# Forest Model Intercomparison Project (ForMIP)

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# ForMIP Highlights

- 3 global forest sector model inter-comparison of 81 future scenarios.
- Socioeconomic drivers strongly influence forest sector model estimates.
- Global forests could sequester 1.2–5.8 $GtCO_2e/yr$ over the next century.
- Forest management can increase carbon *and* harvests w/out expanding area.
- Integrated assessments could improve representation of forest markets and management dynamics.

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How the future of the global forest sink depends on timber demand, forest management, and carbon policies

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ABSTRACT

Deforestation has contributed significantly to net greenhouse gas emissions, but slowing deforestation, regrowing forests and other ecosystem processes have made forests a net sink. Deforestation will still influence future carbon fluxes, but the role of forest growth through aging, management, and other silvicultural inputs on future carbon fluxes are critically important but not always recognized by bookkeeping and integrated assessment models. When projecting the future, it is vital to capture how management processes affect carbon storage in ecosystems and wood products. This study uses multiple global forest sector models to project forest carbon impacts across 81 shared socioeconomic (SSP) and climate mitigation pathway scenarios. We illustrate the importance of modeling management decisions in existing forests in response to changing demands for land resources, wood products and carbon. Although the models vary in key attributes, there is general agreement across a majority of scenarios that the global forest sector could remain a carbon sink in the future, sequestering 1.2–5.8 $GtCO_2e/yr$ over the next century. Carbon fluxes in the baseline scenarios that exclude climate mitigation policy ranged from −0.8 to 4.9 $GtCO_2e/yr$, highlighting the strong influence of SSPs on forest sector model estimates. Improved forest management can jointly increase carbon stocks and harvests without expanding forest area, suggesting that carbon fluxes from managed forests systems deserve more careful consideration by the climate policy community.

1. Introduction

The global forest sector is widely recognized in the scientific and policy communities for its contribution to the global carbon cycle and climate change mitigation (IPCC, 2018; Lauri et al., 2017; Grassi et al., 2017; Roe et al., 2019; Canadell and Raupach, 2008; Friedlingstein et al., 2019; Domke et al., 2020). Natural climate solutions such as avoided deforestation (Kindermann et al., 2008), afforestation (Bastin et al., 2019; Busch et al., 2019), forest restoration (Lewis et al., 2019), and improved forest management (Griscom et al., 2017; Austin et al., 2020) are important components of climate change mitigation goals. Despite this noted importance, knowledge gaps regarding the combined impact of future socioeconomic, management, and policy change on forest carbon stocks and greenhouse gas (GHG) emissions remain (Forsell et al., 2016; Popp et al., 2017). Key gaps include the role of timber demand on carbon flux, the influence of climate change policies on forest management and timber production, and the regional variation in carbon and wood product harvest outcomes.

Global-scale terrestrial carbon storage analyses often use bookkeeping methods that assign carbon density parameters to land cover types and track land use over time (Houghton and Nassikas, 2017) or project impacts from discrete land use change (LUC) decisions via integrated assessment models (IAM) (Popp et al., 2017; Roe et al., 2019) that often assume all global forests are unmanaged or hold forest

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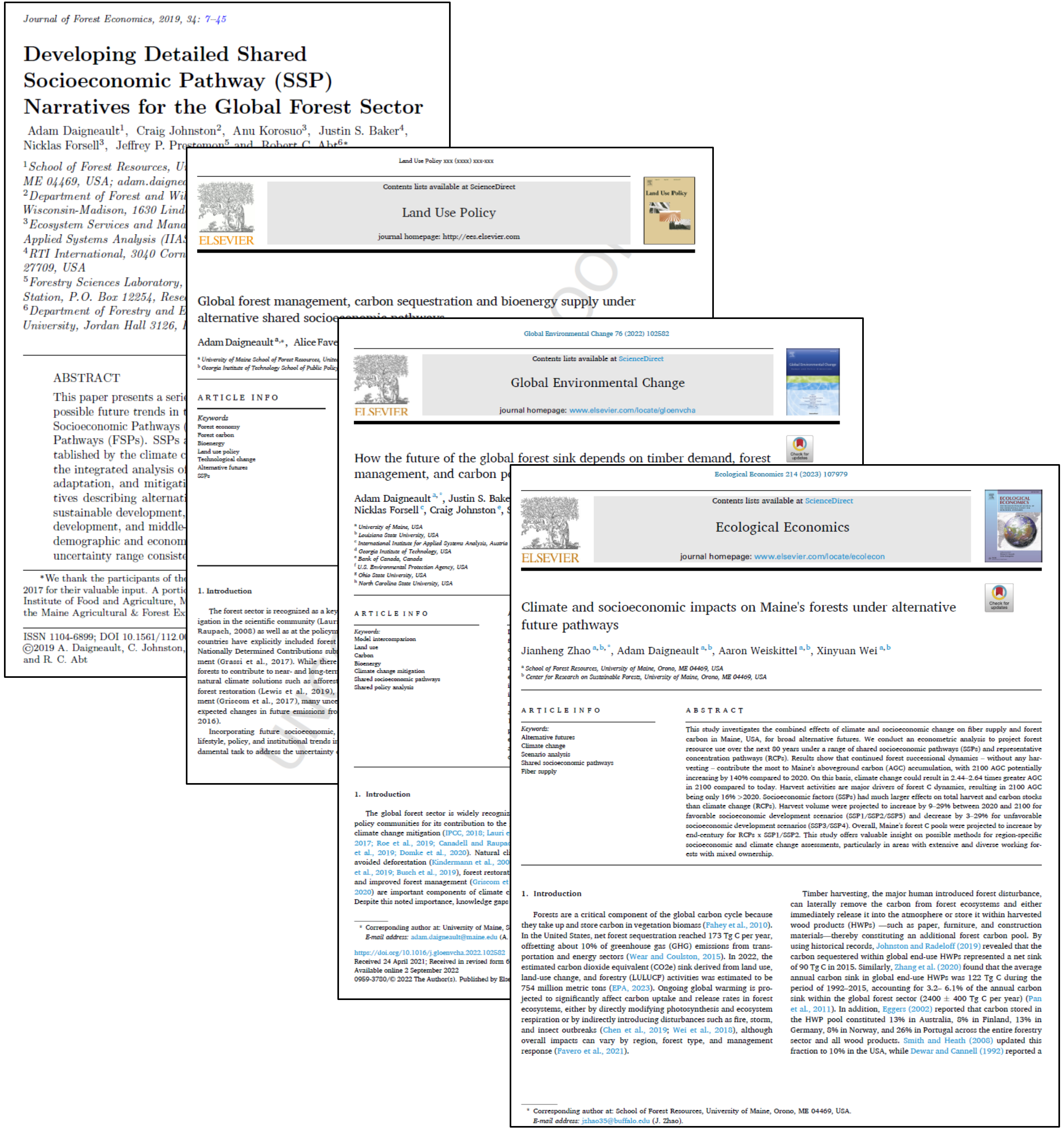
# ForMIP Evolution

