

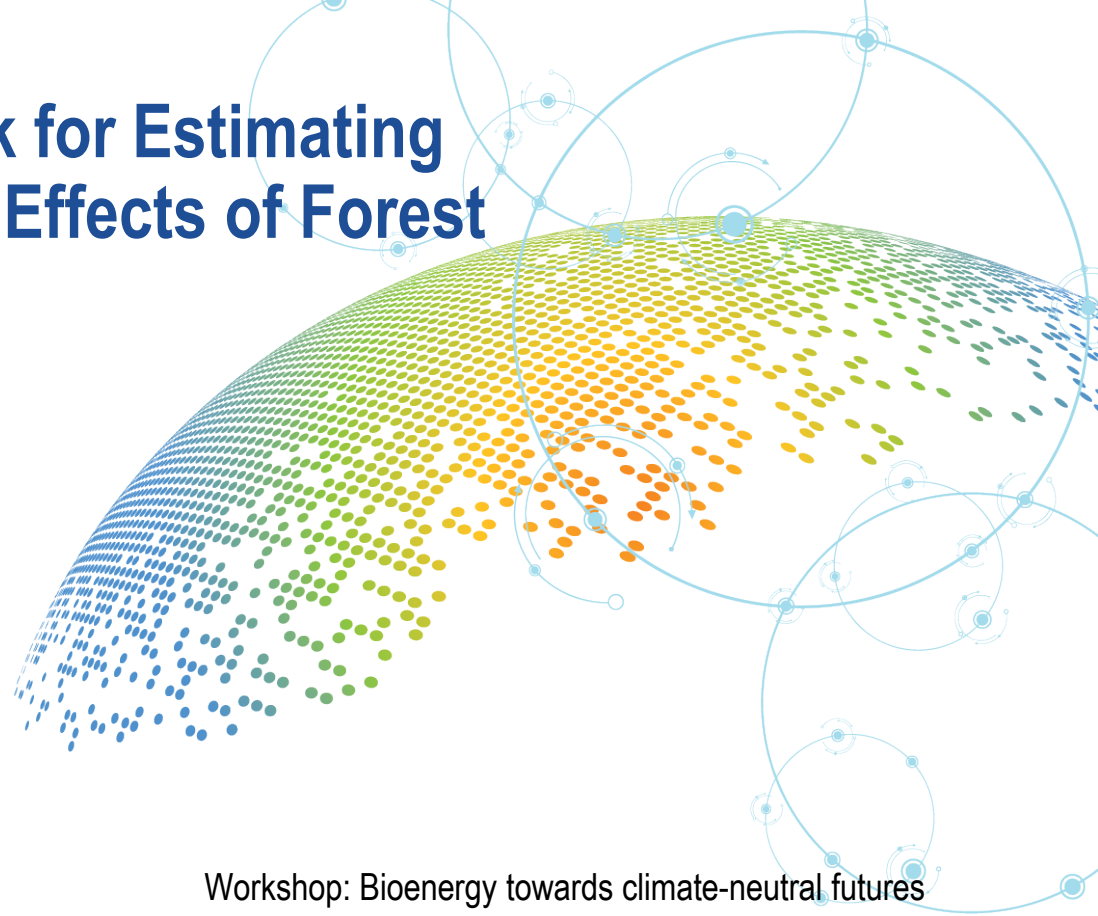
A Multi-Model Framework for Estimating the Net Greenhouse Gas Effects of Forest Biomass Utilization

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Workshop: Bioenergy towards climate-neutral futures

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Motivation and Objectives

- Assess indirect landscape emissions from forest biomass production
- Integrate forest, industrial, and biofuel modeling
 - Goal: estimate net GHG effects of forest biomass utilization across end uses

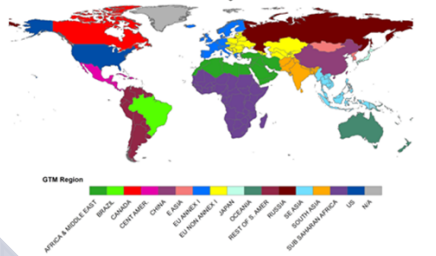
Approach

- Global Timber Model (GTM) to estimate forest carbon responses
- Integration with: Industrial transformation models, Biofuel production models, Life-cycle assessment (LCA) of SAF
- *Why GTM?*
 - System-wide representation of forests and markets
 - Intertemporal and spatial linkages
 - Explicit treatment of market dynamics

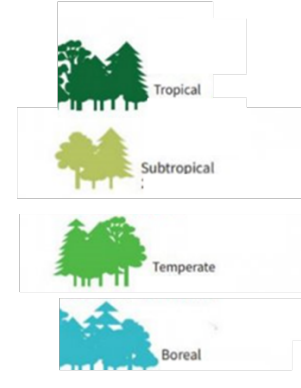
GTM

GTM is a forward-looking model: it **maximizes** the NPV of CS and PS in the forestry sector by selecting the age of harvesting timber and land conversion and management decisions:

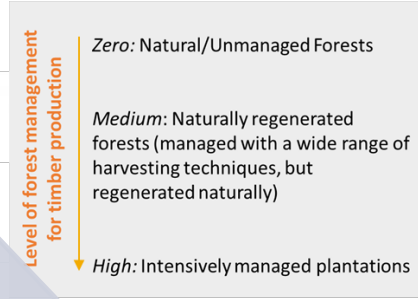
GTM regions



Forest types



Management Types



Inputs

- FAO data (timber production, forest area, carbon stock)
- FIA data (USA)
- GDP/population projections (drivers timber demand)
- Demand for specific products (woody biomass/CLT)
- Policies (e.g. carbon price, land conservation)
- Preferences (sawtimber vs pulpwood)
- International market assumptions (e.g. trade restrictions)
- Natural forest productivity/land available to be converted to forests

