Supplemental Material

Global biomass supply modeling for long-run management of the climate system

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Table SM1. Additional model specific details regarding alternative non-energy uses for residue feedstocks, land-based GHG mitigation, and land allocation mechanism

Model	Alternative non-energy uses for residue feedstocks		Land-based GHG mitigation				Land allocation mechanism
	Crop	Forest	Non-energy crops	Livestock	New forests	Existing forests	
AIM	To retain soil fertility, residue removal constrained to 80%	No alternative use for harvesting residues modeled, thinned wood is available, mill residues can be redirected from current wood processing heat and energy use	Fertilizer N_2O and rice field CH_4 mitigation based on marginal abatement curves	Manure CH_4 and N_2O mitigation based on marginal abatement curves	Afforestation carbon modeling considering planting, growth, management, and harvesting	Avoided deforestation determined by the value of protecting terrestrial carbon stocks relative to land rents and profits for alternative land uses	Nested logit function for allocation between crops, pasture, crop-forestry, agro-forest and grassland, forest managed/unmanaged, pastureland/grassland, and cropland used/unused
BET	Non-energy uses not modeled explicitly, but upper limits placed on energy use	Non-energy uses not modeled explicitly, but upper limits placed on energy use	Not modeled	Not modeled	Not modeled	Avoided deforestation is implemented as protecting mature forests (and allows for logging)	The land modeling component (GLUE) allows conversion between forest subcategories (natural, managed, and growing) and between cropland subcategories (energy crop and cereal), with total forest and cropland area determined exogenously, and pasture area fixed. The share of the forest subcategories is determined by industrial and fuelwood demands and the value placed on terrestrial carbon. The share of the cropland subcategories is determined by food demand, with the land needed for cereals production to provide for demand prioritized over energy crops.
DNE21+	Not modeled	Not modeled	Change in tillage carbon, fertilizer management N_2O, and rice cultivation CH_4 mitigation based on marginal abatement curves	Manure CH_4 & N_2O, enteric CH_4, and grazing intensity mitigation based on marginal abatement curves	Afforestation carbon modeling considering planting, growth, management, and harvesting	Avoided deforestation areas exogenously determined	Food and feed land allocation prioritized before biomass feedstock production or afforestation. Land allocation for biomass and afforestation based on energy system cost minimization using feedstock and afforestation supply curves and the acreage associated with the quantity of each supplied.

FARM	Crop residues not available as an energy feedstock	Non-energy uses not modeled	Not modeled (except carbon taxes affect fertilizer use in agriculture)	Not modeled	Afforestation is based on economic returns to land in forests relative to competing land uses. Drivers include income-driven demand for forest products and rates of yield growth for forests relative to crops.	Not modeled	Arable land is allocated within each Agro-Ecological Zone (AEZ) until rates of return per hectare are equalized across competing uses
GCAM	To retain soil fertility, for each crop, a minimum mass per hectare must be left in place to retain soil fertility (not a percent)	No alternative uses for harvesting residues modeled	Fertilizer production emissions affected by carbon price, mitigation of N_2O from fertilizers and CH_4 from rice production based on marginal abatement curves	Manure CH_4 and N_2O and enteric fermentation CH_4 and N_2O mitigation based on marginal abatement curves	Afforestation for carbon sequestration based on relative profitability, compared to opportunity cost for other uses, considering time for forest and carbon growth	Carbon value of existing forests is weighed against alternative use of the land	Arable land allocated based on relative profitability for all commercial uses and implicit value for natural or non-commercial uses using a nested logit structure
GLOBIOM	Crop residues not available as an energy feedstock	Logging residues (branches, stumps, harvest losses) exclusively used for energy production. Competition for energy and material use of forest industry by-products and roundwood modeled.	Fertilizer management, rice cultivation mitigation based on structural shifts (crop production systems, trade, regional product composition), and mitigation options based on US EPA mitigation options database, and production and demand price responses	Manure CH_4 and N_2O and enteric CH_4 mitigation based on structural shifts (livestock production systems, trade, regional product composition), and mitigation based on the US EPA mitigation options database, and production and demand price responses	Afforestation carbon gains based on modeling planting, growth, management, and harvesting of new forests in G4M that is connected to GLOBIOM. Afforestation decisions based on net present value of forestry versus alternative land uses.	Avoided deforestation, forest carbon based on modeling planting, growth, management, and harvesting of existing forests in G4M that is connected to GLOBIOM. Deforestation decisions based on net present value of forests versus alternative land uses.	Land conversion from one land cover type to another takes place if the marginal revenue of the new production activity exceeds the marginal land conversion cost of the current activity. Land conversion is determined for each Supply Unit within the available land resources with an increasing conversion cost based on area of land converted, and conversion restricted by biophysical land suitability, production potentials, and a matrix of potential land cover transitions.