- 2017-18: Forest Sector Pathway (FSP) development
- 2019-21: Initial ForMIP modeling + individual model publications
- 2022: First ForMIP paper published in GEC
- 2023+: Regional/downscaled modeling, climate change impacts, refined analyses



# ForMIP scenario development and simulation

- **Forest Sector Models (FSM):** 3 global forest sector models (GFPM, GTM, GLOBIOM) that account for timber harvest, forest area, and carbon sequestration for alternative socioeconomic and climate change mitigation pathways.
- **Shared Socioeconomic Pathways (SSP)**: 5 pathways that vary degrees of global macroeconomic and socioeconomic change, including demographics, economic growth, technological change, and policy orientations.
- **Relative Concentration Pathways (RCP):** 6 pathways of global greenhouse gas emissions over time. In this paper, RCPs designate global climate change mitigation targets and do not account for the physical impacts of climate change.
- **Shared Policy Assumptions (SPA):** 2 consistent model assumptions used to achieve climate change mitigation targets. In this paper, mitigation pathways are simulated in each FSM through specific carbon price and bioenergy demand pathways for each SSP-RCP combination.

# Key ForMIP Forest Sector Model Elements

| Element | GTM | GFPM | GLOBIOM |
|---|---|---|---|
| Economic Regions | 16 | 180 | 59 |
| Resolution | regional | country | 0.5°-2° grid |
| Sectors | Sawtimber, pulpwood, bioenergy | forest product industry | Forest industry, forestry, bioenergy, agriculture |
| Forest types^ | 302 | 1 | 6 |
| Climate effect on forests | no | no | no |
| Forest products* | 3 | 14 | 35 |
| Forest products trade | n/a | Bilateral trade, | Bilateral trade, non-linear trade costs, trade-inertia constraints based on historical trade |
| Base year | 2015 | 2015 | 2000 |
| Calibration | Model calibrated to 2015 FAOSTAT and FRA | Model calibrated to FAOSTAT and FRA data from 2014 to 2016 | Model calibrated to FAOSTAT and FRA data from 2000 to 2020 |
| Temporal scale | 10-year | 5-year | 10-year |
| Dynamics | Intertemporal | Recursive dynamic | Recursive dynamic |
| Biomass policy | Fixed demand | Fixed demand | Constant elasticity demand functions, which are shifted over time |
| Carbon policy | Carbon tax/subsidy based on carbon price applied to all pools, including HWP# | Carbon tax/subsidy based on carbon price applied to forest biomass, not for HWP | Carbon tax/subsidy based on carbon price for deforestation/ afforestation/ management, not for HWP |
| Endogenous response | Product price, forest area, management intensity | Product price, Timber harvest, Import, and export | Prices, quantities, land-use and management endogenous, supply side solved spatially-explicit, demand side and trade solved in regional level |
| Land use transition function | Agricultural land rents | Environmental Kuznets Curve | Land-use changes endogenous based on economic surplus maximization, non-linear land-use change costs, feasible areas and mapping of allowed land-use changes |
| Model documentation | https://u.osu.edu/forest/code-repository/ | https://buongiorno.russell.wisc.edu/gfpm/ | https://iiasa.github.io/GLOBIOM/index.html |

^ e.g,. PNW Douglas fir, coniferous, deciduous, etc.).

* (e.g., sawlogs, pulp, etc.).

# HWP = harvested wood products

# Key Global ForMIP Scenario SSP-RCP Elements

Challenges to mitigation ↑

**SSP5:** *Fossil-fueled Development*
- High economic growth
- Low population growth
- Globally connected markets
- High forest product demand
- Rapid technological change
- Medium land use regulations
- Intensive plantation-focused mgmt

