Supplement 1: Selected Baseline Results

Table 1: Baseline projections for land use, agricultural and forestry commodity production, and emissions across SSPs in 2035, 2055, and 2065

Measure Category	Measure	SSP	Scenario	2035	2055	2065
Land use (1000 ha)	Forest	SSP1 - Sustainability	Baseline	261,514	264,659	264,205
			$20at3%	280,463	290,812	295,774
		SSP2 - Middle of the Road	Baseline	257,904	259,588	259,043
			$20at3%	277,598	288,168	293,987
		SSP3 - Regional Rivalry	Baseline	251,318	250,248	249,695
			$20at3%	275,763	290,771	296,623
		SSP4 - Inequality	Baseline	254,442	258,338	258,247
			$20at3%	273,580	286,039	293,655
		SSP5 - Fossil-fueled Development	Baseline	269,715	270,959	269,980
			$20at3%	277,790	284,252	286,277
	Cropland	SSP1 - Sustainability	Baseline	122,844	112,052	107,688
			$20at3%	114,525	102,256	96,848
		SSP2 - Middle of the Road	Baseline	126,498	116,012	111,911
			$20at3%	120,053	107,503	101,126
		SSP3 - Regional Rivalry	Baseline	128,483	116,557	110,944
			$20at3%	124,860	109,258	103,407
		SSP4 - Inequality	Baseline	131,644	119,595	116,332
			$20at3%	126,498	113,264	105,650
		SSP5 - Fossil-fueled Development	Baseline	120,273	111,047	108,514
			$20at3%	117,231	107,347	103,042
	Other Agriculture Area	SSP1 - Sustainability	Baseline	65,316	70,667	74,962
			$20at3%	54,686	54,309	54,233
		SSP2 - Middle of the Road	Baseline	65,186	71,541	75,532

			$20at3%	51,938	51,470	51,373
		SSP3 - Regional Rivalry	Baseline	70,624	82,876	89,042
			$20at3%	49,802	49,652	49,652
		SSP4 - Inequality	Baseline	64,076	71,112	74,466
			$20at3%	50,085	49,743	49,740
		SSP5 - Fossil-fueled Development	Baseline	59,117	63,240	65,208
			$20at3%	54,083	53,647	54,384
	Developed land	SSP1 - Sustainability	Baseline	4,171	6,467	6,990
			$20at3%	4,171	6,467	6,990
		SSP2 - Middle of the Road	Baseline	4,256	6,704	7,359
			$20at3%	4,256	6,704	7,359
		SSP3 - Regional Rivalry	Baseline	3,421	4,164	4,164
			$20at3%	3,421	4,164	4,164
		SSP4 - Inequality	Baseline	3,683	4,800	4,800
			$20at3%	3,683	4,800	4,800
		SSP5 - Fossil-fueled Development	Baseline	4,740	8,599	10,142
			$20at3%	4,740	8,599	10,142
Agricultural commodity	Corn	SSP1 - Sustainability	Baseline	428,867	468,536	479,574
			$20at3%	415,962	449,960	463,567

production (1000 mt)		SSP2 - Middle of the Road	Baseline	433,750	482,218	499,458
			$20at3%	423,186	462,737	474,515
		SSP3 - Regional Rivalry	Baseline	407,817	434,016	440,675
			$20at3%	395,070	415,979	419,221
		SSP4 - Inequality	Baseline	442,274	483,746	496,578
			$20at3%	434,651	462,966	470,046
		SSP5 - Fossil-fueled Development	Baseline	483,304	586,413	639,235
			$20at3%	476,081	569,323	607,418
	Soybeans	SSP1 - Sustainability	Baseline	146,888	150,276	154,227
			$20at3%	128,574	128,890	120,811
		SSP2 - Middle of the Road	Baseline	143,847	148,415	153,985
			$20at3%	128,361	123,872	117,879
		SSP3 - Regional Rivalry	Baseline	129,382	131,245	131,022
			$20at3%	120,900	109,302	104,586
		SSP4 - Inequality	Baseline	140,400	145,657	149,667
			$20at3%	126,792	121,852	113,123
		SSP5 - Fossil-fueled Development	Baseline	144,639	146,350	149,311
			$20at3%	135,015	133,679	129,013
	Wheat	SSP1 - Sustainability	Baseline	109,147	119,289	122,948
			$20at3%	104,994	110,484	108,143
		SSP2 - Middle of the Road	Baseline	108,841	118,776	121,939

