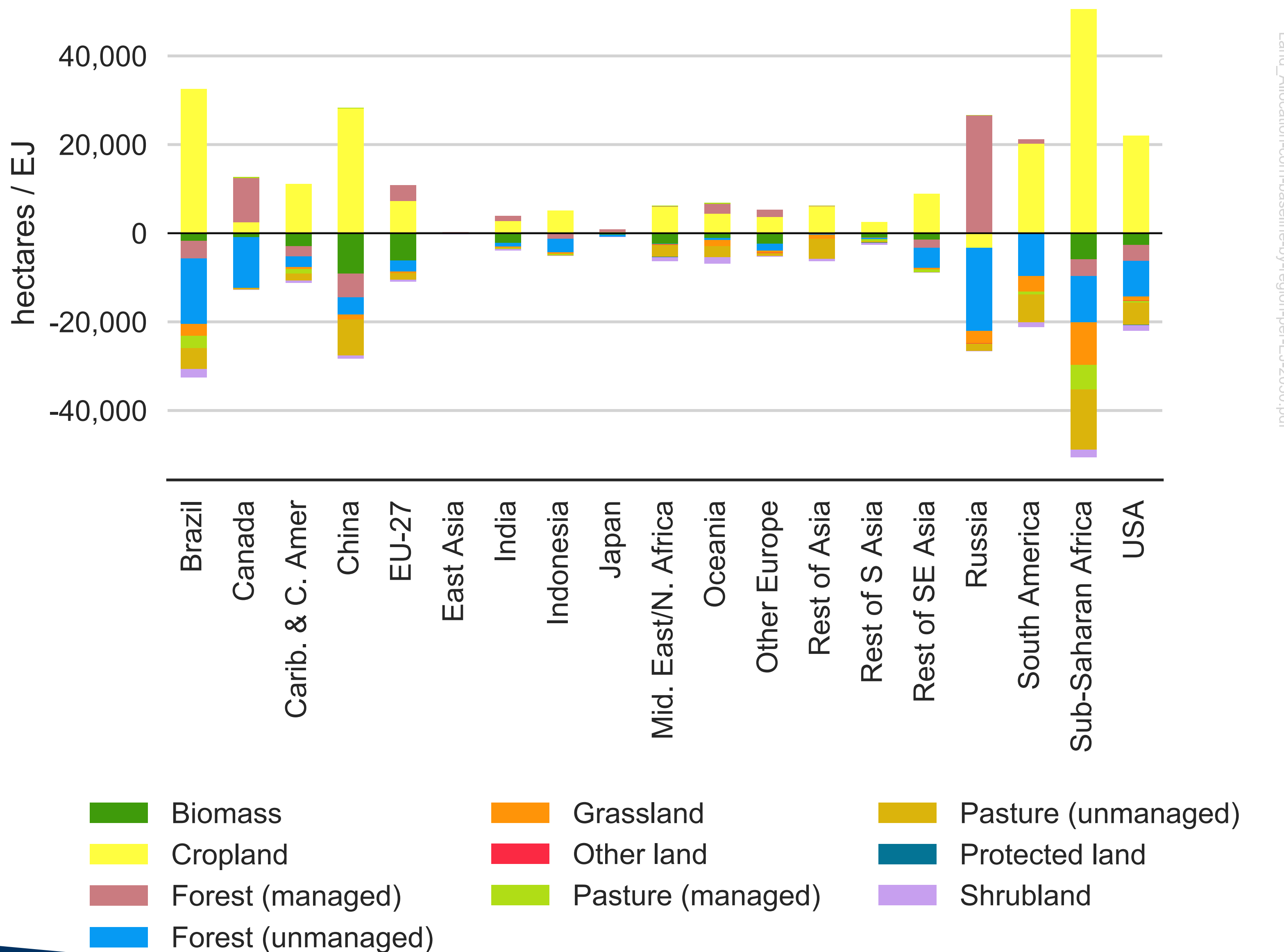
Area change per EJ (2010-2050)



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Conclusions

- A wide range of CI values can be produced
- Many assumptions and subjective choices affect CI
- Rebound effects are mostly positive, reducing the total petroleum substitution and displacing some biofuels
- RF over time highlights the effect of time assumptions
- According to GCAM, corn ethanol likely exacerbates climate change, while cellulosic ethanol likely mitigates it. But neither result is definitive.