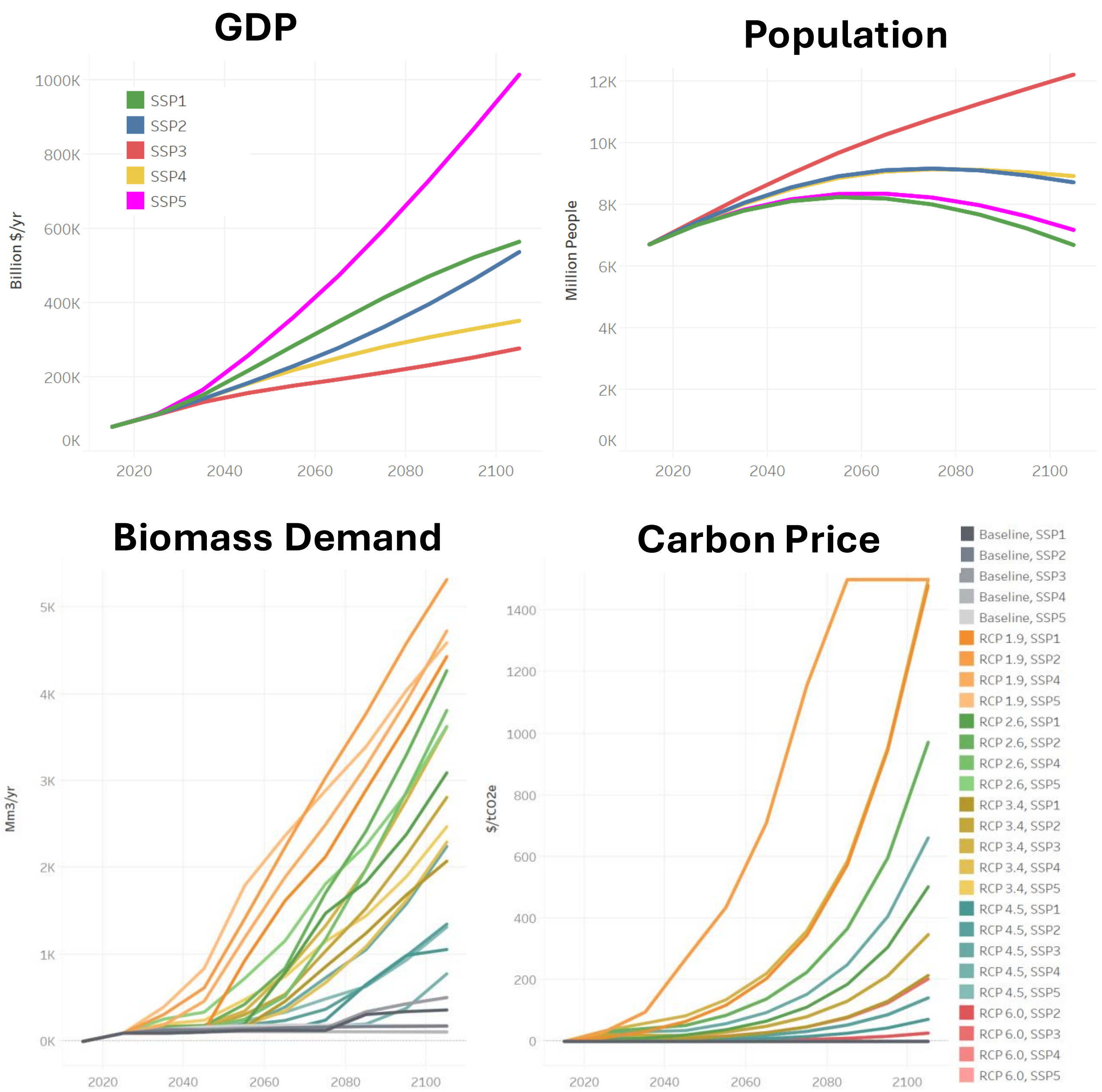
**SSP3:** *Regional Rivalry*
- Low economic growth
- Very high population growth
- Locally focused markets
- Low forest product demand
- Low technological change
- Limited land use regulations
- Natural regeneration-focused mgmt

**SSP2:** *Middle of the Road*
- Medium economic growth
- Moderate population growth
- Regionally connected markets
- Medium forest product demand
- Moderate technological change
- Medium land use regulations
- Mix of plant. and nat regen mgmt

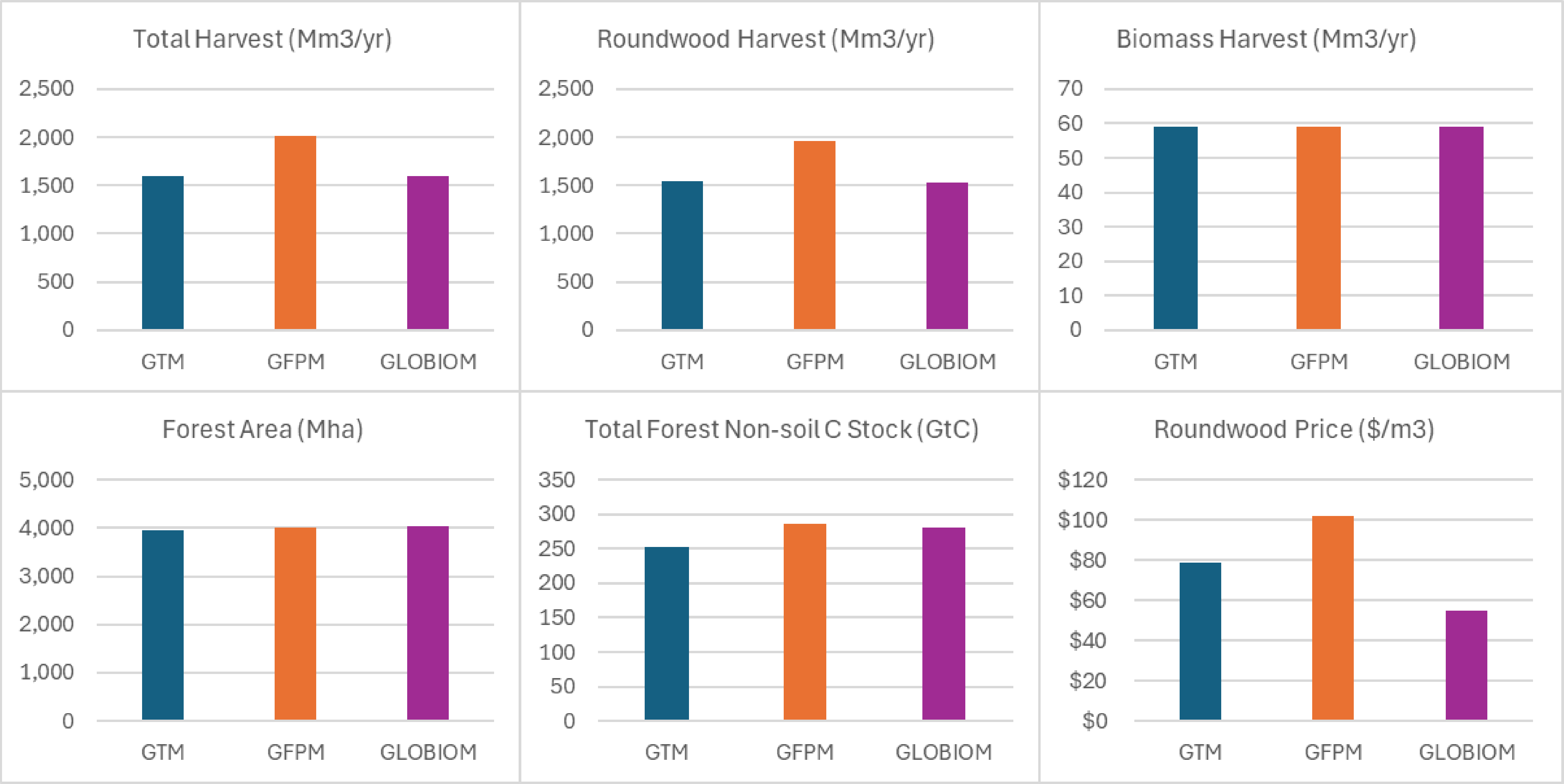
**SSP1:** *Sustainability*
- High economic growth
- Low population growth
- Globally connected markets
- High demand for wood products
- Rapid technological change
- Strict land use regulations
- Mix of plantation and nat regen mgmt