GRAPE	Not modeled	Not modeled	Fertilizer management N_2O and rice CH_4 mitigation based on marginal abatement curves. Soil carbon sequestration strategies not modeled.	Manure N_2O and CH_4 and enteric CH_4 mitigation based on marginal abatement curves	Carbon gains based on forest re-growth. A price on CO_2 emissions serves as economic incentive for afforestation and reforestation relative to alternative use.	Carbon value of existing forests is weighed against alternative use of the land	Land allocation determined by relative returns, but food and feed land prioritized
IMAGE	To retain soil fertility, 350t/km^2 of residues must remain on the field. Also, some residues diverted for livestock feed, depending on livestock production and feed module, and some residues diverted for energetic use as traditional biomass on poor households.	To retain soil fertility, 30-50% (depending on biome and forest management type) of residues have to remain in the forest. Also, some residues diverted for energetic use as traditional biomass on poor households.	Mitigation based on marginal abatement curves	Mitigation based on marginal abatement curves	Afforestation areas exogenously identified. For reforestation, planting and growth simulated using the LPJml DGVM. Assumed available at zero cost once climate policy is applied.	Avoided deforestation areas exogenously identified. Assumed available at zero cost once climate policy is applied.	Food and feed land prioritized, forest land exogenous, followed by grid cell ranking accounting for productivity, topography, climate, soil and water availability
MAgPIE 3.1	Crop residues not available in MAgPIE 3.1	Forest residues not available in MAgPIE 3.1	Fertilizer N_2O and rice CH_4 mitigation based on marginal abatement curves. Soil carbon sequestration strategies not modeled.	Manure CH_4 and N_2O and enteric CH_4 mitigation based on marginal abatement curves	Afforestation is based on re-growth curves for natural vegetation. A price on CO_2 emissions serves as economic incentive for afforestation relative to alternative use.	A price on CO_2 emissions serves as economic incentive for reducing deforestation and loss of other natural land	Land allocation based on recursive-dynamic cost minimization approach. The objective function of the model is to minimize total cost of production for a given amount of regional food and bioenergy demand. The production of crops and livestock commodities is associated with costs for labor, capital, land conversion, yield increases, and international trade. The cost minimization is constrained by spatially explicit data on crop yields as well as land and water availability.

NLU	Only 30% of residue supply is available for energy. For soil fertility, 40% retained on soils, and another 30% globally used for other purposes besides energy (e.g., feed, fiber housing).	Only 50% of residue supply is available for energy. The other 50% is assumed to be used as fuel or fiber feedstock in the pulp and paper industry.	Fertilizer management N_2O mitigation based on emissions substitution (with the substitution parameter calibrated to external costs)	Manure CH_4 & N_2O and enteric CH_4 mitigation based on emissions substitution (with the substitution parameter calibrated to external costs)	Afforestation and reforestation determined exogenously with carbon gains based on a vegetation model, land conversion type, and alternative forest land assumptions (e.g., no deforestation, baseline deforestation)	Avoided deforestation determined exogenously with avoided carbon losses based on a vegetation model, land conversion type, and alternative forest land assumptions (e.g., no deforestation, baseline deforestation)	Cropland, pasture, and biomass feedstock land allocation based on relative returns