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Backup slides

Related papers

- Plevin, R. J. et al. (in prep.). “Assessing the Climate Effects of Biofuels using Integrated Assessment Models – Part 2: Case study using GCAM."
- Plevin, R. J. et al. (2017). "Fuel carbon intensity standards may not mitigate climate change." Energy Policy.
- Plevin, R. J. (2016). "Assessing the Climate Effects of Biofuels Using Integrated Assessment Models, Part I: Methodological Considerations." J. Industrial Ecology.
- Plevin, R. J. et al. (2015). "Carbon accounting and economic model uncertainty of emissions from biofuels-induced land use change." ES&T.
- Plevin, R. J. et al. (2014). "Using Attributional Life Cycle Assessment to Estimate Climate-Change Mitigation Benefits Misleads Policy Makers." Journal of Industrial Ecology 18(1): 73-83.

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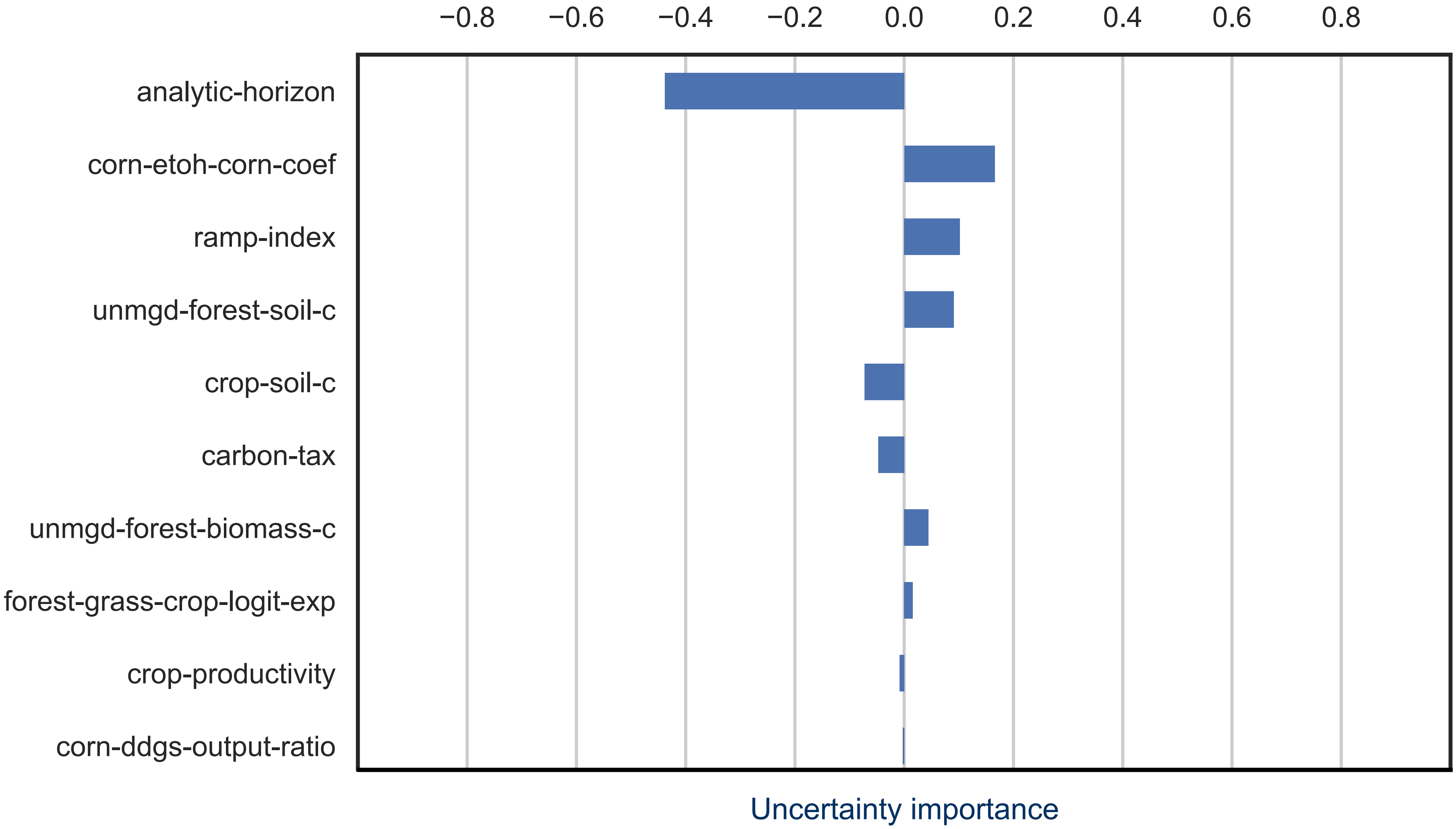
Corn ethanol - LUC only