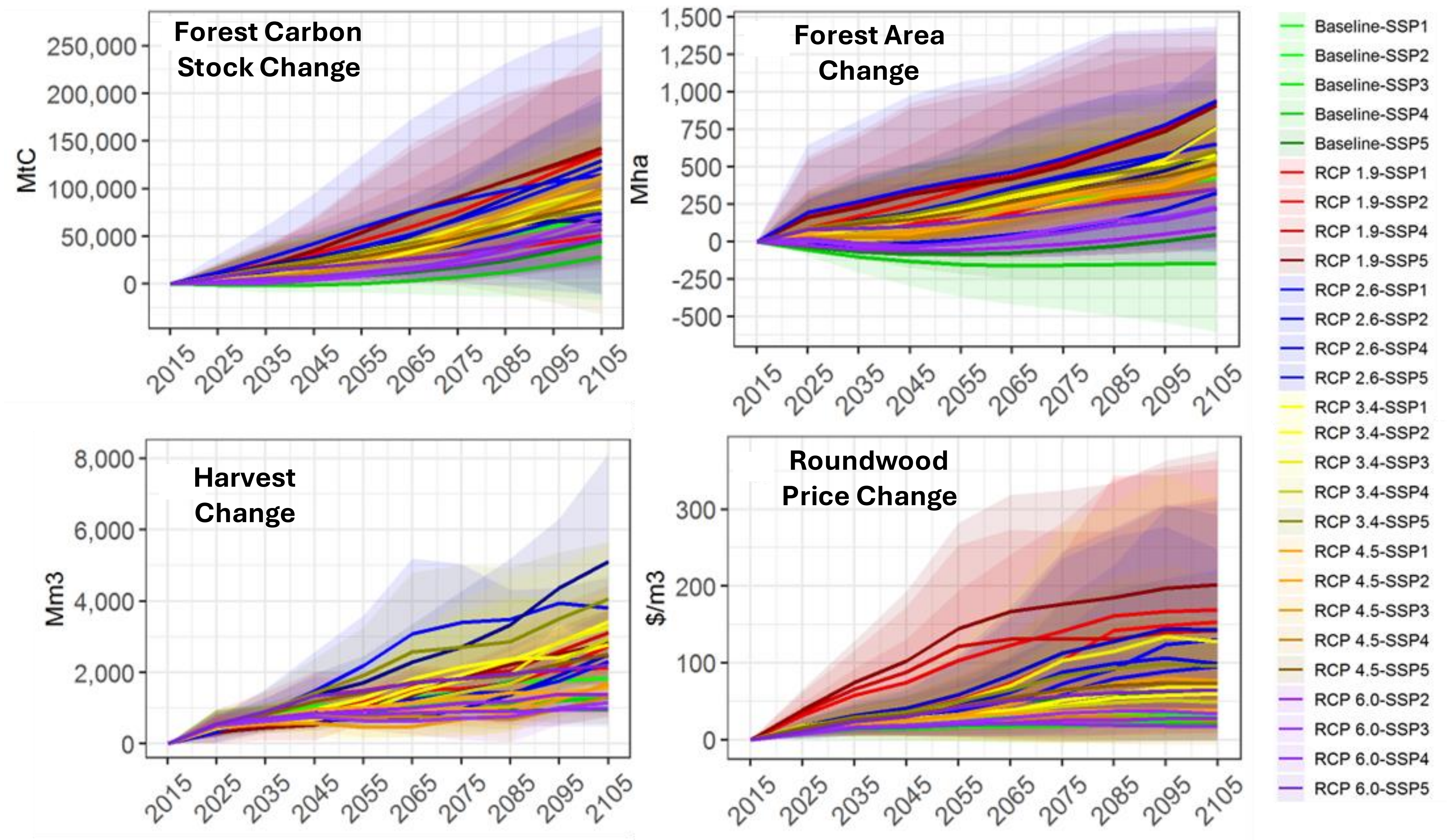
**SSP4:** *Inequality*
- Varying economic growth by region
- High population growth in low income regio
- Regionally connected markets
- Mixed forest product demand
- Medium-high technological change
- Mixed land use regulations
- Mix of plantation and nat regen mgmt