		$20at3%	104,229	108,122	110,419
	SSP3 - Regional Rivalry	Baseline	98,340	104,288	106,944
		$20at3%	93,522	93,071	94,972
	SSP4 - Inequality	Baseline	108,841	116,711	120,909
		$20at3%	104,881	106,631	110,363
	SSP5 - Fossil-fueled Development	Baseline	119,101	126,645	128,832
		$20at3%	115,855	119,008	126,428
Beef	SSP1 - Sustainability	Baseline	13,584	14,845	15,492
		$20at3%	13,123	13,804	14,150
	SSP2 - Middle of the Road	Baseline	13,880	15,123	15,989
		$20at3%	13,177	14,117	14,437
	SSP3 - Regional Rivalry	Baseline	13,243	14,039	14,317
		$20at3%	12,459	12,905	13,100
	SSP4 - Inequality	Baseline	14,130	15,089	15,722
		$20at3%	13,439	14,160	14,439
	SSP5 - Fossil-fueled Development	Baseline	14,993	16,866	17,968
		$20at3%	14,359	15,839	16,173

Chicken	SSP1 - Sustainability	Baseline	17,057	18,677	19,431
		$20at3%	16,922	18,442	18,748
	SSP2 - Middle of the Road	Baseline	17,752	19,873	20,933
		$20at3%	17,532	19,429	20,205
	SSP3 - Regional Rivalry	Baseline	16,544	17,398	17,781
		$20at3%	16,544	17,132	17,101
	SSP4 - Inequality	Baseline	18,772	20,496	21,403
		$20at3%	18,625	20,189	20,444
	SSP5 - Fossil-fueled Development	Baseline	20,883	27,318	31,176
		$20at3%	20,207	26,211	29,541
Pork	SSP1 - Sustainability	Baseline	16,969	18,817	19,440
		$20at3%	16,488	17,567	18,099
	SSP2 - Middle of the Road	Baseline	17,488	19,525	20,460
		$20at3%	16,856	18,256	18,877
	SSP3 - Regional Rivalry	Baseline	16,225	17,312	17,715
		$20at3%	15,625	16,205	16,341
	SSP4 - Inequality	Baseline	18,080	20,018	20,751

			$20at3%	17,532	18,554	18,797
		SSP5 - Fossil-fueled Development	Baseline	20,339	25,879	28,879
			$20at3%	19,845	23,163	25,865
Agricultural commodity demand (1000 mt)	Corn	SSP1 - Sustainability	Baseline	56,470	67,017	72,898
			$20at3%	55,937	65,765	71,548
		SSP2 - Middle of the Road	Baseline	59,627	72,422	78,985
			$20at3%	59,627	71,056	76,604
		SSP3 - Regional Rivalry	Baseline	53,378	57,926	60,263
			$20at3%	52,860	56,823	59,126
		SSP4 - Inequality	Baseline	62,652	70,862	75,552
			$20at3%	62,044	68,837	73,414
		SSP5 - Fossil-fueled Development	Baseline	73,353	102,273	121,236
			$20at3%	72,654	102,273	120,047
	Soybeans	SSP1 - Sustainability	Baseline	8,946	10,801	11,776
			$20at3%	8,685	10,492	11,220
		SSP2 - Middle of the Road	Baseline	8,800	10,480	11,190
			$20at3%	8,541	9,981	10,444

	SSP3 - Regional Rivalry	Baseline		8,320		9,615	10,394	
		$20at3%		8,157		9,338		9,800
	SSP4 - Inequality	Baseline		8,865	10,485		11,386	
		$20at3%		8,601		9,976	10,729	
	SSP5 - Fossil-fueled Development	Baseline		9,081	11,640		12,978	
		$20at3%		8,899	11,522		12,713	
Wheat	SSP1 - Sustainability	Baseline	32,720		36,294		37,854	
		$20at3%	32,484		35,802		37,566	
	SSP2 - Middle of the Road	Baseline	35,086		39,325		41,281	
		$20at3%	34,851		38,709		40,617	
	SSP3 - Regional Rivalry	Baseline	31,668		31,753		31,883	
		$20at3%	31,445		31,320		31,334	
	SSP4 - Inequality	Baseline	36,851		38,547		39,699	
		$20at3%	36,639		38,064		39,105	
	SSP5 - Fossil-fueled Development	Baseline	42,492		55,703		64,229	
		$20at3%	42,337		55,703		63,611	
Beef	SSP1 - Sustainability	Baseline	11,333		12,261		12,741	