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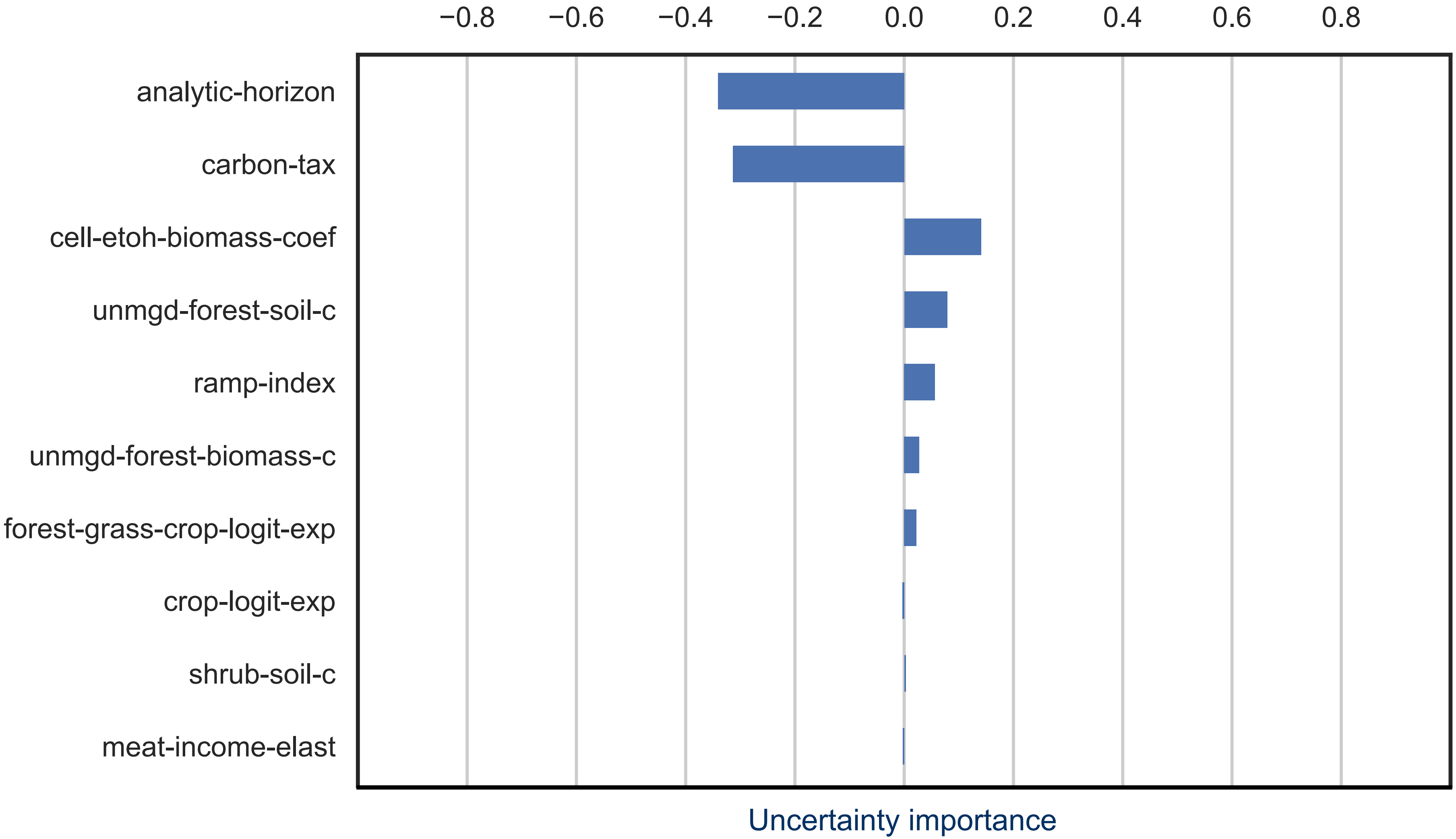
Cellulosic ethanol - LUC only