Challenges to adaptation →



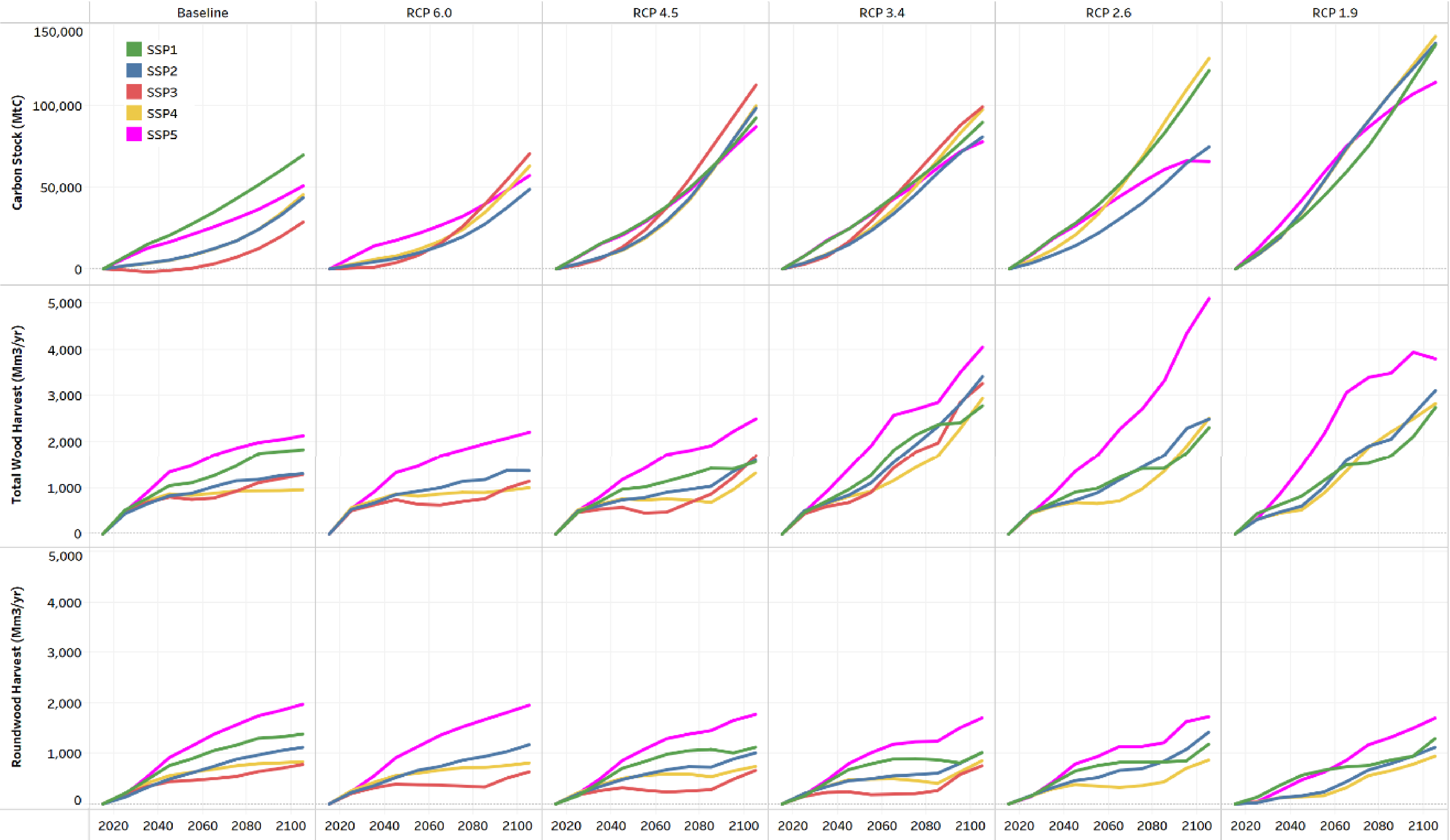
# Key 2015 Baseline Estimates by ForMIP Model