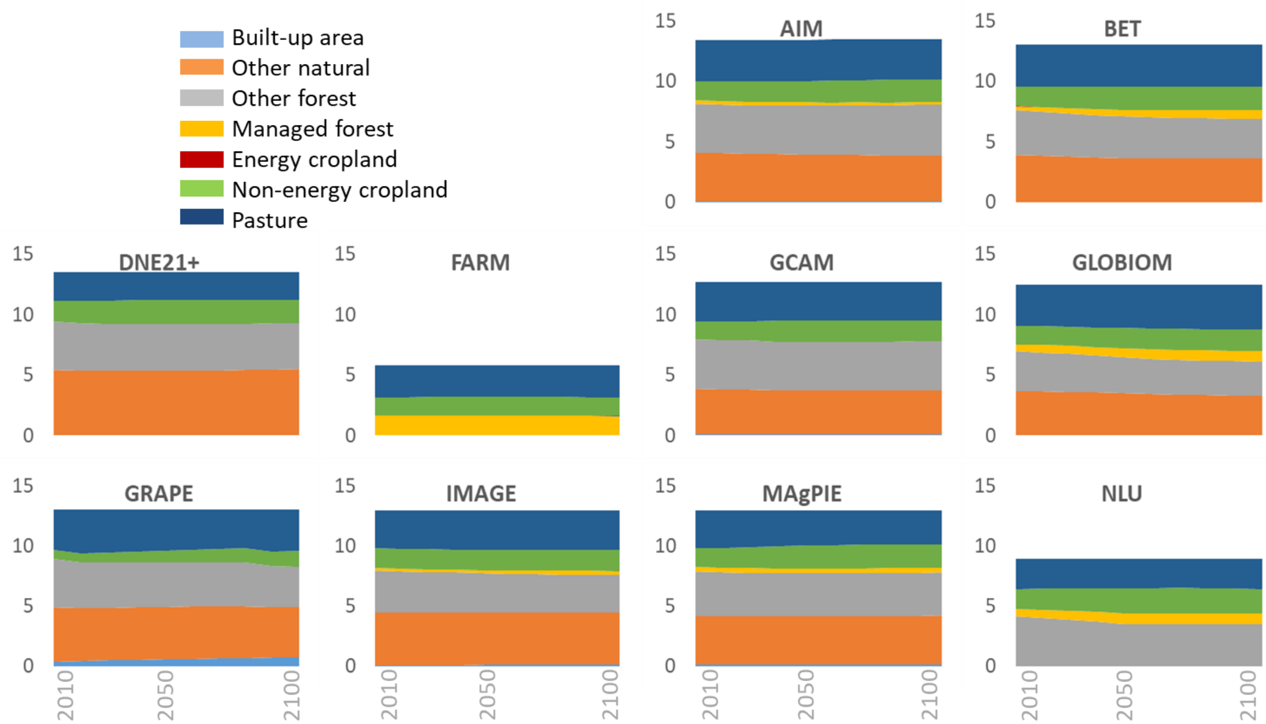

Figure SM1. Baseline global land cover (billion hectares)