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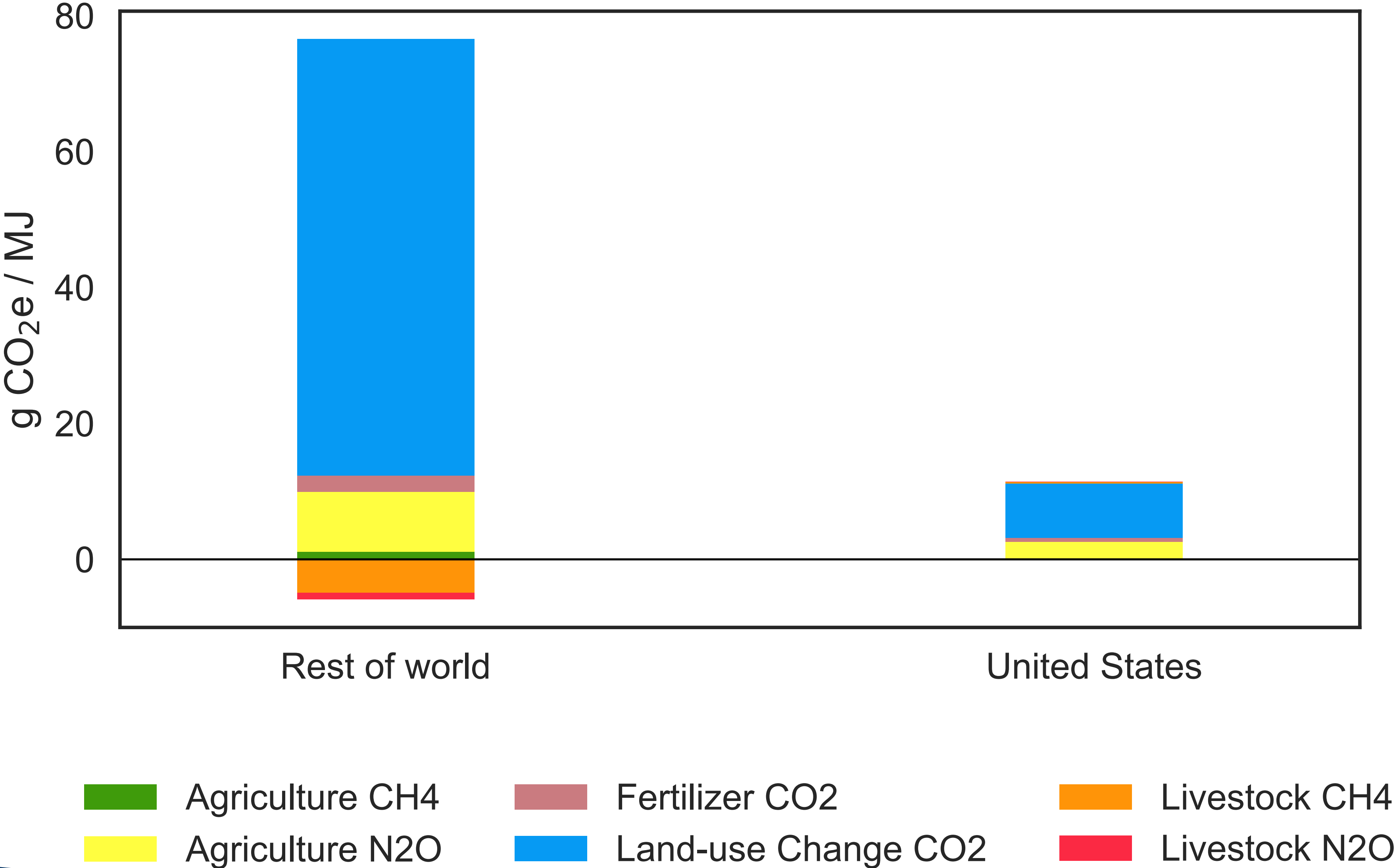