GTM Output

- Regional Timber Production (industrial/energy)
- Regional forest area (by forest type)
- Regional carbon stock (by forest pools)
- Regional producer surplus

Exogenous woody biomass demands included GTM

$$\max \sum_0^{\infty} \rho^t \left\{ \int_0^{Q_t^{tot}} \{D(Q_t^{ind}, Z_t) + Q_t^{bio} - c(Q_t^{tot})\} dQ_t^{tot} - \sum_i C_G^i(m_t^i, G_t^i) - \sum_i C_N^i(m_t^i, N_t^i) - \sum_i R_t^i \left(\sum_a X_{a,t}^i \right) \right\} [1]$$

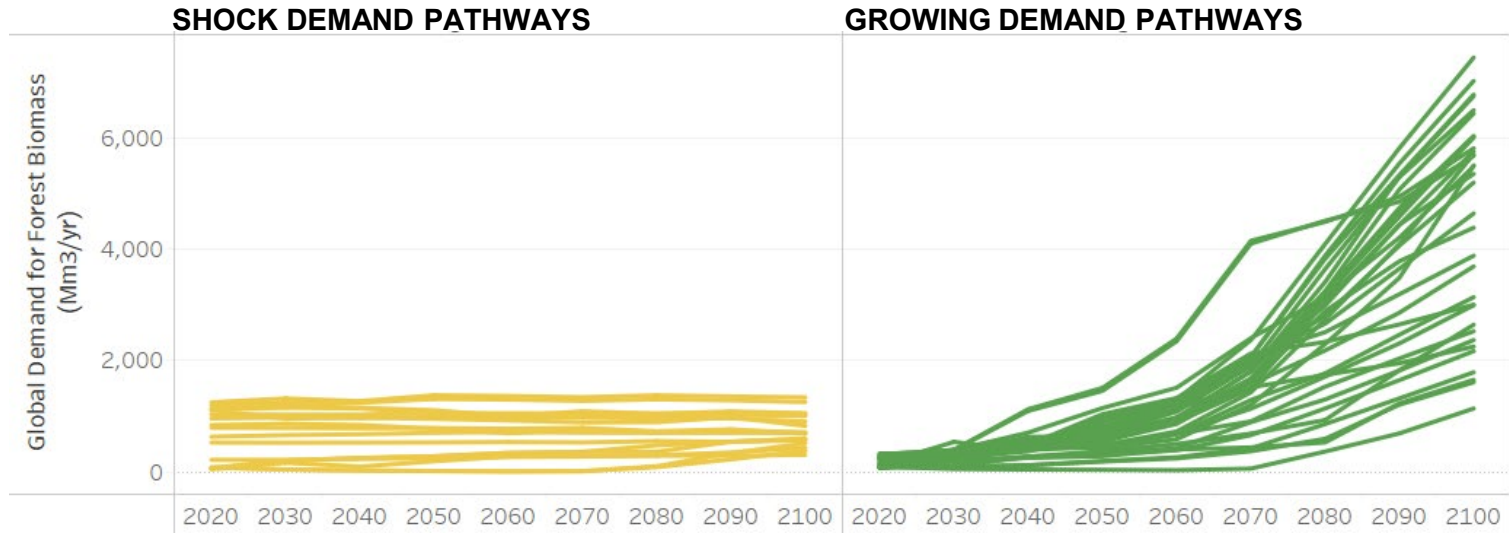


Figure: Exogenous woody biomass demand pathways introduced in GTM

Woody biomass landscape emissions factor

$$Annual_Flux_{scenario,t} = Stock_{scenario,t+1} - Stock_{scenario,t}$$

$$Annual_Flux_{scenario,t} > 0, \text{ net seq}$$

$$Delta_Flux_{scenario,t} = Annual_Flux_{scenario,t} - Annual_Flux_{baseline,t}$$

$$Emissions_factor_{t,scenario} = \frac{DeltaFlux_{scenario,t}}{WoodybiomassProduction_{scenario,t}}$$