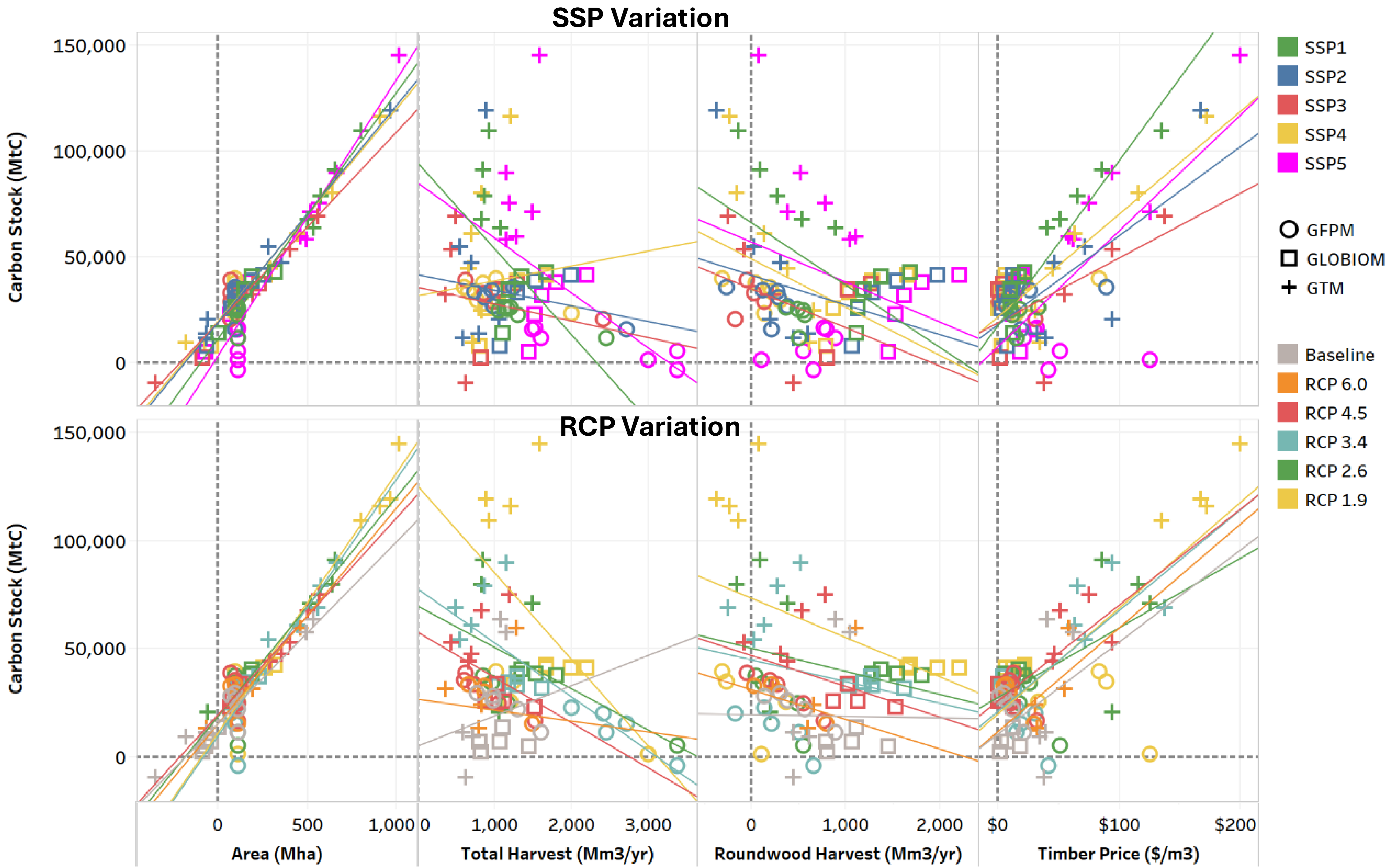


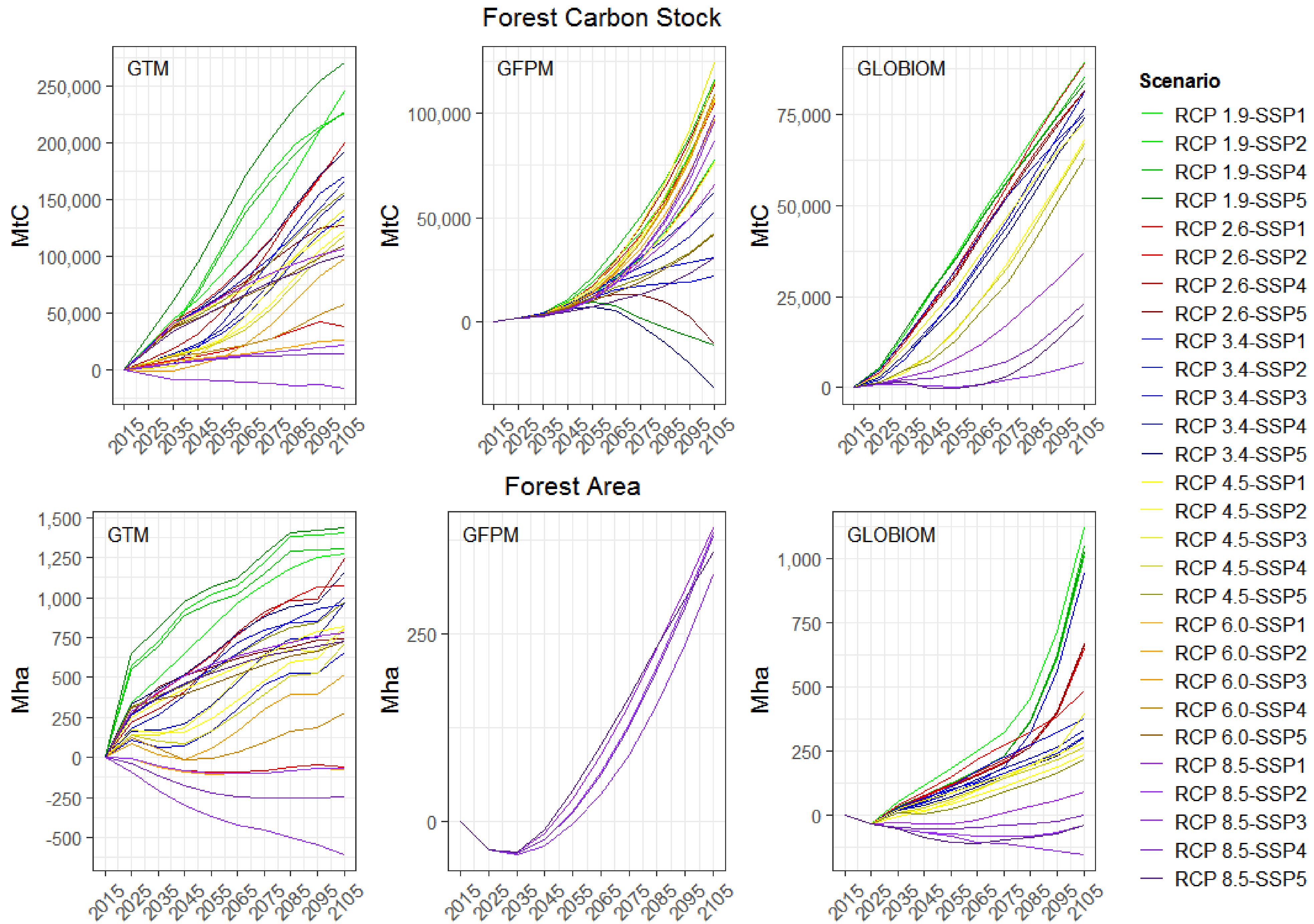


Forest Carbon Stock Change
MtC
250,000
200,000
150,000
100,000
50,000
0
Forest Area Change
Mha
1,500
1,250
1,000
750
500
250
0
-250
-500
Harvest Change
Mm3
8,000
6,000
4,000
2,000
0
Roundwood Price Change
$/m3
300
200
100
0
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105
Baseline-SSP1
Baseline-SSP2
Baseline-SSP3
Baseline-SSP4
Baseline-SSP5
RCP 1.9-SSP1
RCP 1.9-SSP2
RCP 1.9-SSP4
RCP 1.9-SSP5
RCP 2.6-SSP1
RCP 2.6-SSP2
RCP 2.6-SSP4
RCP 2.6-SSP5
RCP 3.4-SSP1
RCP 3.4-SSP2
RCP 3.4-SSP3
RCP 3.4-SSP4
RCP 3.4-SSP5
RCP 4.5-SSP1
RCP 4.5-SSP2
RCP 4.5-SSP3
RCP 4.5-SSP4
RCP 4.5-SSP5
RCP 6.0-SSP2
RCP 6.0-SSP3
RCP 6.0-SSP4
RCP 6.0-SSP5