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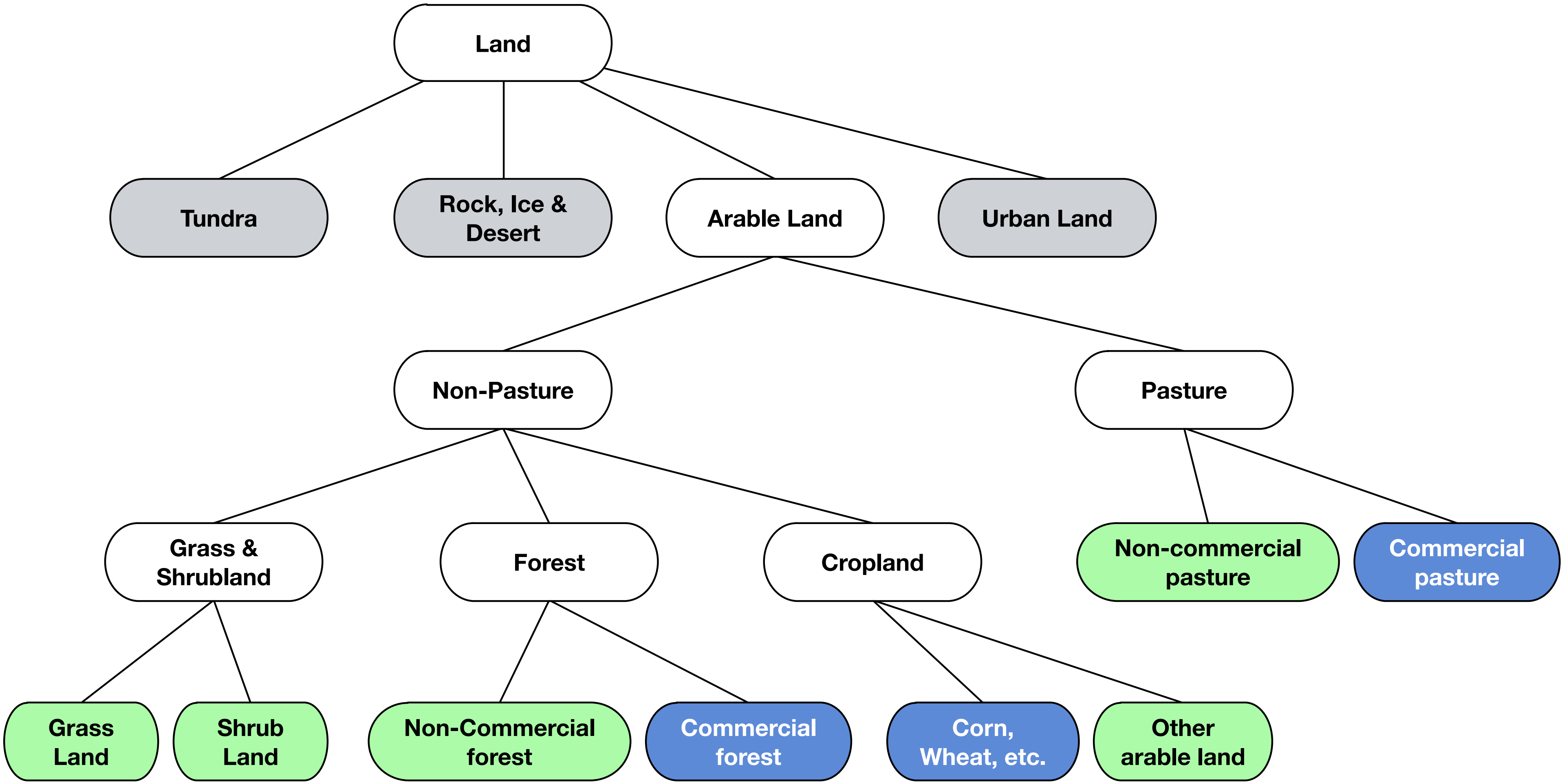
GCAM land nest