$$Emissions_{t,factor}$$

> 0 , net landscape sequestration relative to baseline

< 0 , net landscape emission relative to baseline

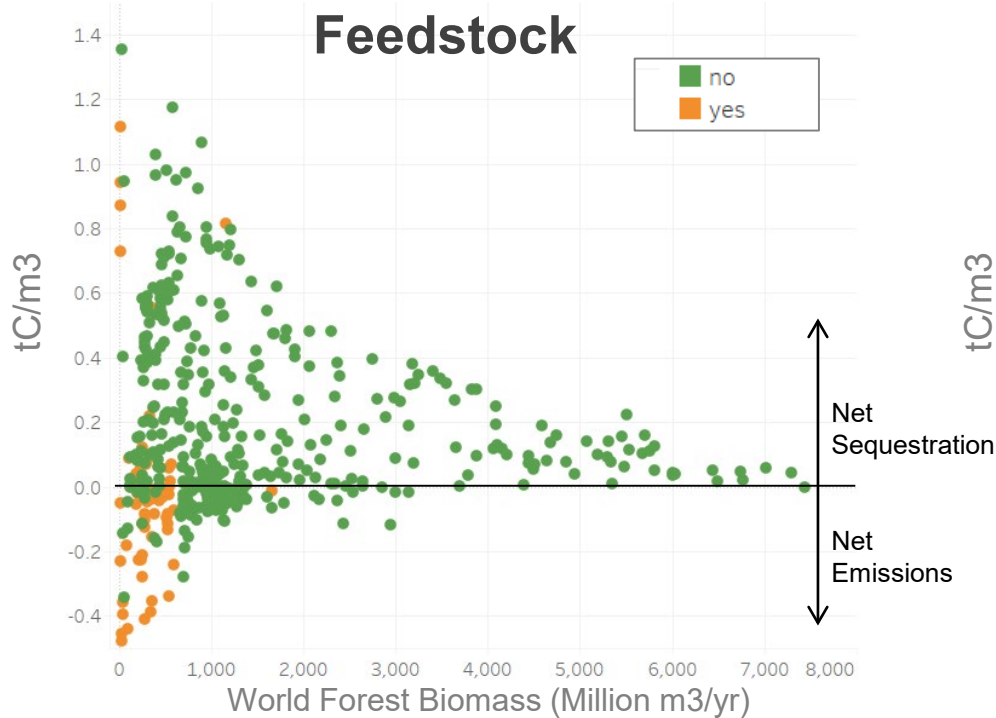
Woody biomass demand affects carbon through:

1. Residue removal
2. Land conversion
3. Timber product substitution
4. Forest management investment

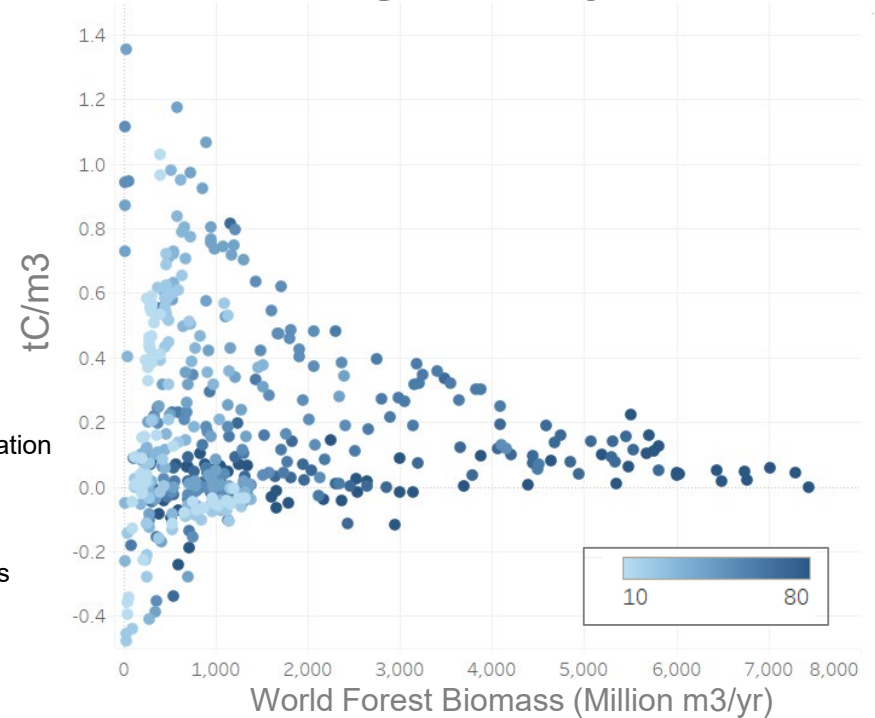
Stock includes carbon in forest biomass, soil, timber products and slash