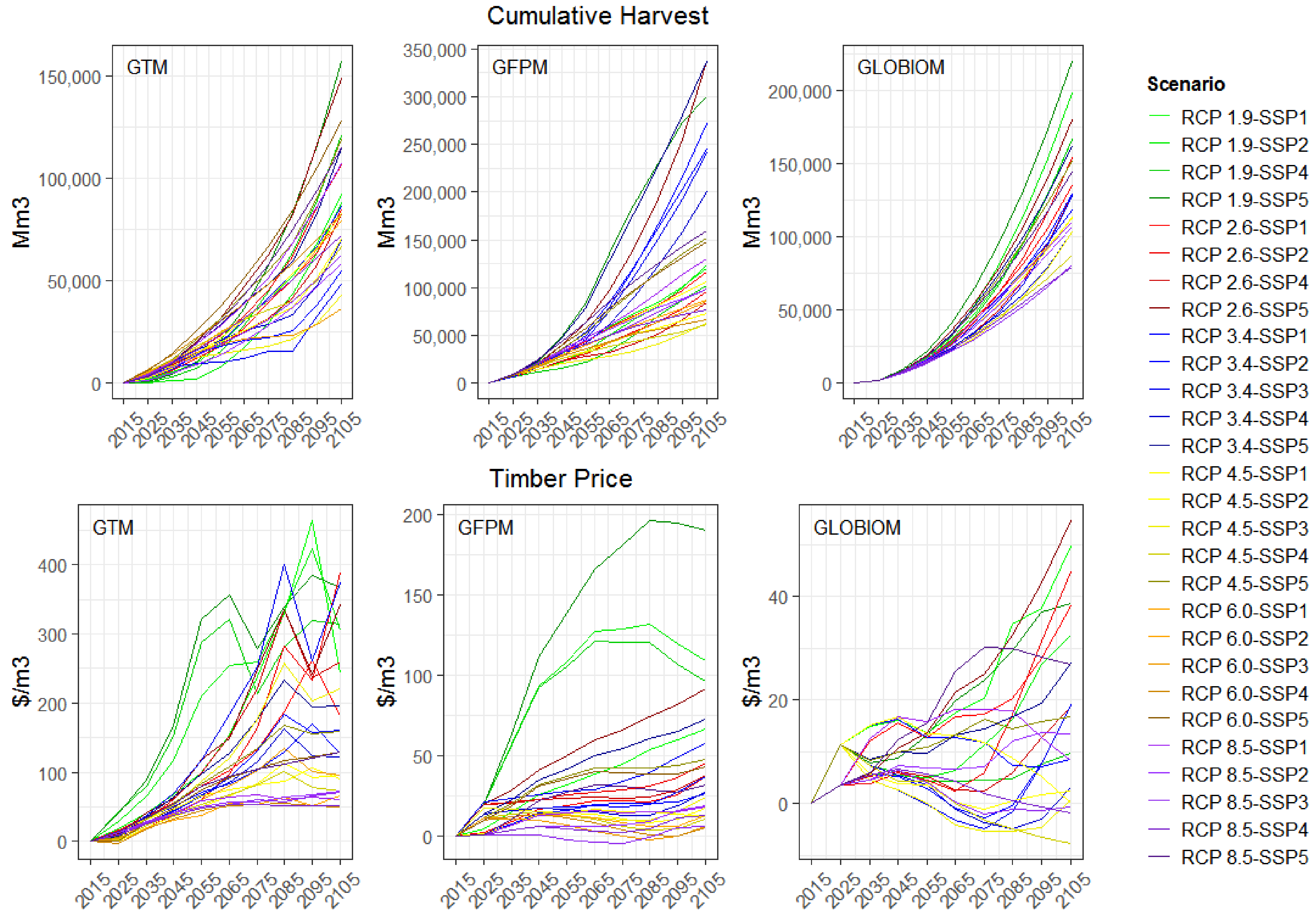
# Mean change in global aboveground carbon stock (MtC), annual total wood harvest (Mm3), and annual industrial roundwood harvests (Mm3) from 2015 by RCP and SSP.




SSP Variation
RCP Variation
Carbon Stock (MtC)
150,000
100,000
50,000
0
Area (Mha)
Total Harvest (Mm3/yr)
Roundwood Harvest (Mm3/yr)
Timber Price ($/m3)
0
500
1,000
0
1,000
2,000
3,000
0
1,000
2,000
$0
$100
$200
SSP1
SSP2
SSP3
SSP4
SSP5
GFPM
GLOBIOM
GTM
Baseline
RCP 6.0
RCP 4.5
RCP 3.4
RCP 2.6
RCP 1.9



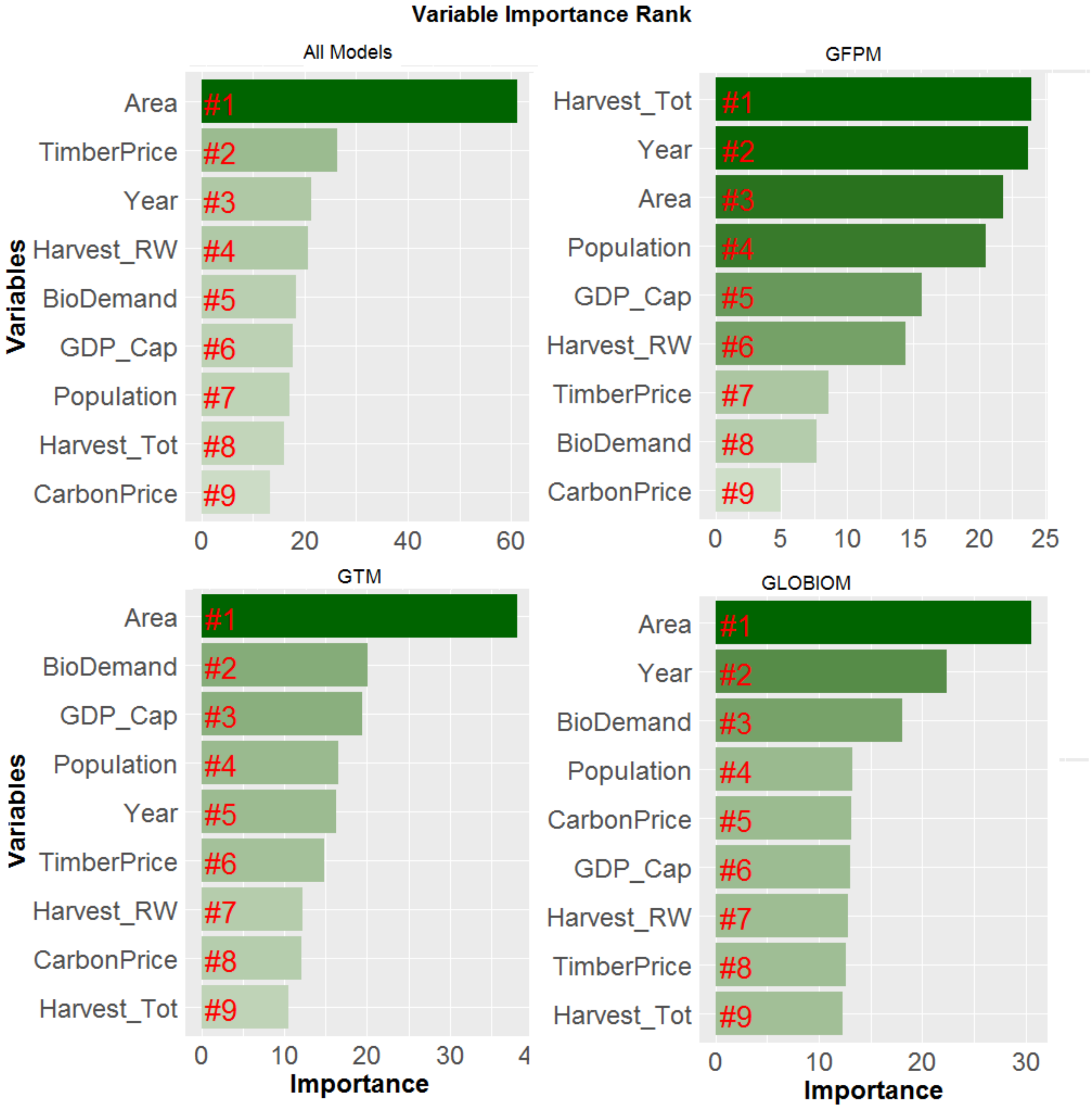
Forest Carbon Stock
GTM
GFPM
GLOBIOM
MtC
250,000
200,000
150,000
100,000
50,000
0
100,000
50,000
0
75,000
50,000
25,000
0
2015
2025
2035
2045
2055
2065
2075
2085
2095
2105
Forest Area
Mha
1,500
1,250
1,000
750
500
250
0
-250
-500
250
0
1,000
750
500
250
0
Scenario
RCP 1.9-SSP1
RCP 1.9-SSP2
RCP 1.9-SSP4
RCP 1.9-SSP5
RCP 2.6-SSP1
RCP 2.6-SSP2
RCP 2.6-SSP4
RCP 2.6-SSP5
RCP 3.4-SSP1
RCP 3.4-SSP2
RCP 3.4-SSP3
RCP 3.4-SSP4
RCP 3.4-SSP5
RCP 4.5-SSP1
RCP 4.5-SSP2
RCP 4.5-SSP3
RCP 4.5-SSP4
RCP 4.5-SSP5
RCP 6.0-SSP1
RCP 6.0-SSP2
RCP 6.0-SSP3
RCP 6.0-SSP4
RCP 6.0-SSP5
RCP 8.5-SSP1
RCP 8.5-SSP2
RCP 8.5-SSP3
RCP 8.5-SSP4
RCP 8.5-SSP5