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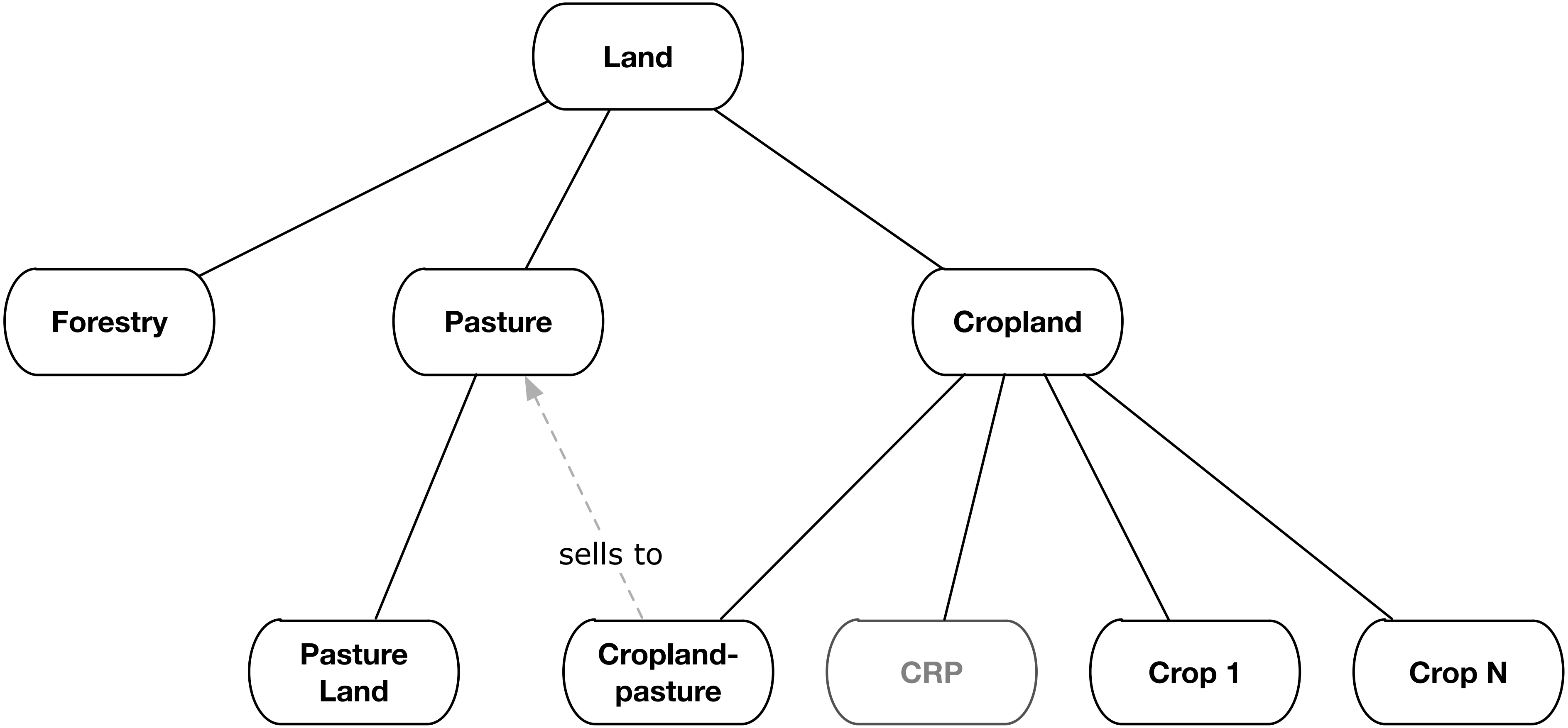
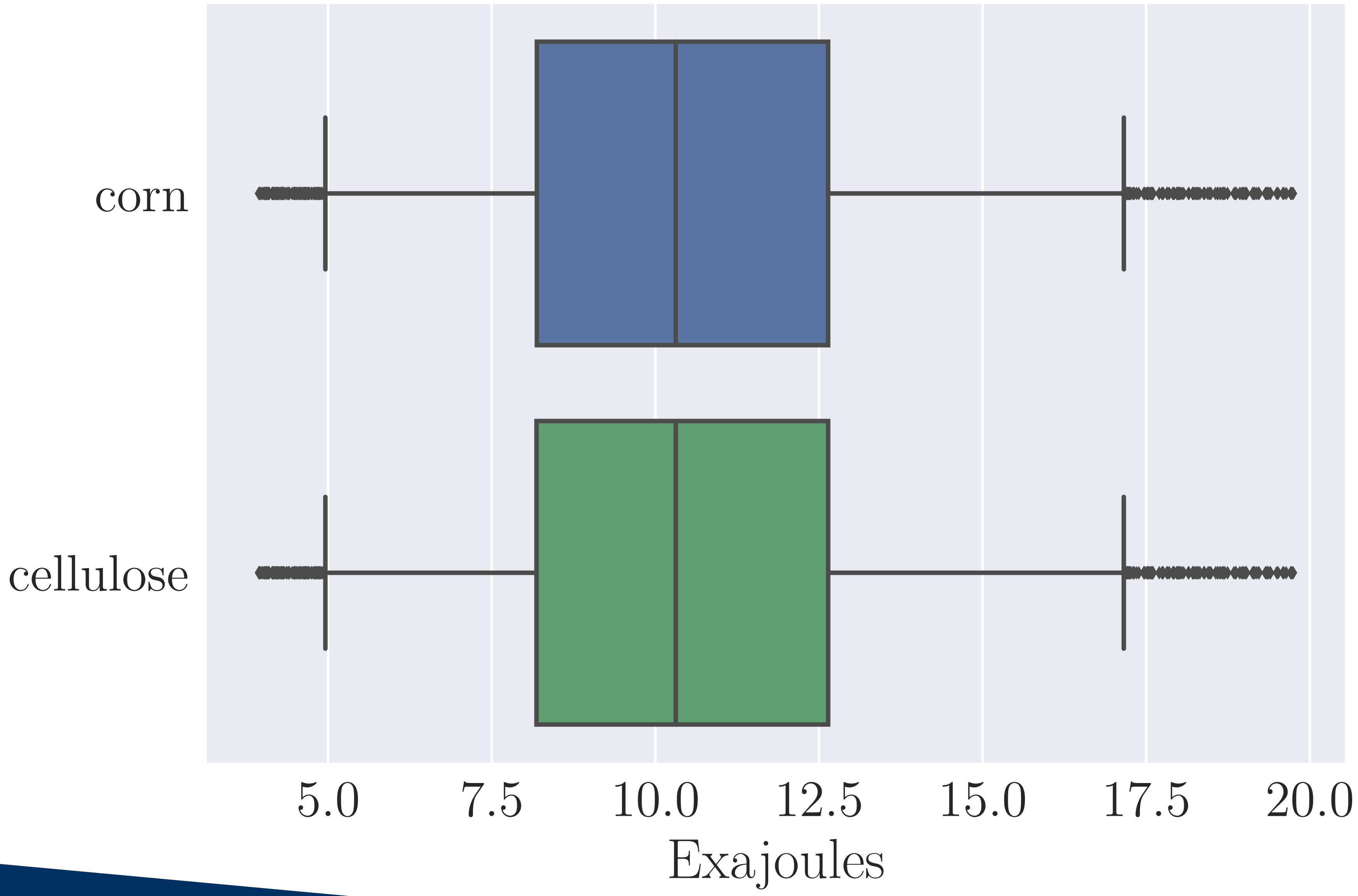
GTAP land nest



