Core Model Proposal #: 369
Add detail to forest sectors: Breakout PFTs into hard, softwood & add explicit product pools for pulp and sawn-wood

Product: Global Change Analysis Model (GCAM)

Institution: Joint Global Change Research Institute (JGCRI)

Authors: Kanishka B. Narayan, Abigail Snyder, Pralit Patel, Neal Graham

Reviewers: Xin Zhao, Marshall Wise

Date committed: 12 Sep 2023

IR document number: PNNL-36042

Related sector: Forests, land use

Type of development: Data system, Input Data
Purpose: This CMP adds details to the forest sectors. This includes the following,

1. Breakout forest Plant Functional Types (PFTs) into Hardwood and Softwood on forestry supply side
2. Breakout secondary forest products into sawn wood and wood pulp product pools
3. Add intermediate sectors to handle processing these products
4. Add trade for these secondary products
5. Breakout demand sectors for forest products
6. Add fix for logging residue biomass calculations

Description of Changes

Forest product representation in the current GCAM core is simple (Figure 1). A single wood product is produced in each region GLU combination from an aggregated forest. This CMP breaks out forest into different plant functional types (PFTs) namely hardwood and softwood forests on the supply side and also breaks out the forest commodities into wood pulp and sawtimber products. Trade is also represented for these secondary products using the same Armington parameters used for agriculture. Another change with this CMP is the removal of wood fuel from forest products. The major changes are explained below,

Forest sector breakout-

i.) Figure 2 summarizes the breakout implemented in this proposal. Forests are broken out into different PFTs namely Hardwood Forests and Softwood Forests. These forests are already broken out in the moirai land data system and therefore have different carbon densities and therefore different productivities. We have also added the ability to add different non land variable costs for hard and softwood forests. Note that PFTs are also broken into Managed, Unmanaged and Protected land types. Another important point to note is that we have not modified the parameterization of woody biomass, nor have we modified any of the land node logits. In separating out Hardwood vs Softwood, we are only breaking out additional PFTs. They are still under Forestland and hence have the same logit. Only difference between the two is the yields, since they have different carbon densities and different mature ages. We get the carbon data and the mature age data for the different forest types from moirai already. This will only affect the initial allocation of managed forest. Since the logit is the same, the model cannot plant more Hardwood vs Softwood. This will however play a bigger role when we implement the dynamic harvest decision since softwood forests mature faster. I have added a figure comparing hardwood vs softwood yields in GLU. Note that the yield can be higher or lower since the density is higher but also because mature ages are smaller for softwood forests.

ii.) Managed hard and softwood Forests are used to produce a single industrial round wood commodity in m3 of wood (Blue boxes in Fig 2). The price for this commodity is the harvested industrial round wood price from the FAO. We used this pooled supply approach since in forest supply chains, wood is harvested before deciding the portion of harvested wood that is sent to sawmills vs the portion that is set to be pulped. This approach is consistent with other forestry models such as the Global Timber Model (GTM). We continue to maintain the Armington parameters for primary forest trade which are held fixed to 2100 (similar to the parameters for agricultural commodities).

iii.) The harvested industrial round wood is the allocated to two intermediate sectors (yellow boxes in Fig 2) namely, sawtimber processing and pulp processing. The calculation of the IO coefficients is explained in detail below.

iv.) Armington trade is implemented for these secondary products namely sawtimber and pulp processing and primary industrial roundwood. The trade share weights for all products are all held fixed to 2100 similar to crop trade. We also updated the trade logits since the same were available for roundwood and secondary products. This is explained in more detail in the sections below,

v.) We changed the logging residue parameters so that there are logging residues differentiated by regions (developing regions produce much more logging residue). We also fixed a bug in current GCAM CORE which does not allow logging residue biomass production.

v.) Finally, there are two demand sectors now, one for sawtimber (m3) and another for wood pulp (tons). Milling residues are calculated both on the sawtimber and pulp demand sectors.

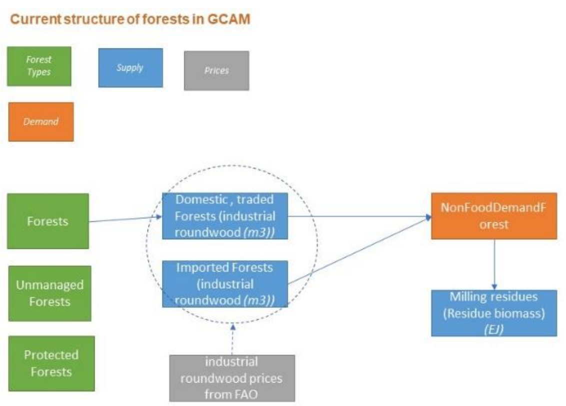

Figure 1 : Structure of forests in current GCAM

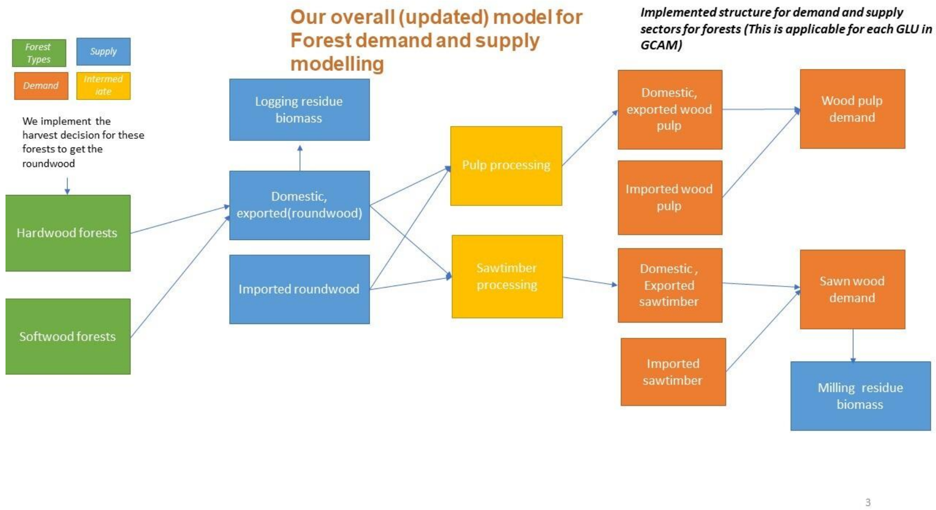

Figure 2: New structure of forests implemented as a part of this CMP.

<u>Fix for logging residue biomass.</u>

Currently in the code, logging residue biomass is calculated when forests are harvested. This biomass production increases as biomass prices increase. However, the amount of biomass produced is restricted by an erosion control parameter. The erosion control parameter is currently set globally and is not differentiated by forest type. We also found that the parameter value currently is too high which leads to too very little logging biomass. This also leads to countries like India importing biomass due to their inability to produce logging residues.

In this CMP, the parameter was divided by the mature age of the trees (by forest type) to get more realistic values that are differentiated by GLU and much lower. This allows regions to produce much more logging residue biomass. We also initialize different harvest parameters for different regions based on expected residue production. E.g., Africa Eastern would produce much more residue biomass relative to actual wood production since much more industrial round wood is lost when converting to sawtimber (See figure 7). To initialize the harvest parameters, we divide the "fraction harvested" global parameter by the IO in Figure 7 which represents the amount of round wood lost when manufacturing wood products. A low value for this parameter leads to higher logging residues. We converge the fraction harvested to the global value over time. This is to reflect improved efficiency in logging over time.

The Figure 3 below shows new logging+milling residue biomass compared to old (for CORE and SSP1 2p6 scenarios). As observed we generate a higher level of forestry residue biomass compared to GCAM CORE. However, the residues now start falling post 2050 which the above-mentioned improved efficiency in logging. But, under a 2p6 scenario (SSP1), we generate much more forestry biomass (close to 14 EJ).

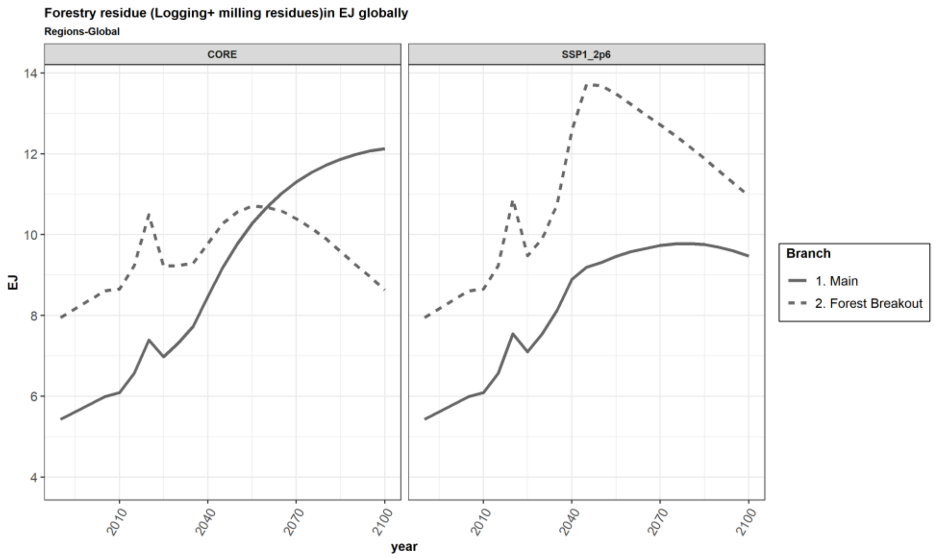

Figure 3: Forestry residue biomass with Forest Breakout

Improvements to wood fuel accounting in GCAM-

Currently round wood production in GCAM is based on wood production data from the FAO. This round wood includes a commodity called wood fuel. Wood fuel as defined by the FAO is basically just residues (from milling and logging) and charcoal, twigs collected from the forest floor converted to a round wood equivalent using a conversion factor . This commodity does not represent trees planted for wood fuel[1,2]. The FAO also notes that in many arid regions, this wood fuel is collected from Shrubland not Forests. Based on this, the IMAGE model has an explicit parameter that sets the fraction of fuelwood harvested from non-forest land to 50% in low-income countries and 68% in middle-income countries[3].