Results depend on feedstock and time

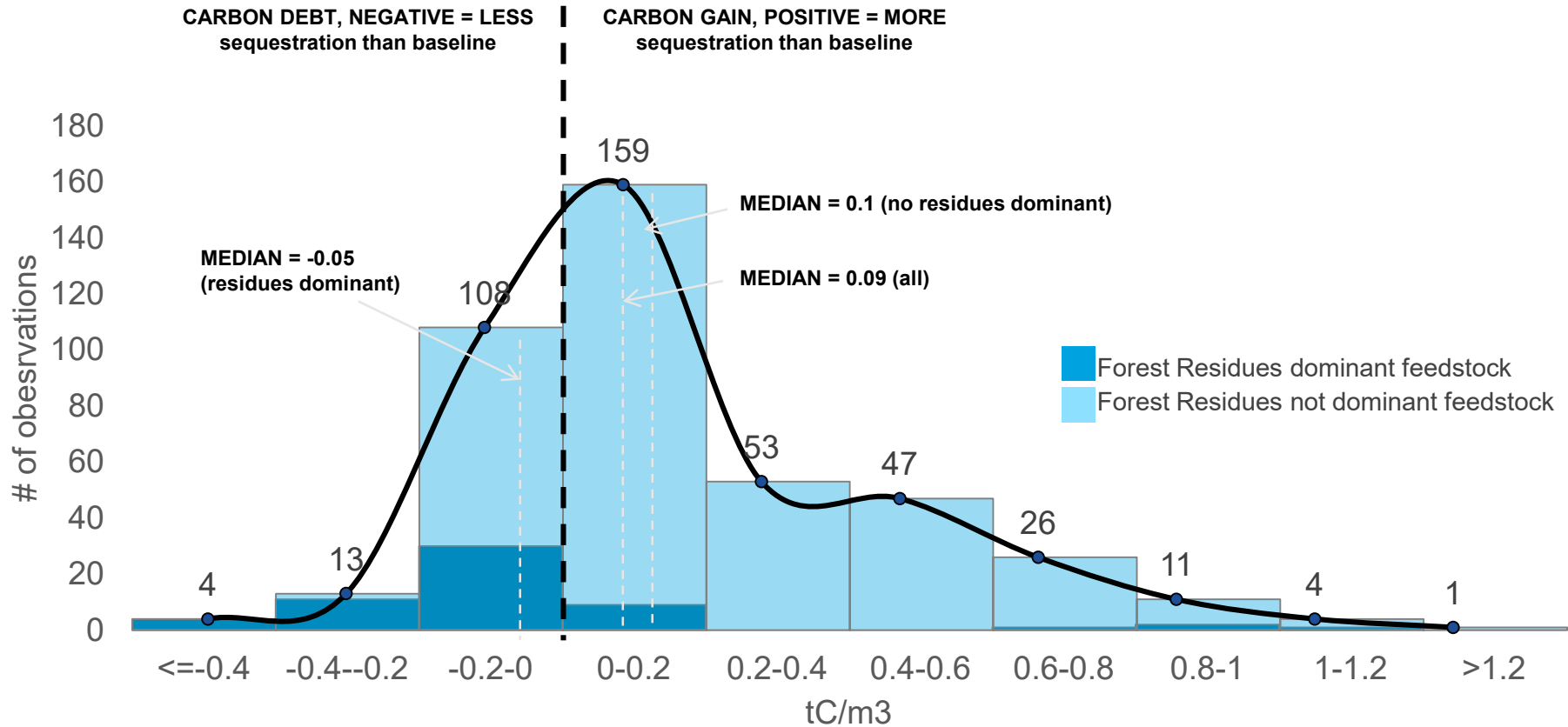
Forest Residues Dominant Feedstock



Timing: 10-80 years

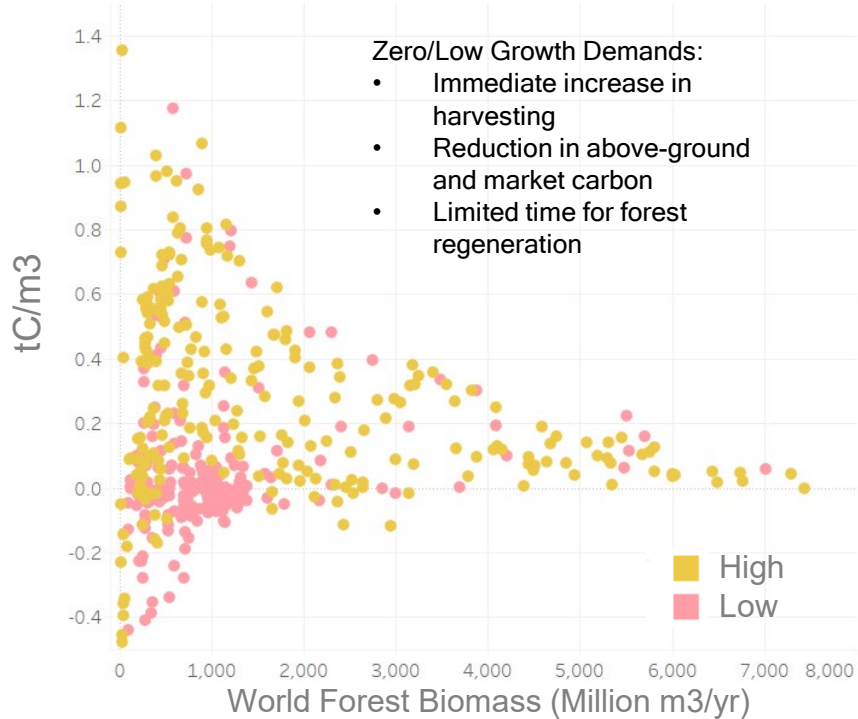


Forest Residues Dominant Feedstock (meet more than 75% of average production)