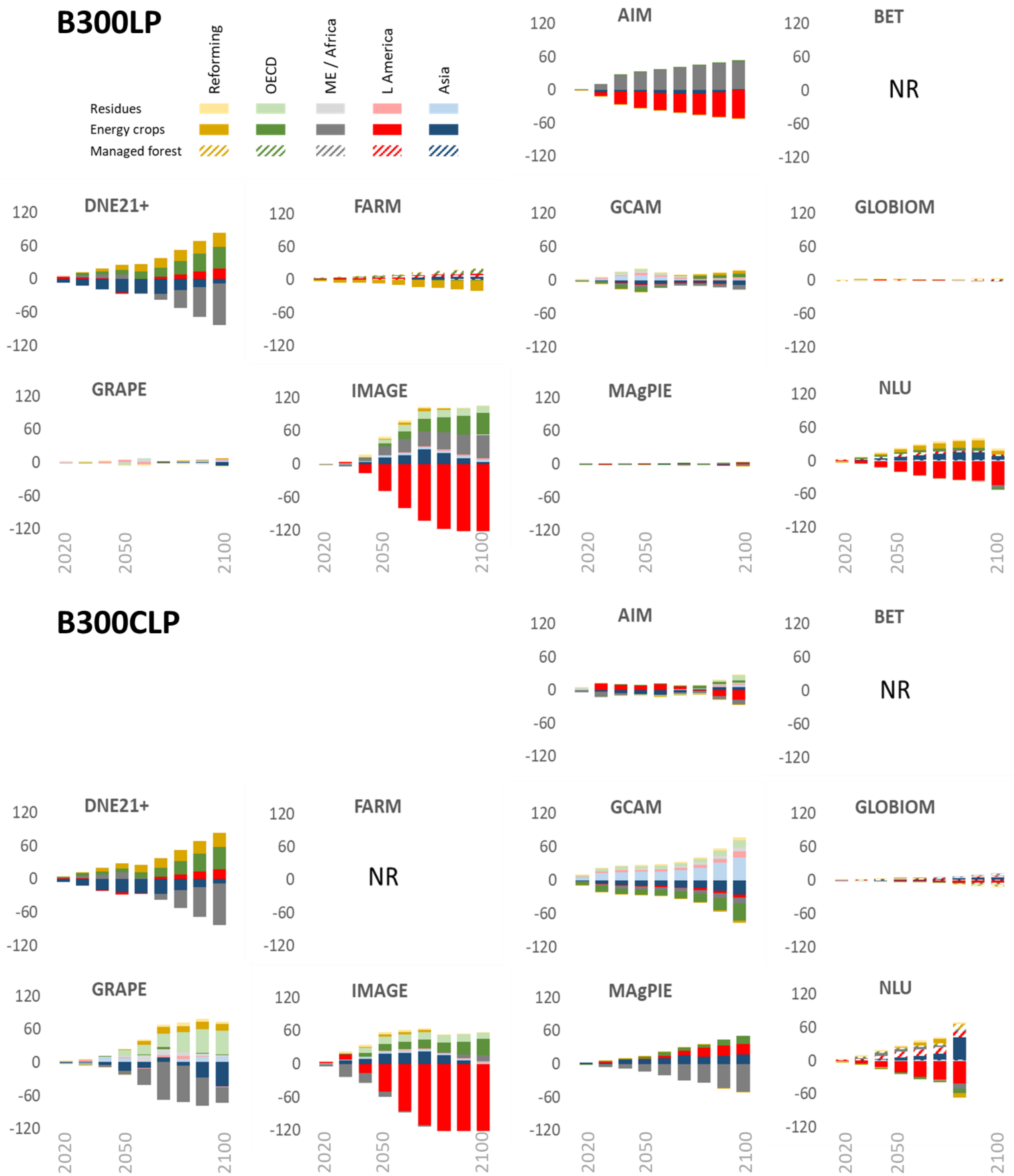

Figure SM2. Changes in feedstock supply due to model land protection assumptions (B300LP) and the combination of land GHG mitigation and protection (B300CLP) for the 300 EJ/year supply scenario (EJ per year). *Note: IMAGE and NLU could not meet the rising annual biomass supply requirement in the land protection scenarios (B300LP and B300CLP), which results in feedstock changes that are not offsetting (or no results being reported for NLU in B300CLP for 2090 and 2100). BET did not run B300LP and B300CLP. FARM did not run B300CLP.*

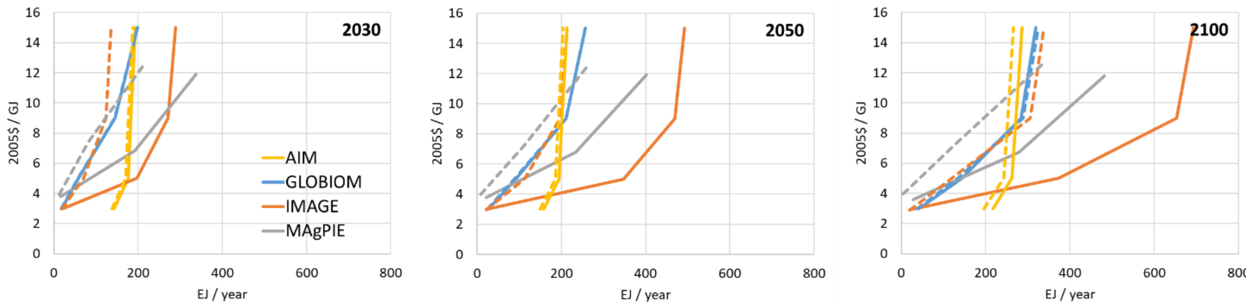

Figure SM3. Estimated global supply of modern biomass feedstocks at farmgate prices without and with land GHG mitigation incentives (solid = without GHG mitigation incentives, dashed = with GHG mitigation incentives). *Note: FARM is not shown because it did not run the biomass price scenarios with land GHG mitigation.*