Inclusion of wood fuel in the forest commodity introduces a number of problems, namely,

i.) In GCAM Forests have to be designated as "managed" to produce this commodity which is erroneous given its definition.

ii.) This "wood fuel" constitutes a biomass and we do not currently calibrate supply for biomass in the model. The demand for wood fuel is already included in the "traditional biomass" demanded by the model, therefore including it in NonFoodDemandForest is double counting.

iii.) Moreover, GCAM already accounts for wood fuel . On the supply side, milling residues are calculated and available as an energy source from residue biomass and GCAM also calculates logging residues as discussed above. Therefore, including wood fuel in total round wood production is clear double counting.

iii.) As a result of this double counting, a number of developing regions don't have enough managed forest cover to produce wood fuel. This leads to unrealistically high levels of managed forests in regions like India and almost no unmanaged forest in arid regions.

iv.) To correct for point no iii.) regions are exogenously assigned a minimum amount of forest cover to cover production of this commodity by reducing other land types. But this creates problems when breaking out regions from our base 32 regions.

Therefore, in this CMP, wood fuel is removed from the total round wood production. Therefore, Forests are managed in GCAM only to produce industrial round wood. This accounting of wood fuel results in more realistic levels of managed forests for many regions (Figure 4), especially developing regions with high wood fuel production see much less managed forests. With the removal of wood fuels, we also removed the exogenous addition of managed forest cover.

This treatment of wood fuel is consistent with other models' treatment of the FAO data-

i.) The Global Timber Model (GTM) does not include any wood fuel from FAO and all wood fuel available in the GTM is purely residue[4].

ii.) The REMIND-MagPie model allows managed forests to only produce industrial round wood. There is a small allowance to produce wood fuel from unmanaged forests[5].

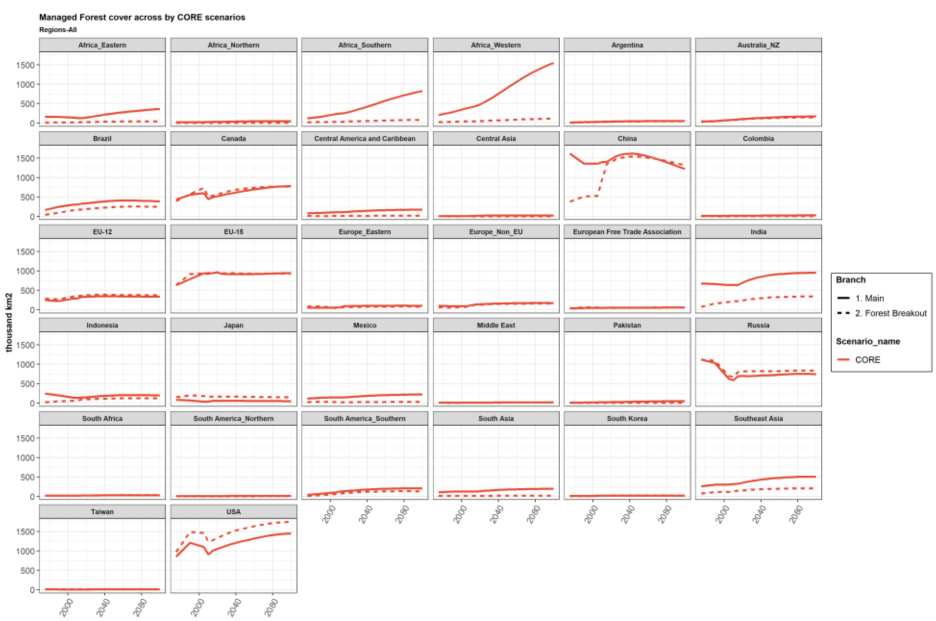

Figure 4: Managed Forest Cover across regions with forest breakout

<u>Changes to forest land allocation as a result of breakout-</u>

As mentioned above, with the breakout, we will have two types of forests in GCAM , namely Hardwood and Softwood Forests. However, it is important to note that there will be some changes in land allocation between these two forests.

1. Firstly, forest yield in GCAM is determined by the carbon density, wood content of carbon and the mature ages. Hardwood forests tend to have higher carbon densities but

have a much higher mature age. Hence yields for Hardwood forests are generally lower than those of softwood forests (See Figure 4C below for the US).

2. As a result, there will be more hardwood forests that are under management compared to softwood forests in regions which can only produce hardwood (See Figure 4B).
3. Also, in regions like the US, Canada where there is more hardwood than softwood forests, managed forests will increase (See Figure 4).
4. Note that Hardwood and Softwood Forests are Plant Functional Types, so a basin where hardwood forests were never available will not suddenly start planting hardwood trees.
5. Also note that the forest vintaging (upcoming proposal)makes more holistic use of the PFTs introduced in this proposal.

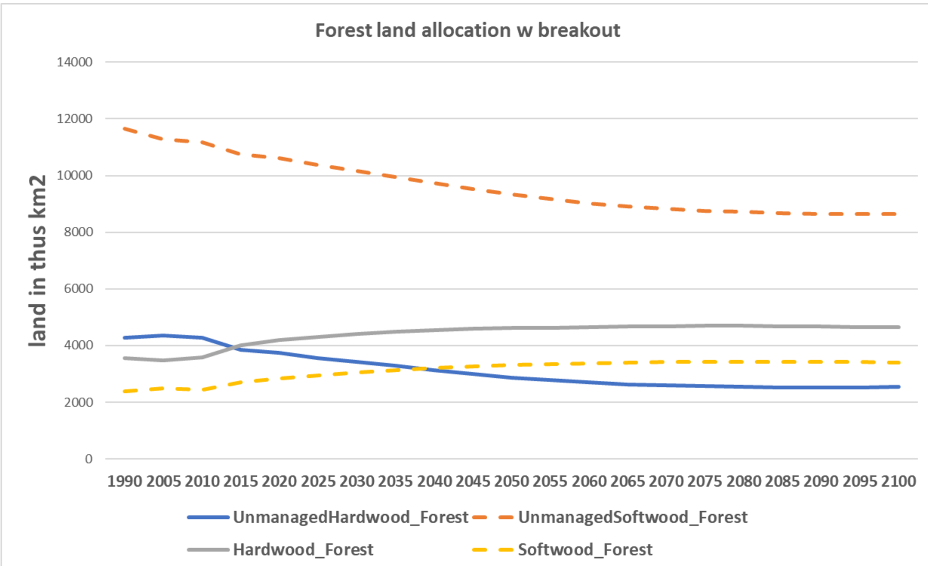

Figure 4B: Forest land allocation by forest type

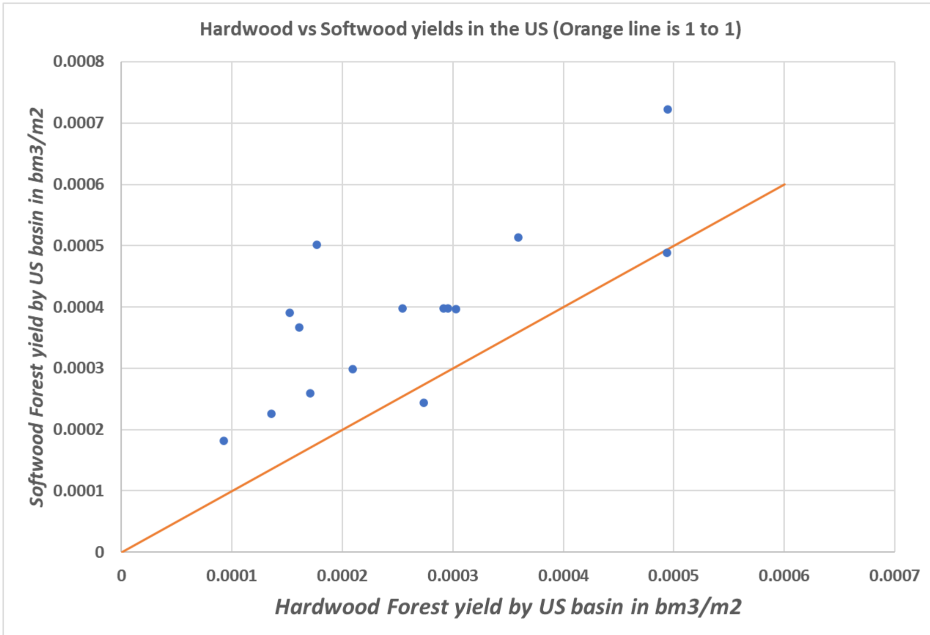

Figure 4C: Hardwood vs Softwood yields in the US.