		$20at3%	10,872	11,220	11,399
	SSP2 - Middle of the Road	Baseline	11,629	12,539	13,238
		$20at3%	10,926	11,533	11,870
	SSP3 - Regional Rivalry	Baseline	11,161	11,648	11,773
		$20at3%	10,377	10,515	10,555
	SSP4 - Inequality	Baseline	11,823	12,440	12,903
		$20at3%	11,132	11,687	11,807
	SSP5 - Fossil-fueled Development	Baseline	12,629	14,695	15,869
		$20at3%	12,153	13,777	14,227
Chicken	SSP1 - Sustainability	Baseline	12,636	13,720	14,206
		$20at3%	12,546	13,584	13,784
	SSP2 - Middle of the Road	Baseline	13,332	14,916	15,708
		$20at3%	13,200	14,621	15,241
	SSP3 - Regional Rivalry	Baseline	12,537	12,859	12,996
		$20at3%	12,537	12,730	12,606
	SSP4 - Inequality	Baseline	14,286	15,466	16,101
		$20at3%	14,230	15,311	15,463

		SSP5 - Fossil-fueled Development	Baseline	16,334	22,581	26,348
			$20at3%	15,844	21,735	25,097
	Pork	SSP1 - Sustainability	Baseline	11,690	12,891	13,190
			$20at3%	11,218	11,661	11,871
		SSP2 - Middle of the Road	Baseline	12,210	13,598	14,210
			$20at3%	11,587	12,350	12,660
		SSP3 - Regional Rivalry	Baseline	11,359	11,840	11,944
			$20at3%	10,768	10,753	10,603
		SSP4 - Inequality	Baseline	12,675	13,950	14,352
			$20at3%	12,136	12,507	12,707
		SSP5 - Fossil-fueled Development	Baseline	14,800	19,670	22,342
			$20at3%	14,314	18,565	21,028
Agricultural commodity exports (1000 mt)	Corn	SSP1 - Sustainability	Baseline	36,469	34,690	32,781
			$20at3%	34,723	31,452	30,252
		SSP2 - Middle of the Road	Baseline	34,562	32,909	31,429
			$20at3%	33,223	29,128	27,344
		SSP3 - Regional Rivalry	Baseline	28,203	27,171	25,999

		$20at3%	26,256	23,745	23,164
	SSP4 - Inequality	Baseline	34,408	34,087	33,161
		$20at3%	33,799	30,174	29,519
	SSP5 - Fossil-fueled Development	Baseline	38,751	32,679	29,779
		$20at3%	38,257	31,662	27,969
Soybeans	SSP1 - Sustainability	Baseline	33,559	33,512	32,290
		$20at3%	29,192	28,823	26,101
	SSP2 - Middle of the Road	Baseline	32,567	32,303	31,896
		$20at3%	27,144	27,582	22,890
	SSP3 - Regional Rivalry	Baseline	28,057	27,513	26,598
		$20at3%	24,938	23,226	20,320
	SSP4 - Inequality	Baseline	34,140	34,210	34,927
		$20at3%	29,617	27,831	25,838
	SSP5 - Fossil-fueled Development	Baseline	32,306	30,191	26,946
		$20at3%	29,828	28,061	22,956
Wheat	SSP1 - Sustainability	Baseline	44,128	47,478	48,290
		$20at3%	42,660	44,671	45,867

	SSP2 - Middle of the Road	Baseline	43,353	46,722	47,406
		$20at3%	41,273	44,010	44,158
	SSP3 - Regional Rivalry	Baseline	37,070	39,998	41,387
		$20at3%	35,728	37,388	37,911
	SSP4 - Inequality	Baseline	43,925	47,949	49,239
		$20at3%	43,380	45,195	46,819
	SSP5 - Fossil-fueled Development	Baseline	46,355	46,105	44,389
		$20at3%	45,584	46,064	43,959
Beef	SSP1 - Sustainability	Baseline	2,251	2,584	2,751
		$20at3%	2,251	2,584	2,751
	SSP2 - Middle of the Road	Baseline	2,251	2,584	2,751
		$20at3%	2,251	2,584	2,568
	SSP3 - Regional Rivalry	Baseline	2,082	2,391	2,545
		$20at3%	2,082	2,391	2,545
	SSP4 - Inequality	Baseline	2,307	2,649	2,820
		$20at3%	2,307	2,472	2,632
	SSP5 - Fossil-fueled Development	Baseline	2,363	2,171	2,099
		$20at3%	2,206	2,062	1,945
Chicken	SSP1 - Sustainability	Baseline	4,421	4,957	5,225