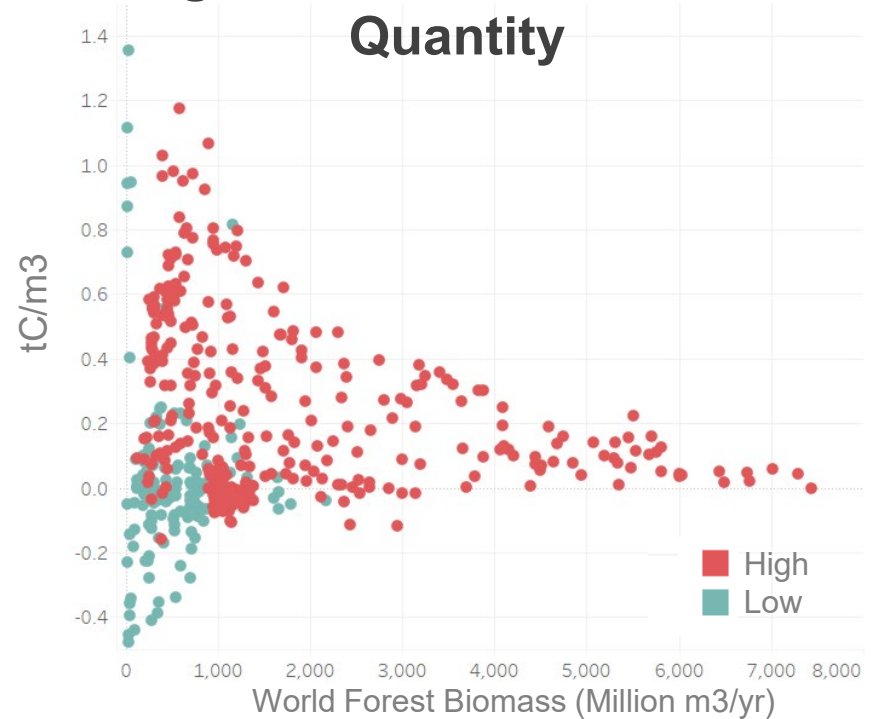


Results depend on expected quantity and demand growth

Forest Biomass Demand Growth



Average Forest Biomass Demand Quantity





Beyond the Forest: Integrated Framework

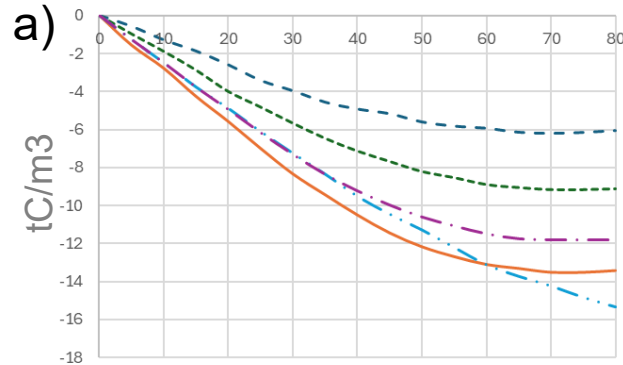
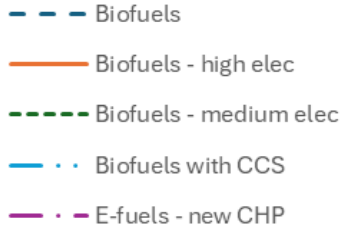
Integrating GTM with:

- Industrial transformation models
- Biofuel production models

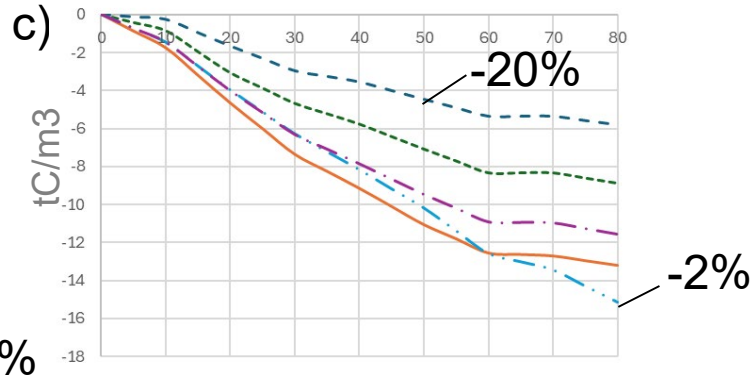
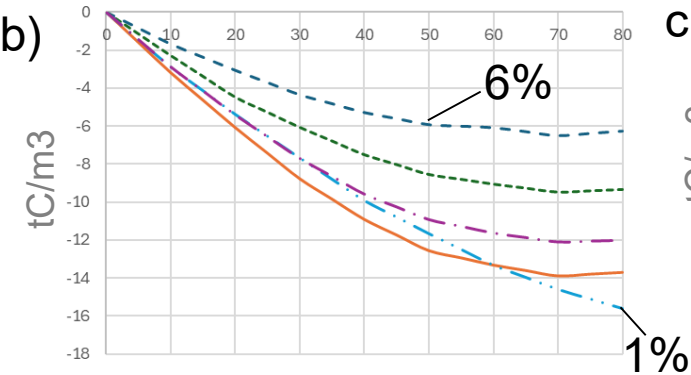
Objective:

- Assess net GHG effects beyond landscape-level impacts
- Build a consistent data framework for bioenergy applications

Application 1: Results depend on indirect emissions factors for land use change and changes in land use management



a) No indirect landscape emissions
b) and c) include upper and lower GTM estimates



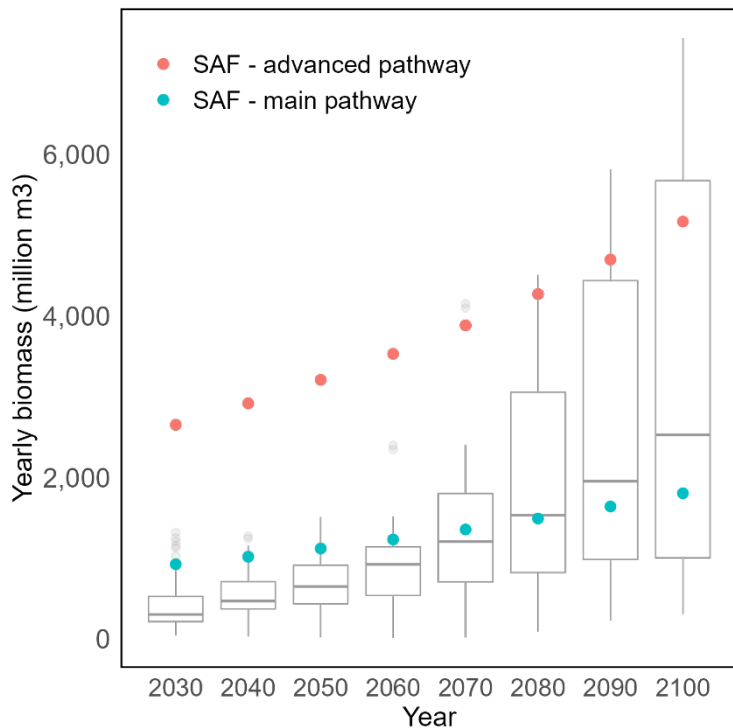
Application 1: Substitution effect - Results depend on emissions factors for fossil fuels, electricity, and district heating