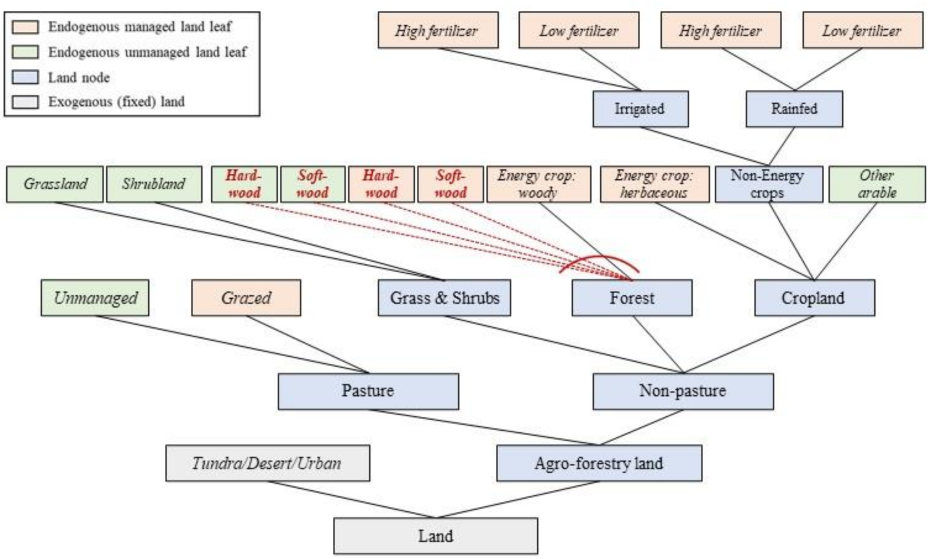

Figure 4D: Structure of forests in land nest

<u>Trade of wood products</u>

As seen in figure 2 above, we now represent trade at two levels for forest products. Industrial round wood or the primary product can be traded, and secondary products (saw timber and wood pulp) can also be traded. The parameters are similar in both product pools (Parameters are updated for both primary and secondary products). Share weights in regional and traded sectors for secondary products are held fixed at base year values to 2100 . Note that the change in trade parameters had minimal effect on scenarios in terms of prices.

However, there are some changes in exports (Figure 4D) and imports (Figure 4E) of roundwood. These are largely driven by removal of wood fuel from the product pools since overall trends remain the same. Also note that trade is not adjusted for intra -regional values (within a GCAM region). This means, we aren't tracking intra-regional trade and this trade is only among our regions This will be tackled when the forest is fully integrated on the gcamdata faostat (in a separate CMP).

We also show the secondary product imports and exports by region (Figure 4F & 4G).

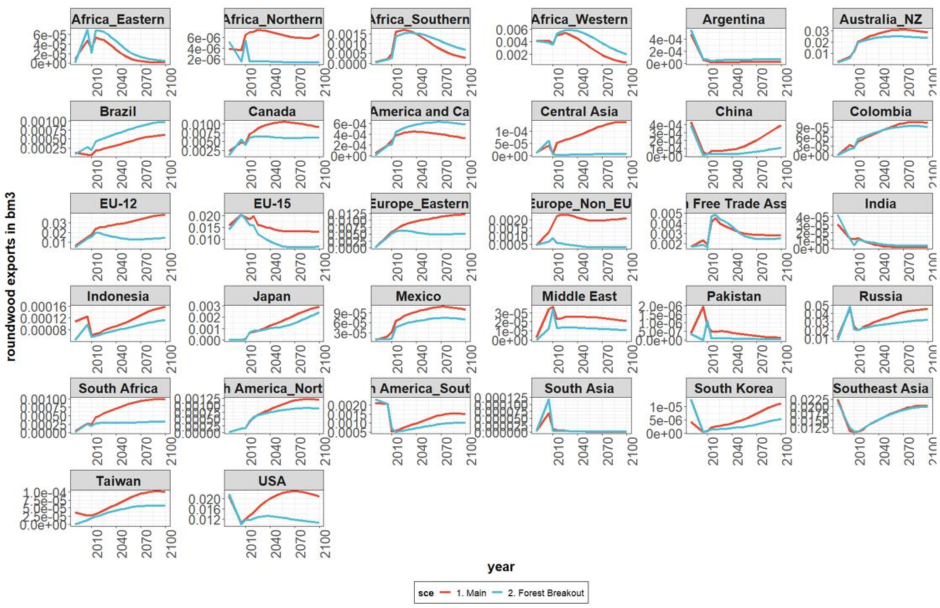

Figure 4D: Roundwood exports

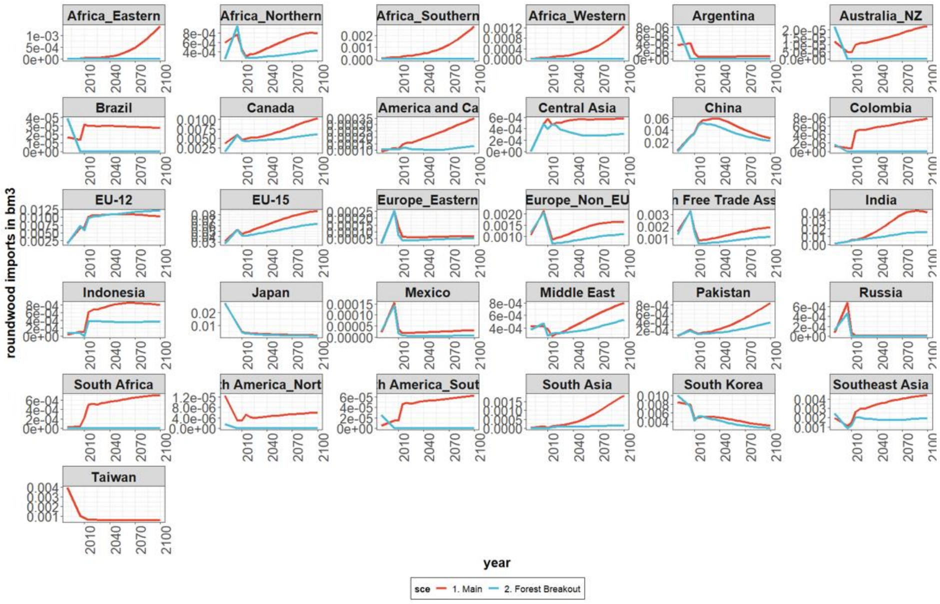

Figure 4E: Roundwood imports

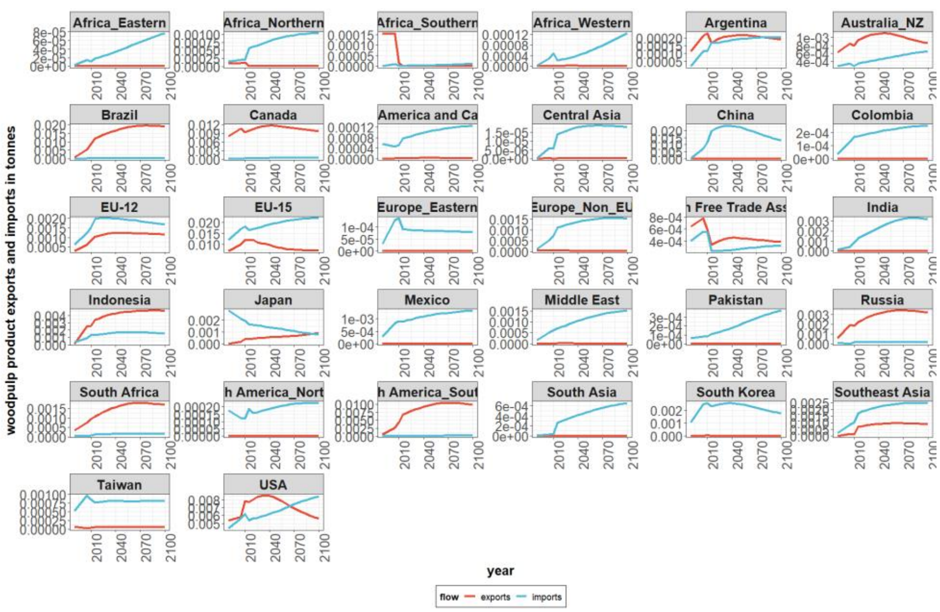

Figure 4F: woodpulp imports and exports by region

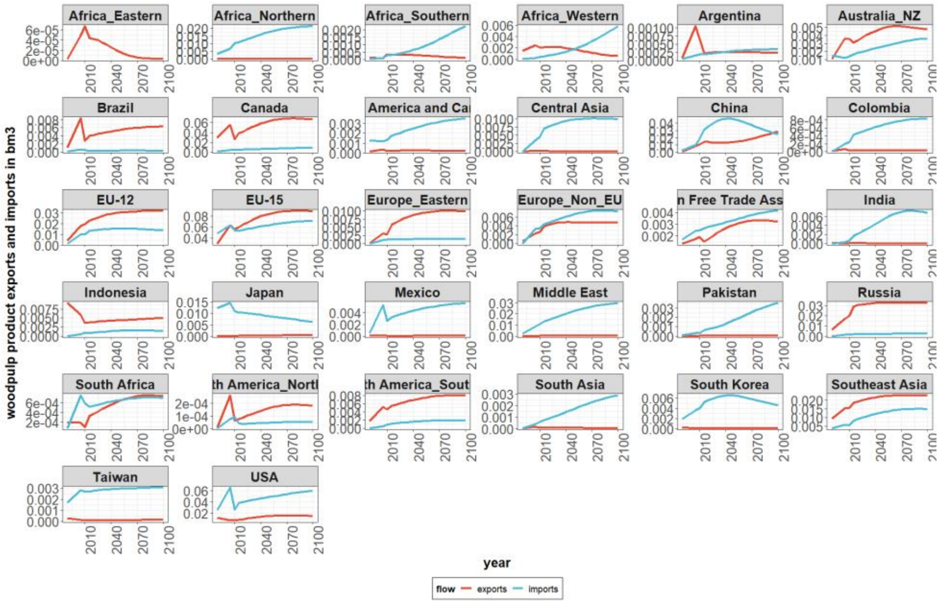

Figure 4F: sawnwood imports and exports by region

Revised estimates of residue biomass

Now with the forest breakout, residue biomass is calculated from sawn wood and pulping. Figure 5 shows the global residue biomass production with and without the forest breakout. Overall residue biomass production is reduced by 2100. The overall trend is largely a result of revisions to logging residues (as observed in Figure 3 above). Figure 6 shows the residue biomass production globally by sector. With our changes, forest logging becomes one of the largest producers of residue biomass across sectors.