Based on Taheripour et al. (2011)

Cumulative biofuel shock



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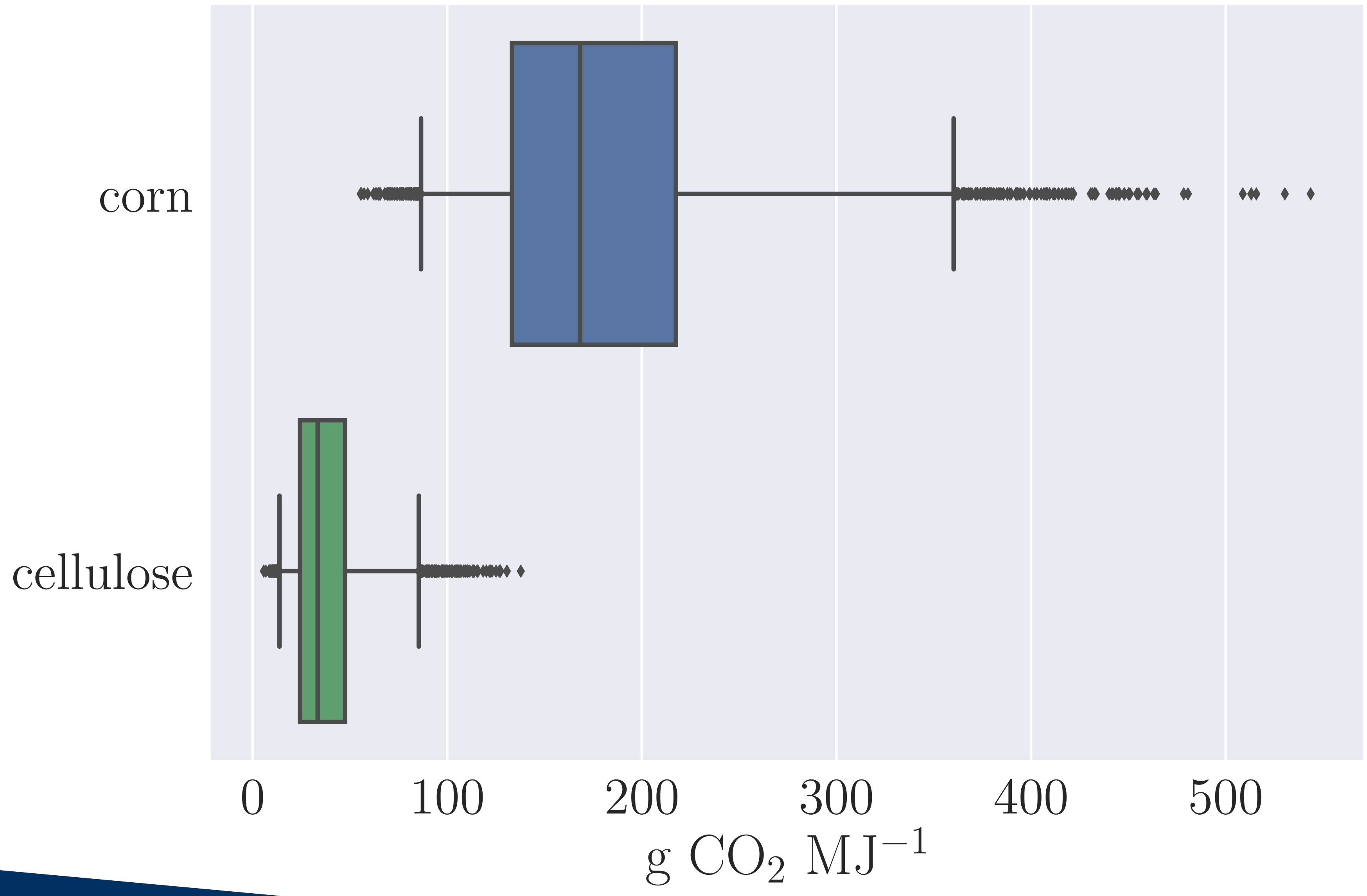
Carbon intensity: LUC emissions only