- a) Emission factors = constant
- b) 50% linear decrease from 2050 to 2100
- c) 100% linear decrease from 2025 to 2100

Application 1: Results depend on country-specific C intensity of electricity used in biofuel production

- a) Nordic countries
- b) Denmark
- c) Germany

Application 2: Sustainable Aviation Fuel

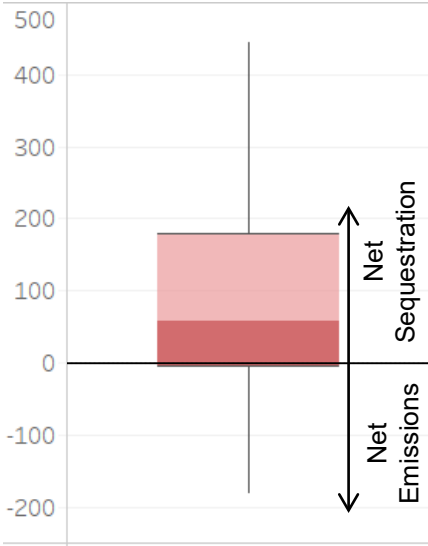


For each year, the boxplot shows the distribution of global annual biomass produced across all GTM runs, where the box represents the interquartile range (25th-75th percentiles), the line indicates the median

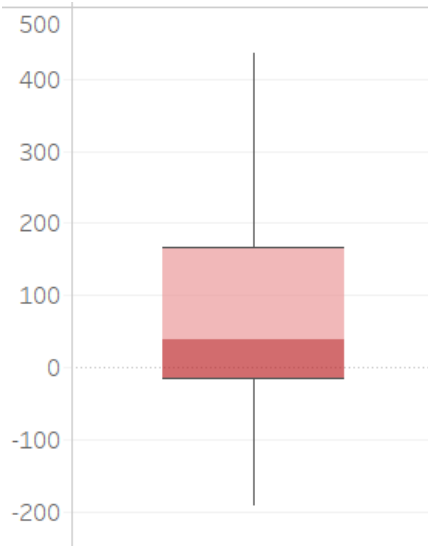
Net GHG emissions from SAF using GTM+LCA

Next 50 years

Indirect land use emissions
(gC/MJ SAF)

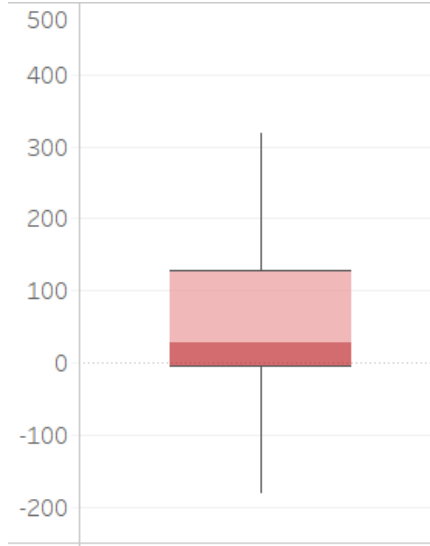


Indirect land use emissions
+ LCA emissions production
(gC/MJ SAF)

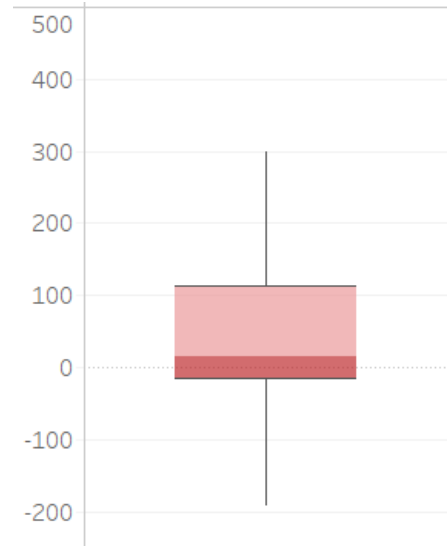


Next 80 years

Indirect land use emissions
(gC/MJ SAF)



Indirect land use emissions
+ LCA emissions production
(gC/MJ SAF)



Production carbon emissions: life-cycle emissions to produce 1 MJ of bio-based SAF from forest residues ATJ (Alcohol-to-Jet) production pathway is equal to 10 gC/MJ (Conventional jet fuel ~89 gC/MJ)

Key Takeaways

- Biomass impacts are not binary
- Energy substitution is a major uncertainty
- Forest responses drive long-term outcomes
- Market behavior and forward-looking decisions matter

What's Missing ?

- Wildfire risk & natural disturbances
- Forest conservation policies
- New timber products (e.g. CLT)
- Co-location of bio-electricity generation and data centers
- Consideration of energy security: implications for bioenergy/bioeconomy
- Regional diversity in biomass supply



Thank you

Contact: Name | email: afavero@rti.org

Where is woody biomass coming from?