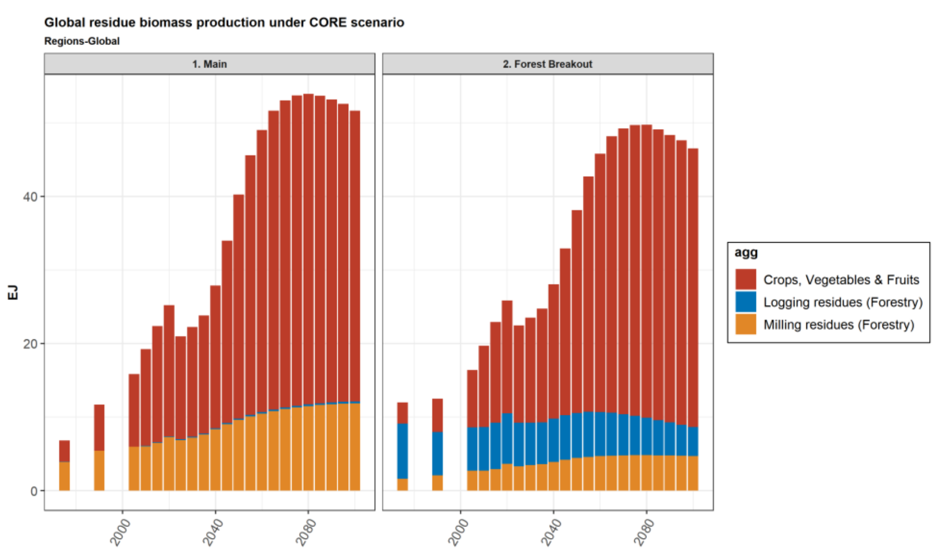

Figure 5: Global residue biomass production

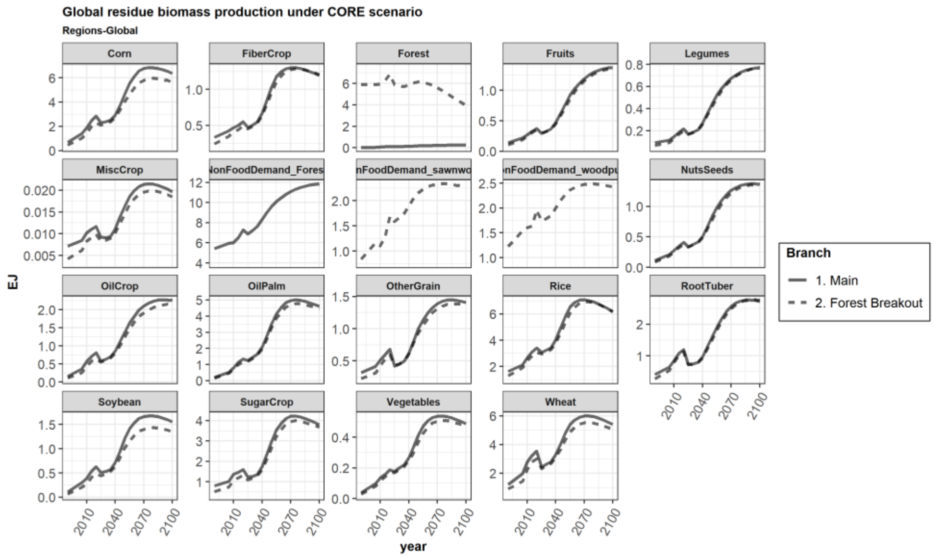

Figure 6: Global residue biomass production by sector.

<u>Assignment of IO co-efficient for sawn wood processing and pulp processing</u>

While the FAO data provides details on the quantities of sawn wood products produced and the quantity of wood pulp produced, it is difficult to ascertain how much of harvested industrial round wood was used in each of the products. Table 1 shows how the sawn wood and wood pulp product pools are mapped from FAO categories. Sawn wood is a pool that consists of sawn wood, veneer sheets and wood-based panels and wood pulp is purely pulp that is produced using chemical and mechanical processes. Reports from the FAO suggest that that there is much more homogeneity across regions in terms of the IO (m3/ton) for wood pulp than saw timber[6]. Accordingly, we first selected a global IO for wood pulp production. This is set at 5.15 (m3 of industrial round wood per ton of pulp) (90% of pulp processing is chemical which has an IO of 5.44 and 10% is mechanical which is 2.55. Taking weighted average of the two, we get 5.15.).

Once we assign the pulp IO and determine the amount of round wood used for pulp production, the remainder of wood consumed is allocated to the sawn wood processing. This yields a regionally heterogenous IO for sawn wood manufacturing (Figure 7).

FAO item code	**GCAM_commodity**
Sawnwood	sawnwood
Veneer sheets	sawnwood
Wood pulp	woodpulp
Wood-based panels	sawnwood

Table 1: Mapping of FAO categories to GCAM product pools

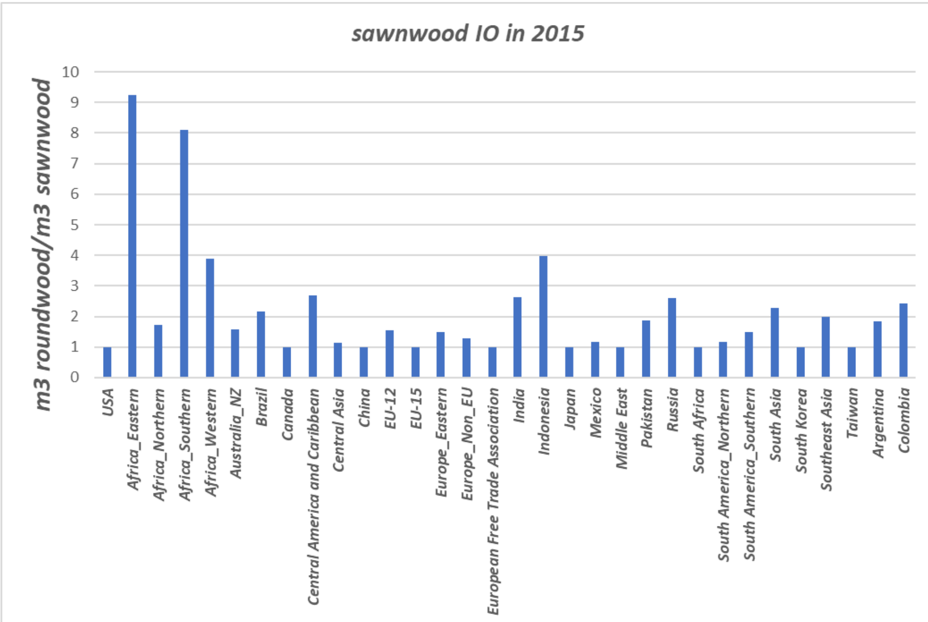

Figure 7: Sawn wood IO across GCAM regions

Validation

In the sections below we present validation figures for the CORE scenarios, SSP scenarios and 2p6 scenarios.

CORE scenarios

Figure 8 shows changes in land allocation to 2100 globally with and without forest breakout. Managed forests decrease by roughly 4000 km2 (-32%) relative to the main branch by 2100. Managed forests decrease with the removal of the double counting of wood fuel in forest products. Land allocated to biomass production increases by 600 km2 (+19%) relative to the main branch by 2100. Figure 3 above shows regional increases and decreases in managed forest cover. As explained above, managed forest cover is reduced in a number of developing countries as a result of removal of wood fuel from total round wood production.