			$20at3%	4,376	4,858	4,964
		SSP2 - Middle of the Road	Baseline	4,421	4,957	5,225
			$20at3%	4,332	4,808	4,964
		SSP3 - Regional Rivalry	Baseline	4,007	4,539	4,785
			$20at3%	4,007	4,402	4,495
		SSP4 - Inequality	Baseline	4,486	5,030	5,302
			$20at3%	4,395	4,878	4,981
		SSP5 - Fossil-fueled Development	Baseline	4,549	4,736	4,828
			$20at3%	4,363	4,476	4,444
	Pork	SSP1 - Sustainability	Baseline	5,390	6,058	6,393
			$20at3%	5,390	6,058	6,393
		SSP2 - Middle of the Road	Baseline	5,390	6,058	6,393
			$20at3%	5,390	6,058	6,393
		SSP3 - Regional Rivalry	Baseline	4,985	5,604	5,913
			$20at3%	4,985	5,604	5,913
		SSP4 - Inequality	Baseline	5,524	6,210	6,552
			$20at3%	5,524	6,210	6,265
		SSP5 - Fossil-fueled Development	Baseline	5,659	6,361	6,712
			$20at3%	5,659	4,771	5,034
Forest product production	Lumber (1000 m3)	SSP1 - Sustainability	Baseline	107,524	121,092	139,177
			$20at3%	104,480	115,169	130,939

(1000 m3 and 1000 mt)		SSP2 - Middle of the Road	Baseline	102,356	116,429	130,983
			$20at3%	100,463	111,024	123,646
		SSP3 - Regional Rivalry	Baseline	94,280	92,445	103,052
			$20at3%	91,622	87,889	96,024
		SSP4 - Inequality	Baseline	104,225	109,356	124,331
			$20at3%	101,250	105,390	116,950
		SSP5 - Fossil-fueled Development	Baseline	112,353	143,453	170,175
			$20at3%	110,504	140,113	165,978
	Plywood (1000 m3)	SSP1 - Sustainability	Baseline	17,440	17,566	19,576
			$20at3%	16,032	14,892	15,369
		SSP2 - Middle of the Road	Baseline	17,648	16,666	19,625
			$20at3%	16,315	14,519	14,423
		SSP3 - Regional Rivalry	Baseline	17,118	15,032	15,994
			$20at3%	14,875	11,666	11,439
		SSP4 - Inequality	Baseline	16,786	15,405	16,972
			$20at3%	15,317	13,395	13,439
		SSP5 - Fossil-fueled Development	Baseline	14,593	17,003	19,902
			$20at3%	14,369	16,156	16,621

	Pulp and paper (1000 mt)	SSP1 - Sustainability	Baseline	122,432	135,458	115,677
			$20at3%	121,842	134,541	114,729
		SSP2 - Middle of the Road	Baseline	121,775	133,200	115,795
			$20at3%	121,149	133,200	114,842
		SSP3 - Regional Rivalry	Baseline	115,705	119,951	110,768
			$20at3%	115,705	119,668	109,551
		SSP4 - Inequality	Baseline	118,717	125,841	113,715
			$20at3%	118,131	125,230	112,806
		SSP5 - Fossil-fueled Development	Baseline	124,713	143,711	121,903
			$20at3%	124,713	142,727	121,041
	Harvested Logs (1000 m3)	SSP1 - Sustainability	Baseline	409,706	464,522	471,518
			$20at3%	383,951	428,925	422,047
		SSP2 - Middle of the Road	Baseline	399,749	450,957	450,987
			$20at3%	373,632	414,667	403,384
		SSP3 - Regional Rivalry	Baseline	369,792	405,131	394,835
			$20at3%	346,018	341,558	328,241
		SSP4 - Inequality	Baseline	394,273	431,769	437,167
			$20at3%	370,170	388,607	385,132
		SSP5 - Fossil-fueled Development	Baseline	430,159	539,491	584,477
			$20at3%	408,872	503,233	535,402
Forest product	*Lumber (1000 m3)*	SSP1 - Sustainability	Baseline	8,610	9,674	10,645