- For low demand scenarios, forest residues supply more than 50%
- The share of biomass from new forests increases in the long term

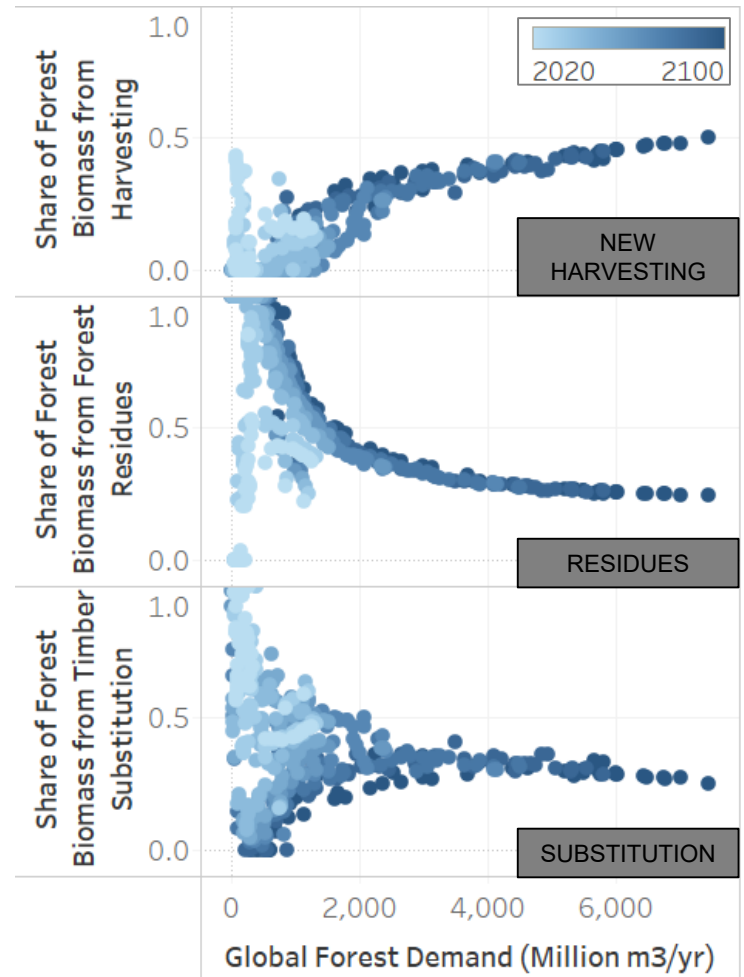
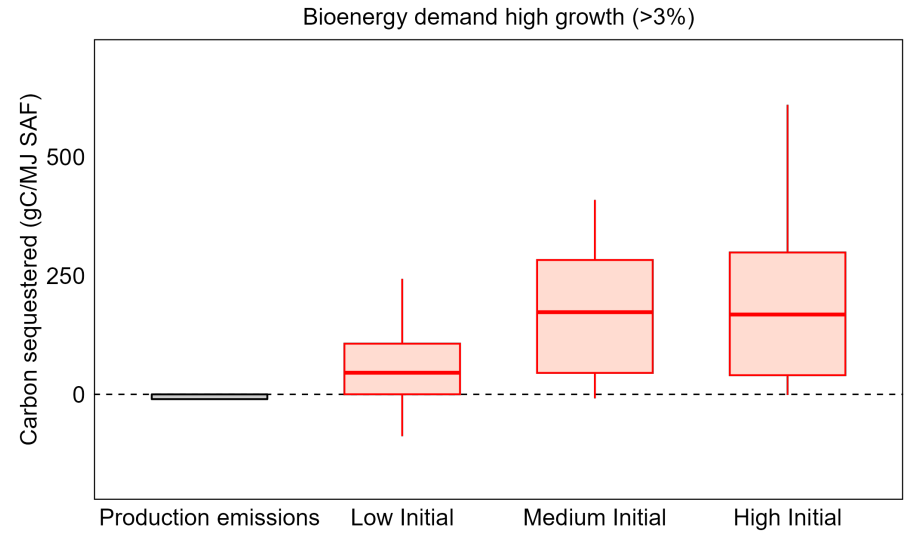
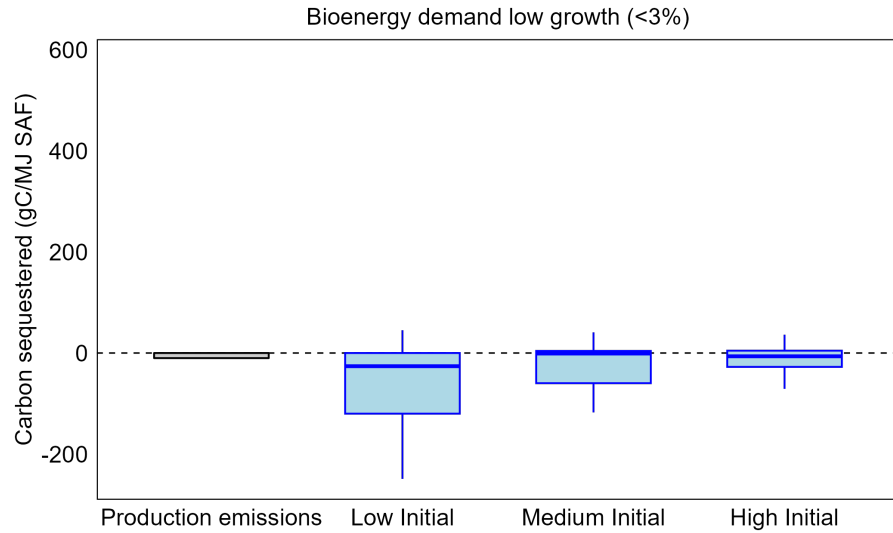


Figure: Share of supply of woody biomass vs global woody biomass demand 2020-2100. Each dot represents one annual result per run



Production carbon emissions: life-cycle emissions to produce 1 MJ of bio-based SAF from forest residues ATJ (Alcohol-to-Jet) production pathway (shown as the grey baseline bar).