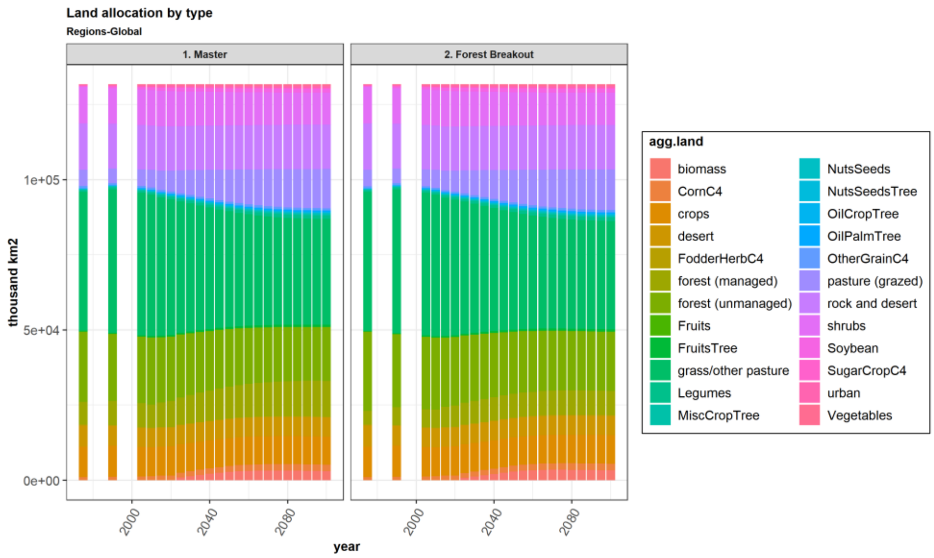

Figure 8: Land allocation by type globally for the CORE scenarios

Figure 9 below shows agricultural production by crop type. With an increase in land allocated to biomass production, there is an increase in global biomass production of 13 EJ (+13%) by 2100. As noted in previous core model proposals, an increase in biomass landcover does not lead to a commensurate increase in biomass production due to regionally differentiated yields for biomass. As observed in figure 13 total Forest commodity production is reduced by almost half throughout the time period with the removal of the double counting of wood fuel. Changes in other crop production types are relatively small.

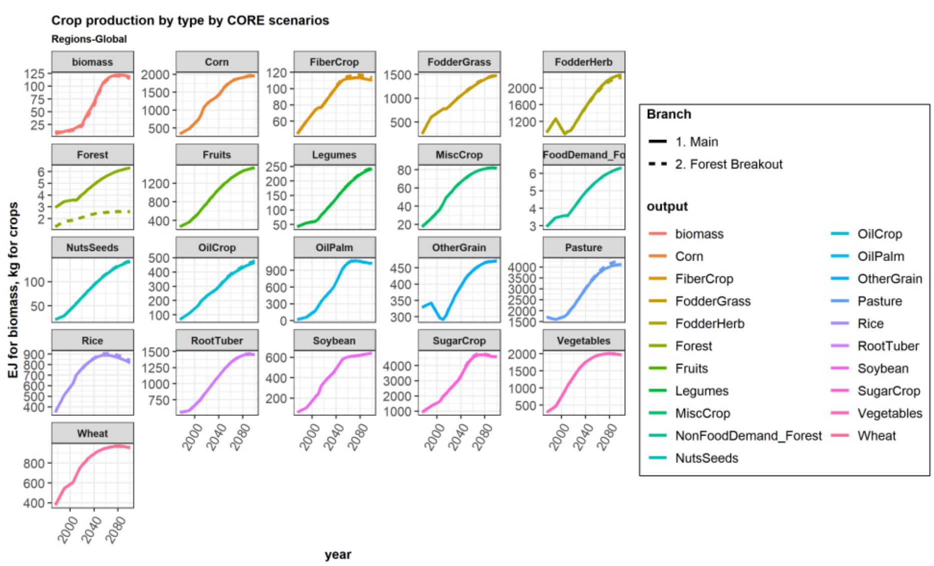

Figure 9: Crop production by type

Figure 10 below shows changes in industrial round wood prices across GCAM regions to 2100. Price changes are now driven by the demand for the two new secondary product pools and their trade. Industrial round wood prices in India, Africa Eastern and Pakistan no longer rise to high levels by 2100 relative to GCAM CORE.

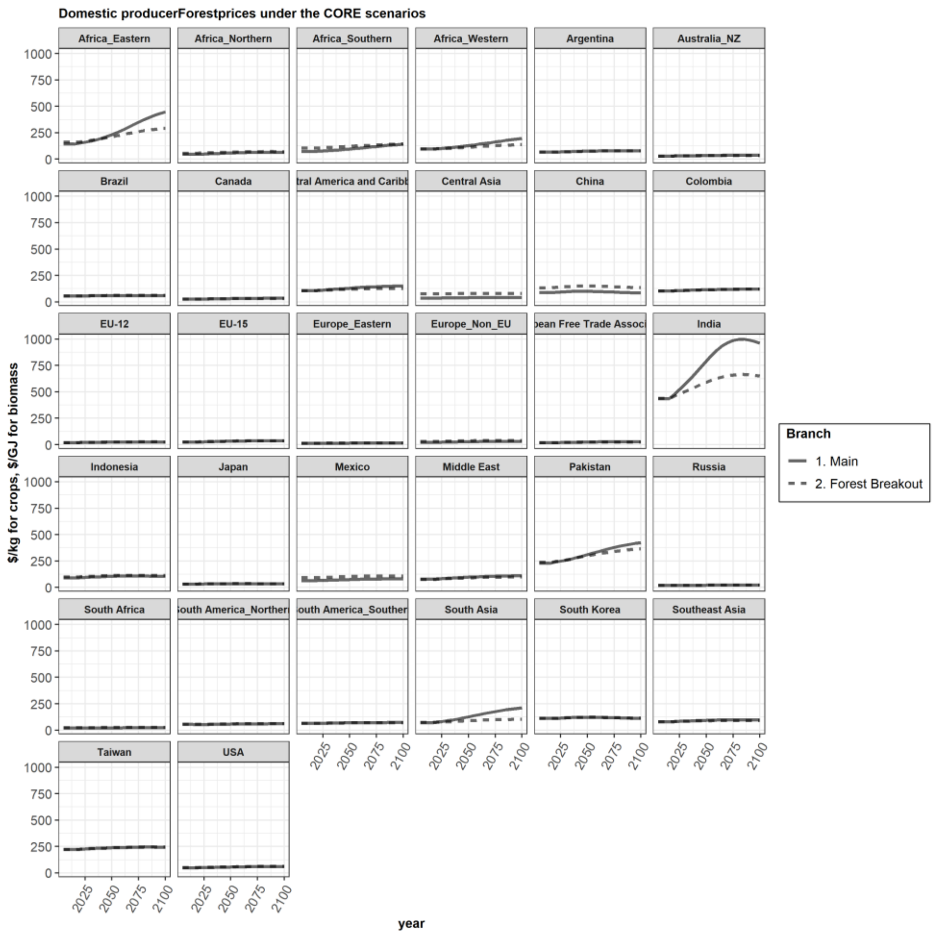

Figure 10: Round wood prices by GCAM region for the CORE scenarios

Figure 11 below shows biomass prices to 2100 across GCAM regions. With changes to residue biomass accounting there are changes to biomass prices starting in the calibration years. In Africa Eastern for example , we observe an increase in the biomass prices which does not last for the entire time horizon. Price trends are found to be generally consistent with and without the forest breakout. Reductions in biomass prices are observed in regions which produce large levels of forestry residues.

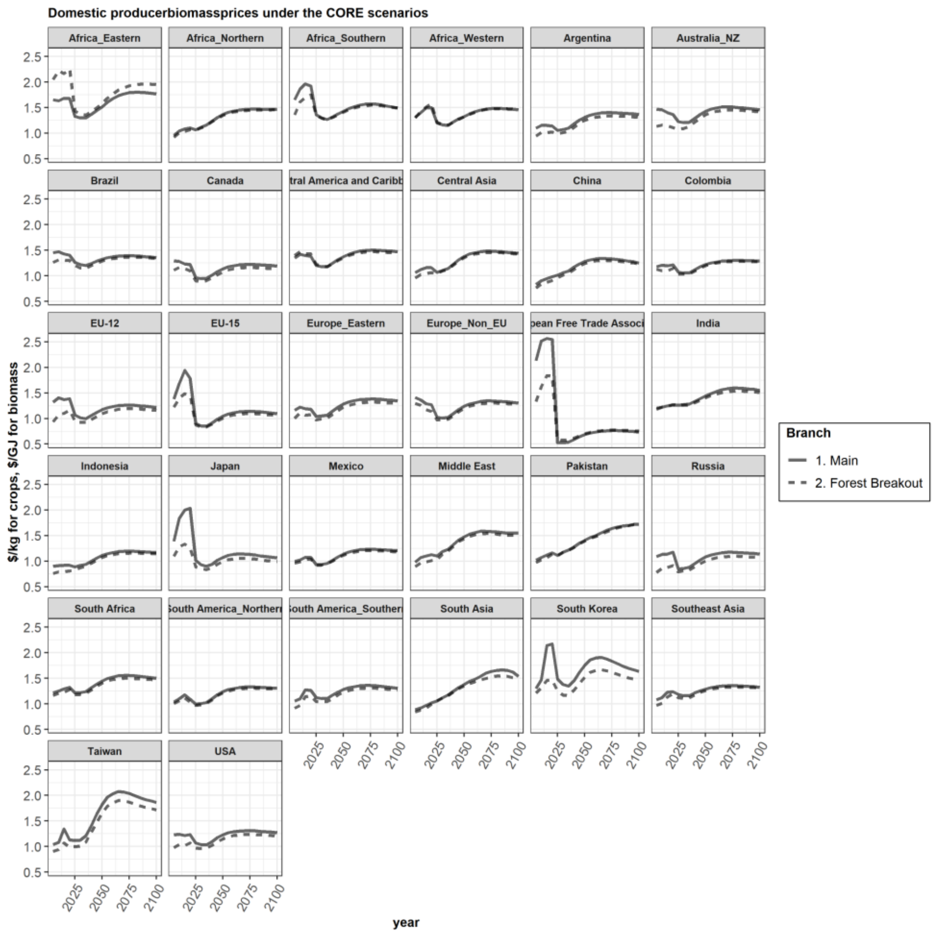

Figure 11: Biomass producer prices across GCAM regions

There is a slight decrease in CO2 emissions by 2100 globally with the forest breakout (Figure 12). Overall trends however remain the same.