exports (1000 m3 and 1000 mt)			$20at3%	8,610	9,674	10,645
		SSP2 - Middle of the Road	Baseline	8,326	9,040	9,701
			$20at3%	8,326	9,040	9,701
		SSP3 - Regional Rivalry	Baseline	7,597	7,639	7,784
			$20at3%	7,597	7,639	7,784
		SSP4 - Inequality	Baseline	7,933	8,304	8,768
			$20at3%	7,933	8,304	8,768
		SSP5 - Fossil-fueled Development	Baseline	9,073	10,602	11,870
			$20at3%	9,073	10,602	11,870
	Plywood (1000 m3)	SSP1 - Sustainability	Baseline	956	1,074	1,182
			$20at3%	956	1,074	1,182
		SSP2 - Middle of the Road	Baseline	924	1,004	1,077
			$20at3%	924	1,004	1,077
		SSP3 - Regional Rivalry	Baseline	843	848	864
			$20at3%	843	848	864
		SSP4 - Inequality	Baseline	881	922	974
			$20at3%	881	922	974
			Baseline	1,007	1,177	1,317

		SSP5 - Fossil-fueled Development	$20at3%	1,007	1,177	1,317
	Pulp and paper (1000 mt)	SSP1 - Sustainability	Baseline	20,629	25,026	27,222
			$20at3%	20,629	25,026	27,222
		SSP2 - Middle of the Road	Baseline	19,705	22,458	23,579
			$20at3%	19,705	22,458	23,579
		SSP3 - Regional Rivalry	Baseline	18,676	19,718	20,132
			$20at3%	18,676	19,718	20,132
		SSP4 - Inequality	Baseline	18,944	21,250	22,783
			$20at3%	18,944	21,250	22,783
		SSP5 - Fossil-fueled Development	Baseline	21,274	25,178	26,873
			$20at3%	21,274	25,178	26,873
Emissions (GtCO2e/yr.)	Ag CO2	SSP1 - Sustainability	Baseline	0.16	0.16	0.16
			$20at3%	0.15	0.15	0.15
		SSP2 - Middle of the Road	Baseline	0.16	0.16	0.17
			$20at3%	0.16	0.16	0.15
		SSP3 - Regional Rivalry	Baseline	0.16	0.16	0.16
			$20at3%	0.15	0.15	0.14
		SSP4 - Inequality	Baseline	0.17	0.17	0.17

		$20at3%	0.16	0.16	0.15
	SSP5 - Fossil-fueled Development	Baseline	0.17	0.18	0.18
		$20at3%	0.17	0.17	0.18
Crop Non-CO2	SSP1 - Sustainability	Baseline	0.06	0.06	0.06
		$20at3%	0.05	0.05	0.05
	SSP2 - Middle of the Road	Baseline	0.06	0.06	0.06
		$20at3%	0.05	0.05	0.05
	SSP3 - Regional Rivalry	Baseline	0.06	0.06	0.06
		$20at3%	0.05	0.05	0.05
	SSP4 - Inequality	Baseline	0.06	0.06	0.06
		$20at3%	0.06	0.05	0.05
	SSP5 - Fossil-fueled Development	Baseline	0.06	0.06	0.06
		$20at3%	0.06	0.06	0.06
Livestock Non-CO2	SSP1 - Sustainability	Baseline	0.15	0.17	0.17
		$20at3%	0.14	0.13	0.12
	SSP2 - Middle of the Road	Baseline	0.15	0.17	0.19
		$20at3%	0.14	0.13	0.12
	SSP3 - Regional Rivalry	Baseline	0.14	0.16	0.17
		$20at3%	0.13	0.12	0.11
	SSP4 - Inequality	Baseline	0.15	0.18	0.18
		$20at3%	0.14	0.13	0.12

	SSP5 - Fossil-fueled Development	Baseline	0.17	0.20	0.22
		$20at3%	0.15	0.15	0.15
Soils	SSP1 - Sustainability	Baseline	0.06	0.01	-0.11
		$20at3%	-0.06	-0.16	-0.23
	SSP2 - Middle of the Road	Baseline	0.08	0.02	-0.07
		$20at3%	-0.04	-0.15	-0.18
	SSP3 - Regional Rivalry	Baseline	0.09	0.01	0.02
		$20at3%	-0.06	-0.12	-0.14
	SSP4 - Inequality	Baseline	0.12	0.02	-0.05
		$20at3%	-0.01	-0.17	-0.16
	SSP5 - Fossil-fueled Development	Baseline	0.10	-0.02	-0.24
		$20at3%	-0.01	-0.11	-0.23
Forestry	SSP1 - Sustainability	Baseline	-0.20	-0.01	-0.07
		$20at3%	-0.43	-0.30	-0.14
	SSP2 - Middle of the Road	Baseline	-0.17	0.03	0.03
		$20at3%	-0.44	-0.30	-0.15
	SSP3 - Regional Rivalry	Baseline	-0.13	0.06	0.09
		$20at3%	-0.41	-0.47	-0.32
	SSP4 - Inequality	Baseline	-0.15	0.00	-0.02
		$20at3%	-0.43	-0.31	-0.18
		Baseline	-0.31	0.05	0.07