The boxplots depict the distribution of annual carbon sequestration (or additional emissions) attributable to biomass feedstock use per 1 MJ of SAF. Values are pooled across all model runs (except run =0) and all simulation years from 2020 to 2100.

Bioenergy demand low growth: runs where the implied average annual growth in global bioenergy demand is $\leq 3\%$ per year (computed from 2020 to 2100).

Low / Medium / High initial: runs grouped by the initial (2020) biomass level: Low <150 million m³, Medium 150–250 million m³, High >250 million m³.

Application 3: Soft-link

SOFT-LINK



OUTPUT

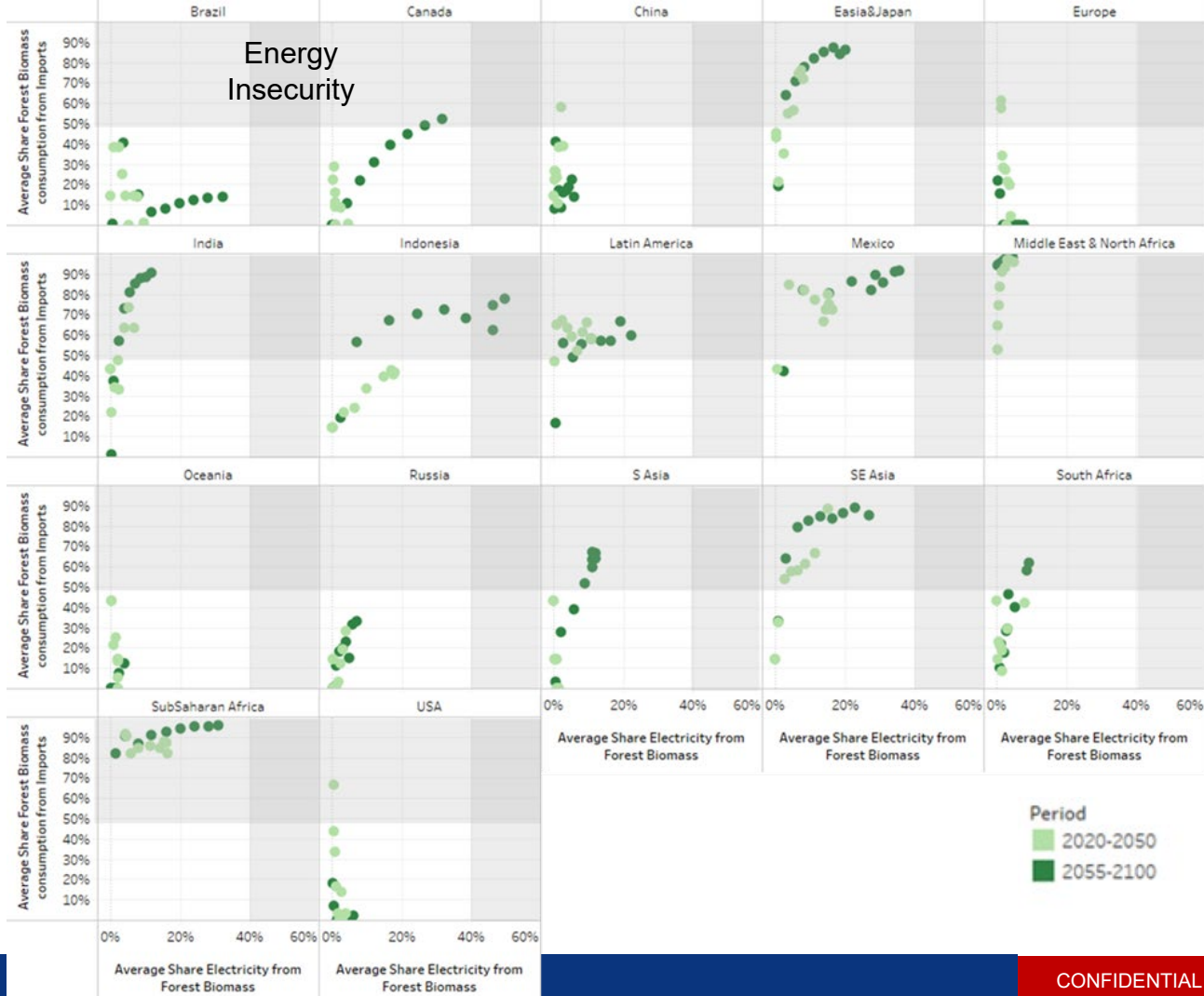
- FOREST BIOMASS SUPPLY
- FOREST AREA
- CARBON STOCK
- TEMPERATURE
- ENERGY CONSUMPTION
- ENERGY EMISSIONS

Application 3

Energy security

- Bio-energy Demand for bio-energy from IAM WITCH under
- Bio-energy demand from economic model GTM

[Favero et al. 2023](#)



GTM

GTM is a forward-looking model: it **maximizes** the NPV of CS and PS in the forestry sector by selecting the age of harvesting timber and land conversion and management decisions:

$$\max \sum_0^{\infty} \rho^t \left\{ \int_0^{Q_t^{tot}} \overbrace{\{D(Q_t^{ind}, Z_t) - C(Q_t^{tot})\}}^{\text{Production costs}} dQ_t^{tot} - \sum_i \overbrace{C_G^i(m_t^i, G_t^i) - C_N^i(m_t^i, N_t^i)}^{\text{Management/conversion costs}} - \sum_i \overbrace{R_t^i \left(\sum_a X_{a,t}^i \right)}^{\text{Land Rental costs}} \right\} [1]$$