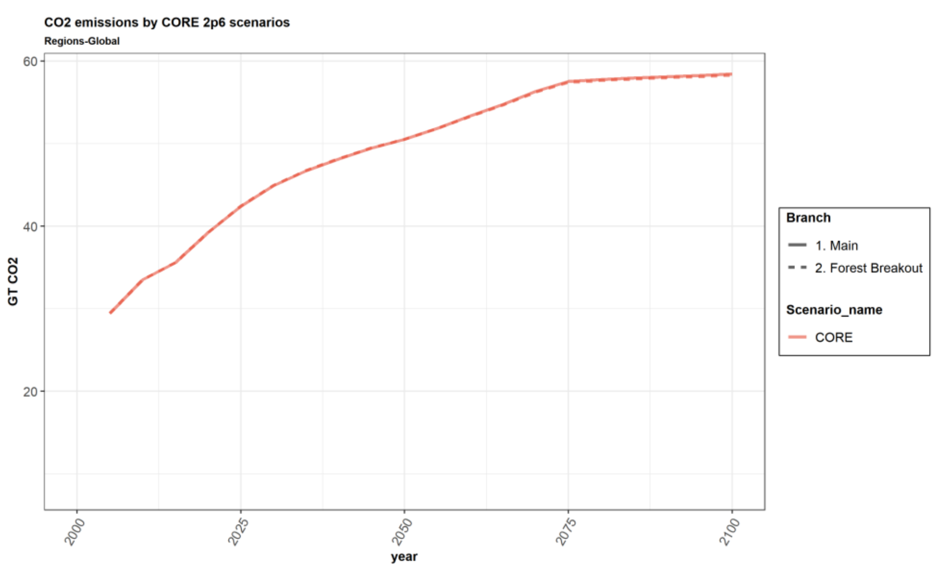

Figure 12: CO2 emissions globally

Global LUC emissions (Figure 13) trends remain the same with the forest breakout.

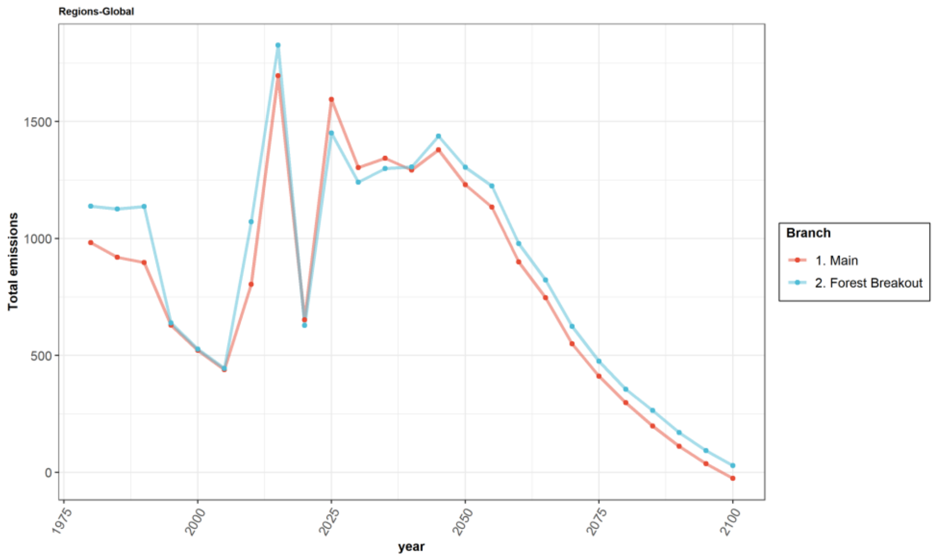

Figure 13: Global LUC emissions

SSP scenarios

Figure 14 shows the trends in global land allocation across SSP scenarios. The trends under the SSP scenarios largely follow the trend in the CORE scenarios, i.e., there is a decrease in managed forests along with an increase in land allocated to biomass production and unmanaged forests.

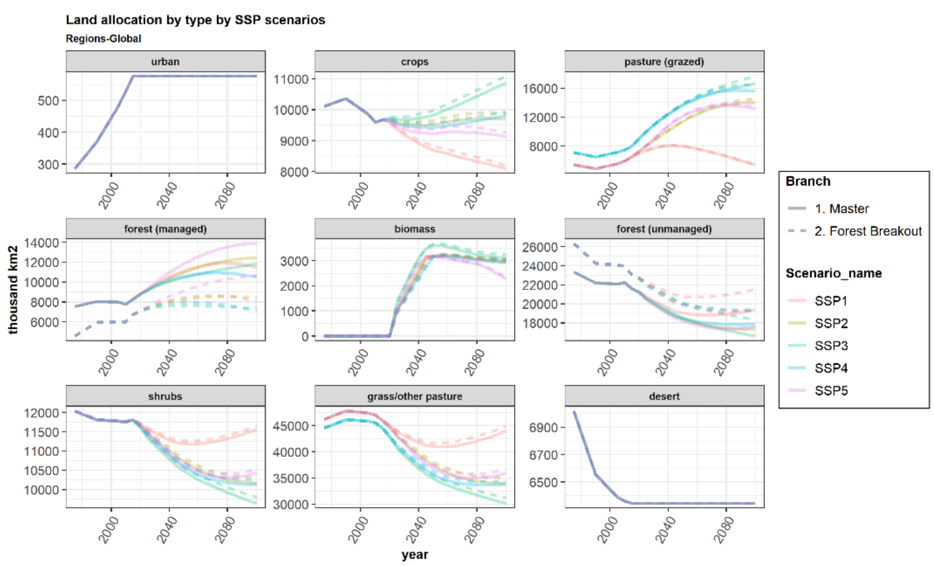

Figure 14: Global land allocation under SSP scenarios

Similarly, as seen in Figure 15, there is decrease in Forest (Industrial roundwood) production under all SSP scenarios similar to the CORE scenario.

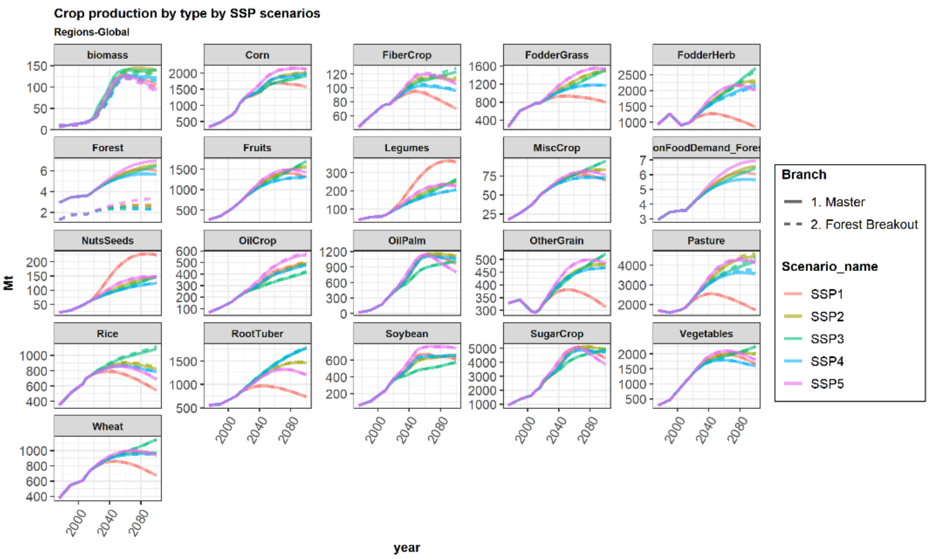

Figure 15: Global crop production by land type

There are no major changes in global primary energy consumption across SSP scenarios (Figure 16).