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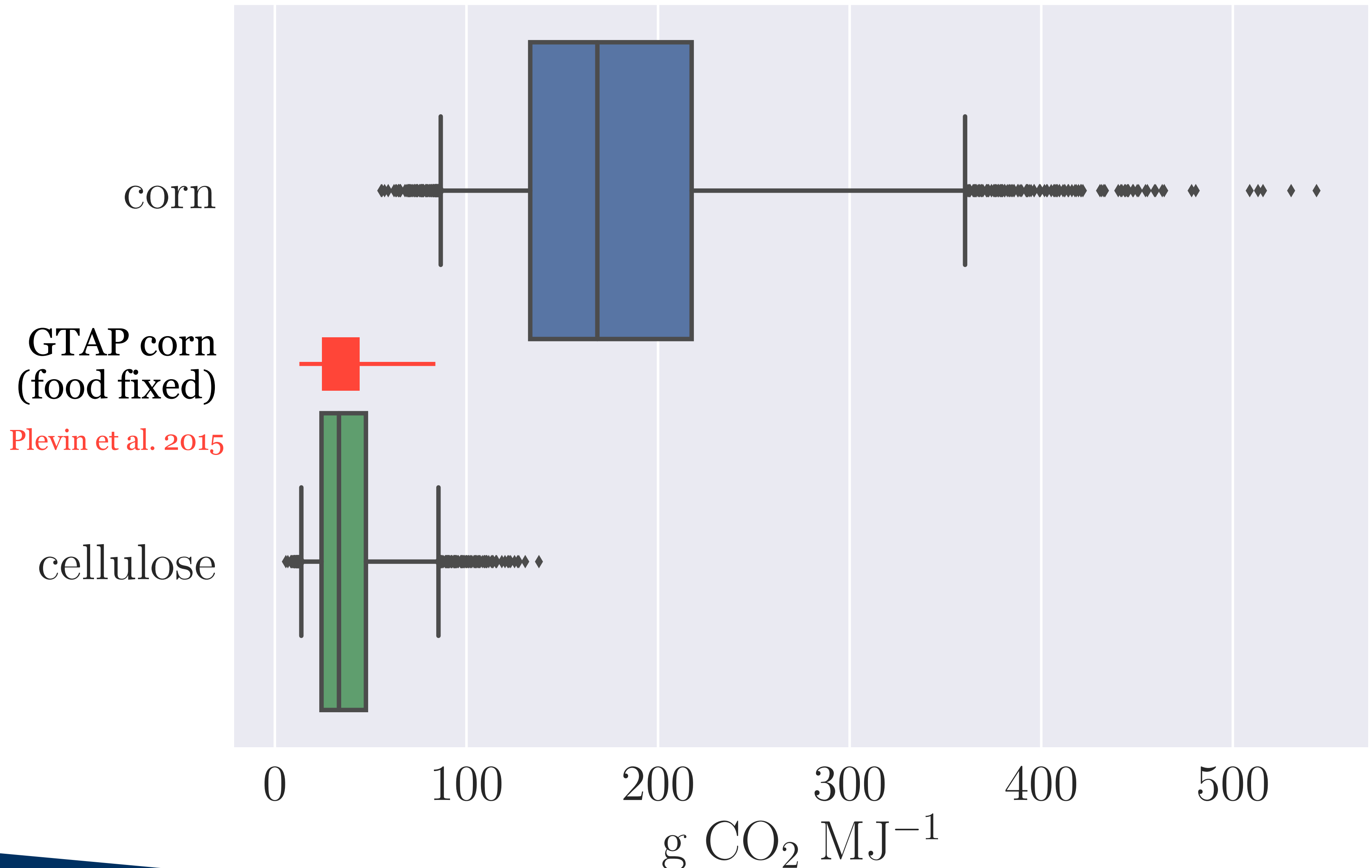

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