Cumulative Harvest
GTM
GFPM
GLOBIOM
Mm3
Timber Price
$/m3
Scenario
RCP 1.9-SSP1
RCP 1.9-SSP2
RCP 1.9-SSP4
RCP 1.9-SSP5
RCP 2.6-SSP1
RCP 2.6-SSP2
RCP 2.6-SSP4
RCP 2.6-SSP5
RCP 3.4-SSP1
RCP 3.4-SSP2
RCP 3.4-SSP3
RCP 3.4-SSP4
RCP 3.4-SSP5
RCP 4.5-SSP1
RCP 4.5-SSP2
RCP 4.5-SSP3
RCP 4.5-SSP4
RCP 4.5-SSP5
RCP 6.0-SSP1
RCP 6.0-SSP2
RCP 6.0-SSP3
RCP 6.0-SSP4
RCP 6.0-SSP5
RCP 8.5-SSP1
RCP 8.5-SSP2
RCP 8.5-SSP3
RCP 8.5-SSP4
RCP 8.5-SSP5

# Relative importance of scenario parameters and endogenous model outcomes on projected carbon stock changes across scenarios & models

Variables:

- Area = forest area
- TimberPrice = timber price
- Year = model year
- Harvest_RW = roundwood harvest
- BioDemand = woody biomass demand
- GDP_Cap = GDP/capita
- Population = global population
- Harvest_tot = roundwood + biomass harvest
- CarbonPrice= carbon price



# Summary

- ForMIP shows importance of modeling management responses to changing demands for land resources, wood products and carbon.
- 95% of scenarios had forest C stocks increasing through 2100 (1.2–5.8 GtCO2e/yr )
- Carbon fluxes in the baseline scenarios excluding mitigation policy ranged from -0.8 to 4.9 GtCO2e/yr
- Key influences of forest C change: Area, prices, roundwood + biomass demand
- Noticeable model variability in key estimates, but direction and overall outcomes consistent
- Global forests can jointly increase carbon stocks *and* timber harvests without necessarily expanding area
- Carbon fluxes from managed forests systems deserve more careful consideration by the climate policy community

# Ongoing + Future Work

- Further evaluating impacts of harvests + harvested wood products on scenario outcomes
- Downscaling ForMIP scenarios for consistent regional analysis
- Incorporating climate change impacts into global models
- More direct use by national and regional policymakers

# Want to know more & access data?

ForMIP paper published in *Global Environmental Change* (open access)

Key inputs and scenario estimates included as supplementary material

https://www.sciencedirect.com/science/article/pii/S0959378022001200

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1. Introduction

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# Additional Slides

# ForMIP Scenarios

**Table 2**
Key elements for global forest sector shared socioeconomic pathways (SSPs).

| Element | SSP1 (Sustainability) | SSP2 (Middle of the Road) | SSP3 (Regional Rivalry) | SSP4 (Inequality) | SSP5 (Fossil-fueled Development) |
|---|---|---|---|---|---|
| Economic growth | High | Medium | Low | HIC: High<br>LIC: Low | High |
| Population Growth | Low | Medium | High | HIC: Low<br>LIC: High | Low |
| Market connectivity | Global | Regional to Global | Local to Regional | HIC: Global<br>LIC: Regional | Global |
| Technological change | High | Medium | Low | HIC: High<br>LIC: Medium | High |
| Land use regulation | Very high | Medium | Low | HIC: High<br>LIC: Med-low | Medium |
| Forest management intensity | Medium-high | Medium | Low | HIC: High<br>LIC: Low | High |
| Forest product demand | Medium-high | Medium | Low | HIC: High<br>LIC: Low | Very high |

HIC: High-income countries; LIC: Low-income countries; Climate and woody biomass elements vary by RCP.

# Regional Estimates