Table SM2. Estimated 2050 regional energy crop acreage, supply, share of total biomass supply, and average yield with $5 and $9 per GJ biomass prices

Biomass price $5/GJ (2005$)

		Asia	**L America**	**ME / Africa**	**OECD**	**Reforming**
AIM	Energy crop acreage (million ha)	57	190	160	2	17
	Energy crop supply (EJ/year)	20	111	59	0	1
	Energy crop share of biomass supply	96%	100%	99%	15%	83%
	Yield (GJ/ha)	350	585	370	134	71
FARM	Energy crop acreage (million ha)	23	92	5	165	186
	Energy crop supply (EJ/year)	12	67	3	119	166
	Energy crop share of biomass supply	87%	98%	94%	98%	100%
	Yield (GJ/ha)	537	724	657	719	894
GLOBIOM	Energy crop acreage (million ha)	80	69	56	0	5
	Energy crop supply (EJ/year)	21	21	13	0	1
	Energy crop share of biomass supply	74%	76%	49%	0%	12%
	Yield (GJ/ha)	263	300	225	n/a	109
IMAGE	Energy crop acreage (million ha)	155	548	301	114	208
	Energy crop supply (EJ/year)	55	150	78	11	19
	Energy crop share of biomass supply	76%	99%	97%	59%	72%
	Yield (GJ/ha)	352	274	258	92	90
MAgPIE	Energy crop acreage (million ha)	8	26	12	6	0
	Energy crop supply (EJ/year)	4	11	3	4	0
	Energy crop share of biomass supply	100%	100%	100%	100%	n/a
	Yield (GJ/ha)	537	408	268	652	n/a

Biomass price $9/GJ (2005$)

		Asia	L America	ME / Africa	OECD	Reforming
AIM	Energy crop acreage (million ha)	66	203	180	3	27
	Energy crop supply (EJ/year)	21	115	61	0	1
	Energy crop share of biomass supply	96%	100%	99%	24%	86%
	Yield (GJ/ha)	320	564	339	177	56
FARM	Energy crop acreage (million ha)	148	148	104	254	226
	Energy crop supply (EJ/year)	93	133	125	225	257
	Energy crop share of biomass supply	98%	99%	100%	99%	100%
	Yield (GJ/ha)	628	897	1194	883	1139
GLOBIOM	Energy crop acreage (million ha)	116	114	73	71	32
	Energy crop supply (EJ/year)	30	33	15	13	3
	Energy crop share of biomass supply	63%	46%	32%	42%	24%
	Yield (GJ/ha)	254	284	211	188	97
IMAGE	Energy crop acreage (million ha)	254	581	358	633	359
	Energy crop supply (EJ/year)	76	159	84	56	51
	Energy crop share of biomass supply	80%	99%	99%	79%	88%
	Yield (GJ/ha)	300	273	234	89	141
MAgPIE	Energy crop acreage (million ha)	89	233	282	120	2
	Energy crop supply (EJ/year)	40	73	75	46	0
	Energy crop share of biomass supply	100%	100%	100%	100%	100%
	Yield (GJ/ha)	454	314	264	382	77

Table SM3. Various integrated modeling global results from the standardized climate management scenario consistent with limiting global average warming to 2˚C. *Note: Blanks indicate results not reported. Non-energy crop prices unchanged in IMAGE due to an assumption that allocates land to food first.*

Model	2100 modern biomass primary energy	Cumulative land CO_2 2010-2100	Cumulative land N_2O 2010-2100	2050 GHG price	2050 non-energy crop price change above baseline
	EJ/yr	$GtCO_2$	$GtCO_2eq$	2005\$/tCO_2	%
AIM	176	20.7	144.8	$ 304	44%
BET	302	308.0		$ 340	
DNE21+	303	-37.5	225.3	$ 311	
FARM	415	27.1		$ 628	12%
GCAM	293	-920.4	0.2	$ 242	539%
MESSAGE-GLOBIOM	222	-110.5	156.3	$ 104	
GRAPE	284	116.7	1264.9	$ 267	2%
IMAGE	155	340.0	222.9	$ 304	0%
REMIND-MAgPIE	424	207.1	214.6	$ 135	
IMACLIM-NLU	87	4.6	320.0	$ 1,260	2378%