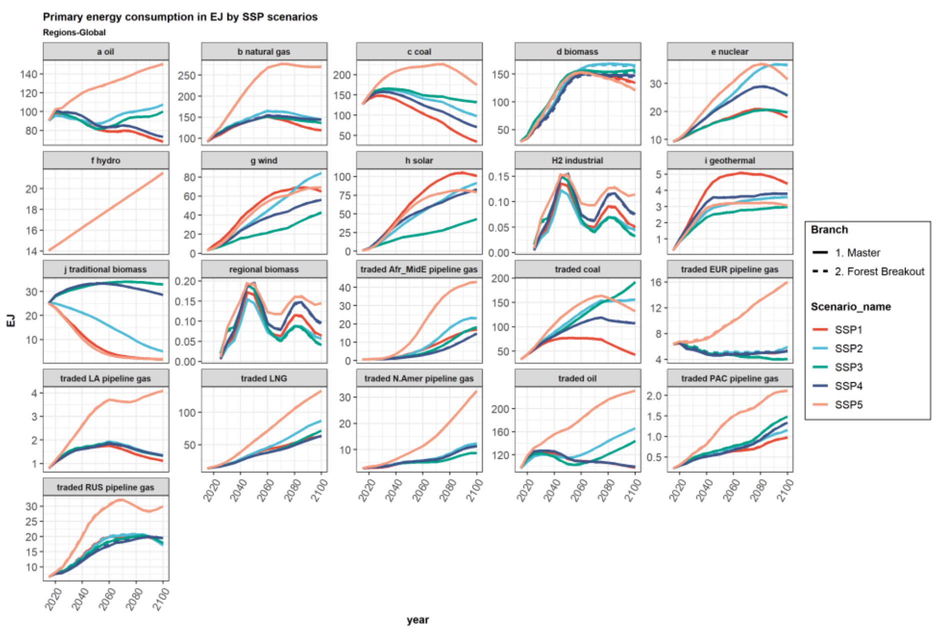

Figure 16: Global primary energy consumption under SSP scenarios

There are no major changes in Global CO2 emissions across SSP scenarios with the forest breakout (Figure 17)

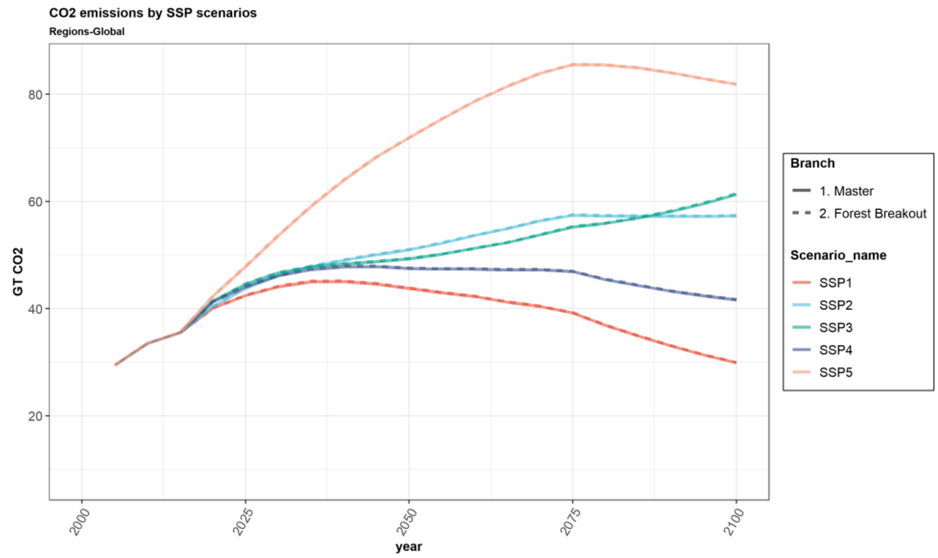

Figure 17: Global CO2 emissions by SSP

There is an increase observed in global LUC emissions (Figure 18) that is consistent with the increase observed for the CORE scenarios.

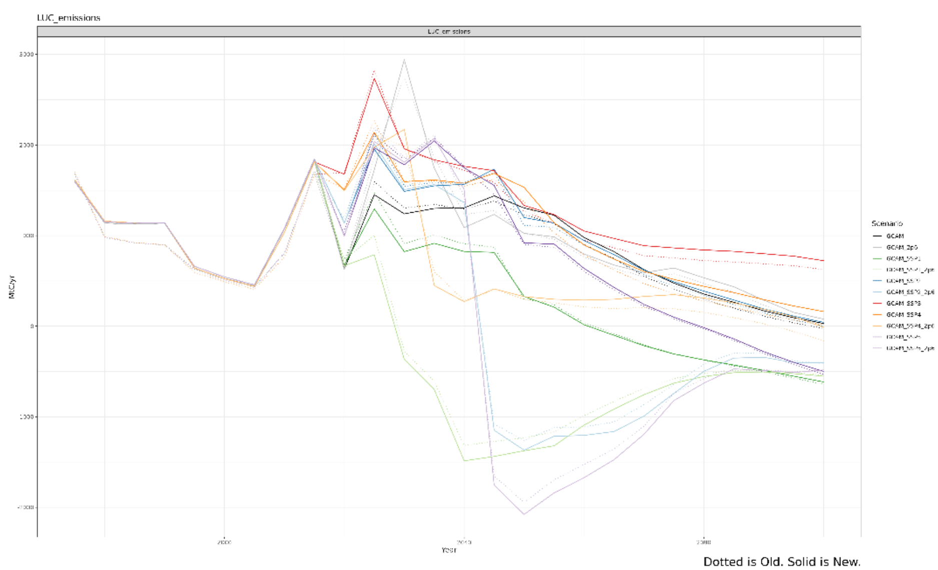

Figure 18: Global LUC emissions under the SSPs

Figure 23 below shows global climate forcing. No major changes are observed with the forest breakout.

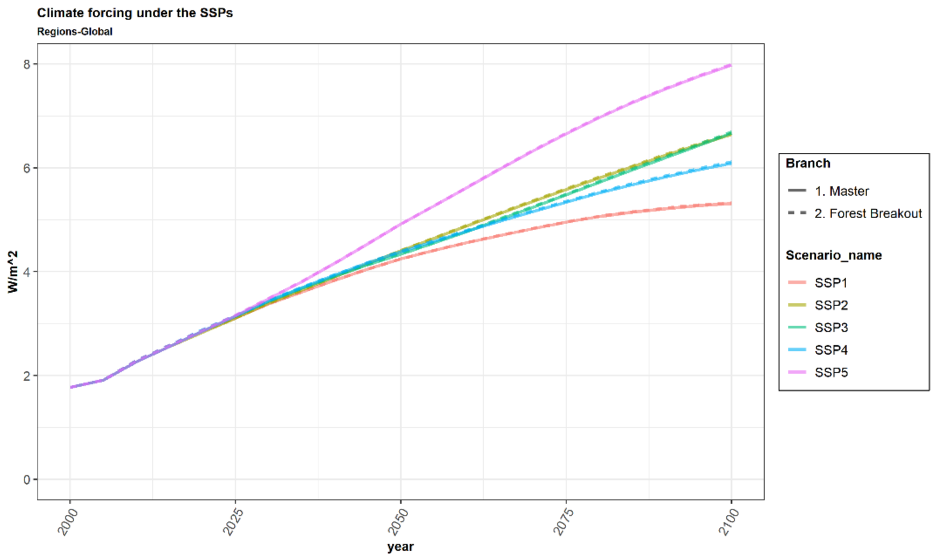

Figure 23: Climate forcing under the SSPs.

2p6 scenarios

Figures below show analysis for the 2p6 scenarios. The results generally follow trends observed under the SSPs and the CORE scenario. Figure 24 shows land allocation under the 2p6 scenarios.

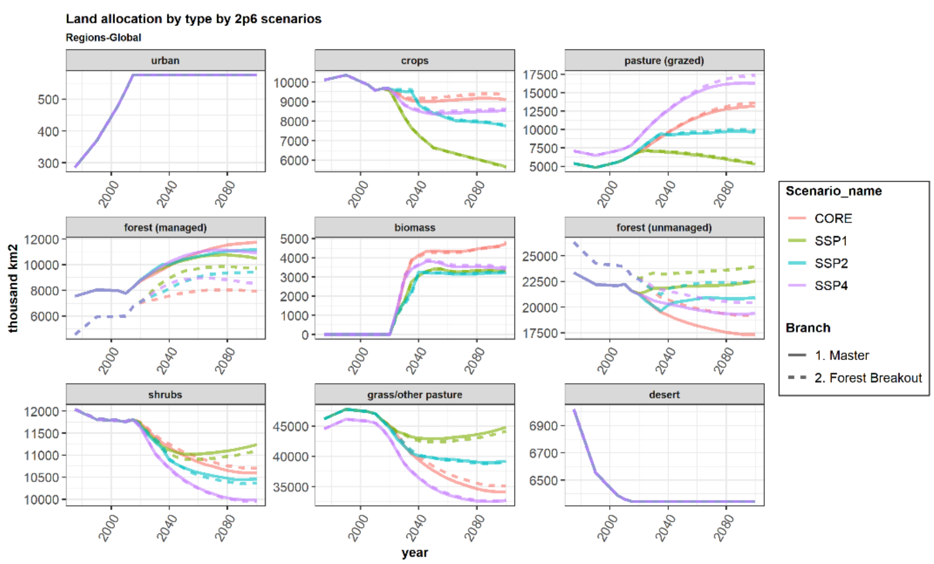

Figure 24: Land allocation under 2p6 scenarios

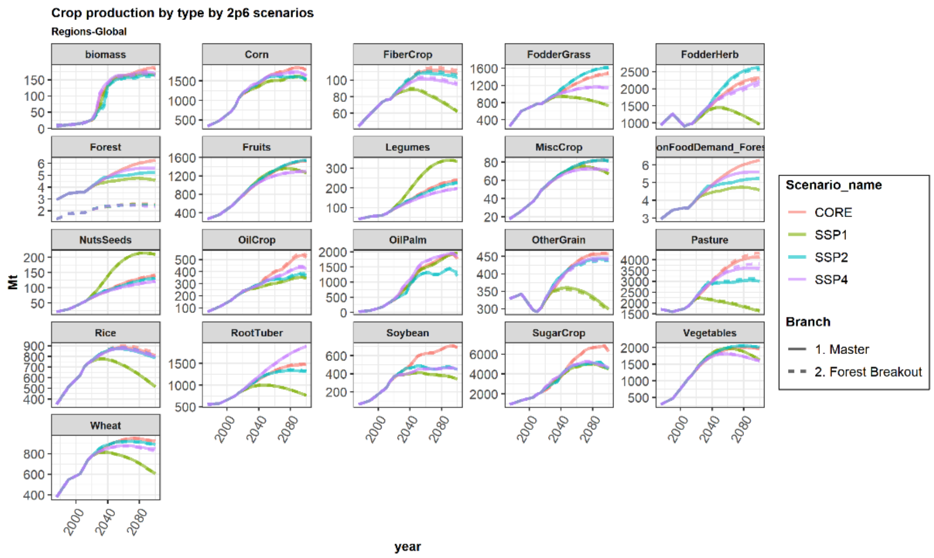

Figure 25: Crop production under 2p6 scenarios

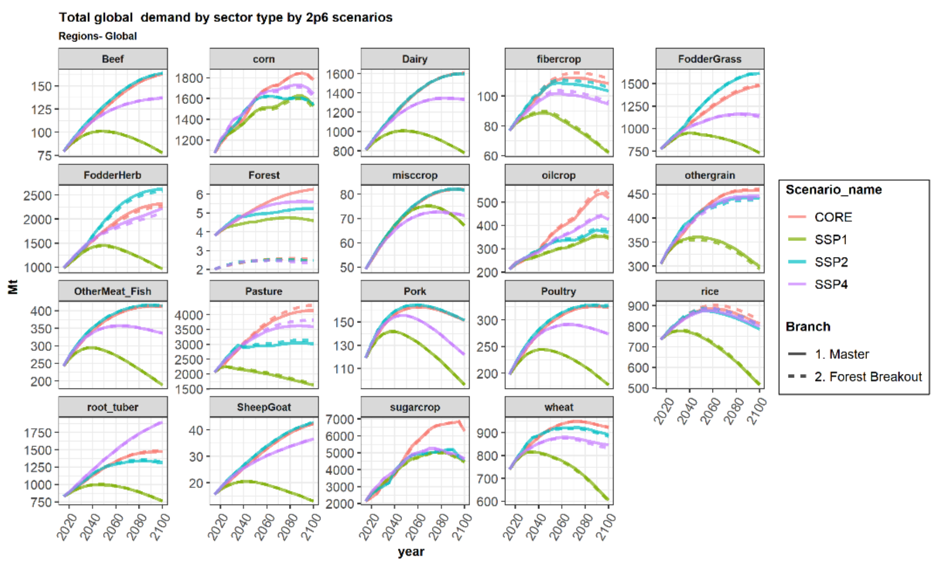

Figure 26: Global demand by commodity under 2p6 scenarios

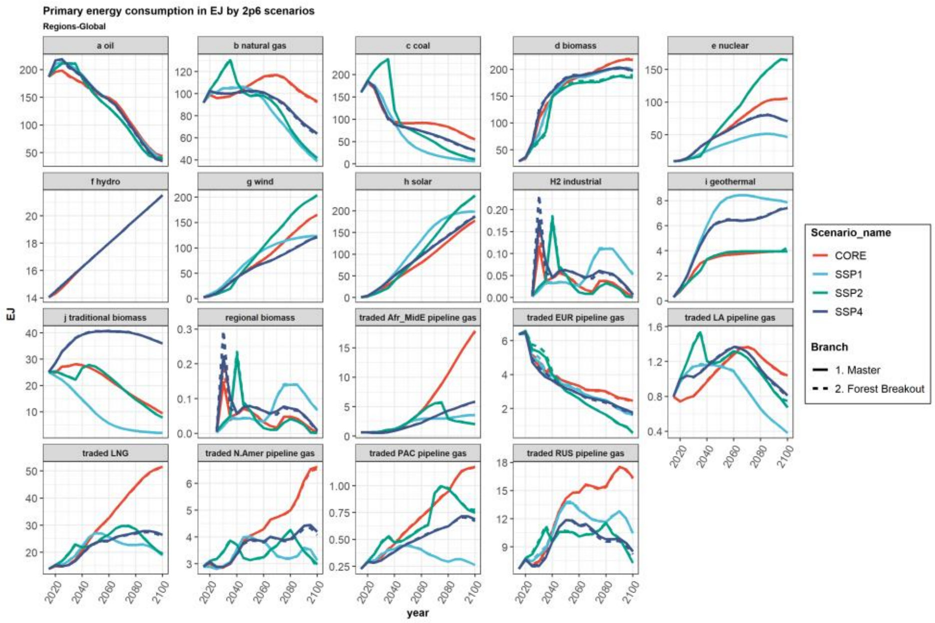

Figure 27: Primary energy consumption under 2p6 scenarios

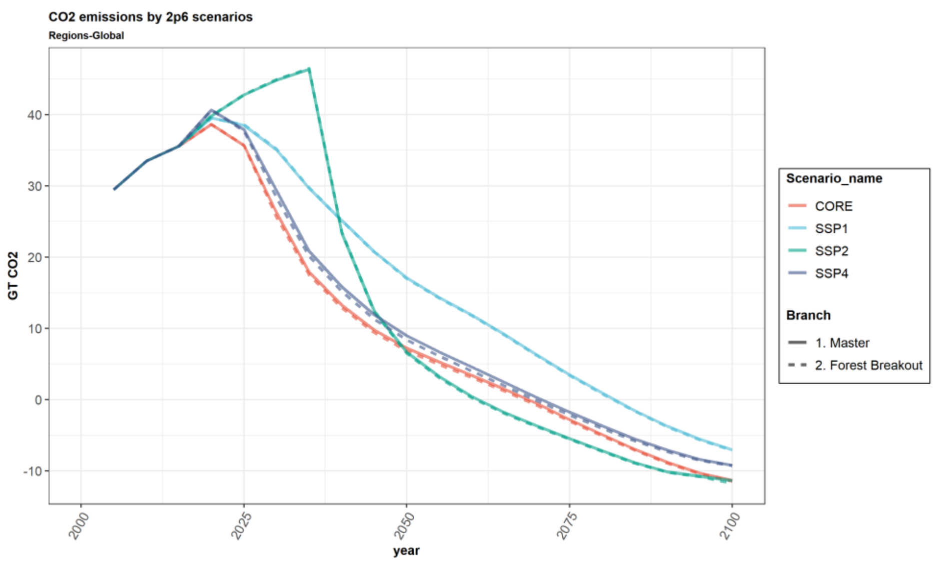

Figure 28: Global CO2 emissions under 2p6 scenarios

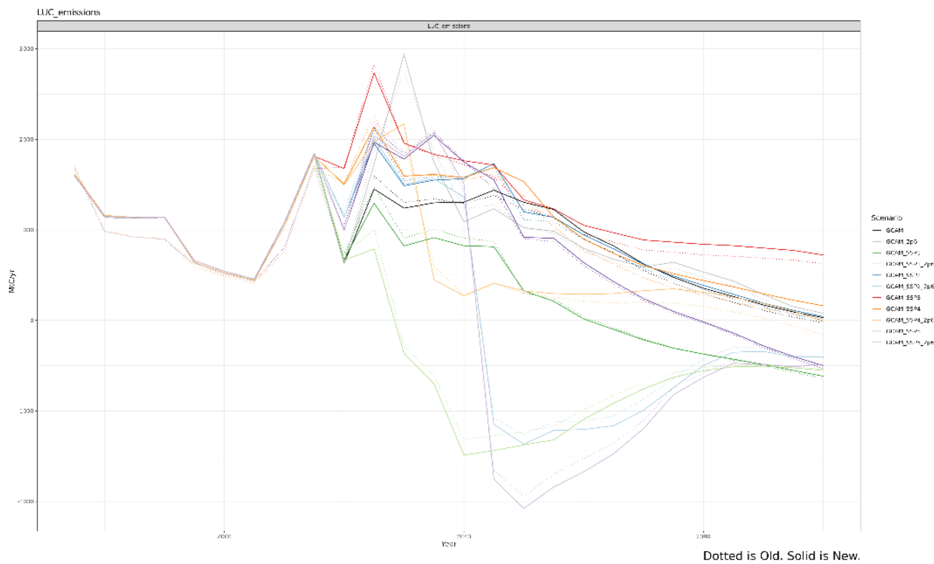

Figure 29: LUC emissions under 2p6 scenarios

Documentation Updates

References

1. Definition of wood fuel by FAO - https://www.fao.org/forestry/energy/en/
2. UWET discussion on FAO wood fuels- https://www.fao.org/3/j0926e/J0926e02.htm#TopOfPage
3. IMAGE documentation of Forestry module- https://models.pbl.nl/image/index.php/Traditional_biomass_from_non-forest_land
4. https://onlinelibrary.wiley.com/doi/pdf/10.1111/gcbb.13013
5. https://gmd.copernicus.org/preprints/gmd-2021-76/gmd-2021-76.pdf
6. UNECE report on forest conversion factors- https://unece.org/fileadmin/DAM/timber/publications/DP-49.pdf
7. https://www.sciencedirect.com/science/article/pii/S037811271500314X