	SSP5 - Fossil-fueled Development	$20at3%	-0.42	-0.16	0.11

Supplement 2: Selected Mitigation Scenario Results

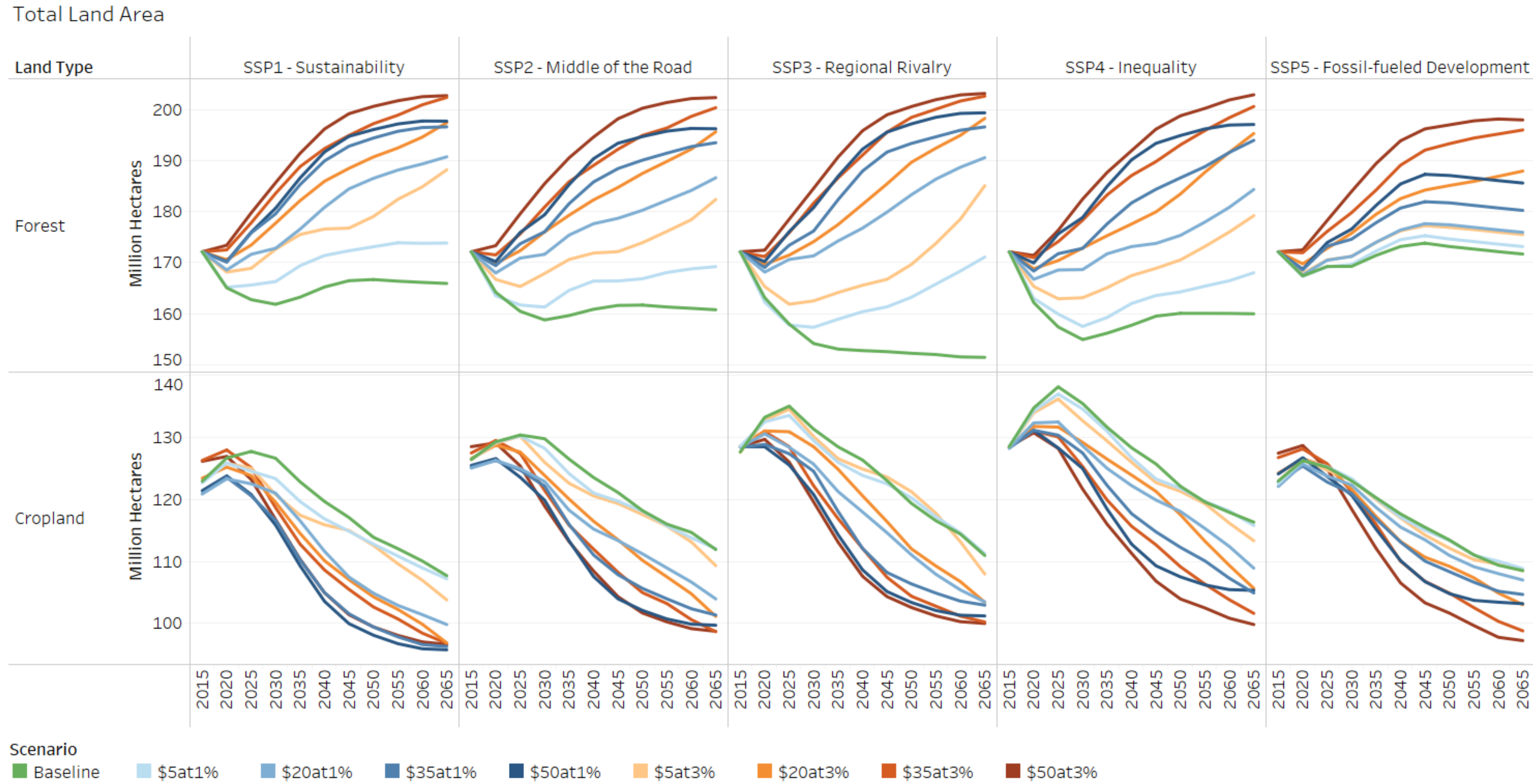

Figure 10: Forestland (top) and cropland (bottom) projections across SSPs and mitigation price scenarios, from 2015 to 2065 in million hectares.

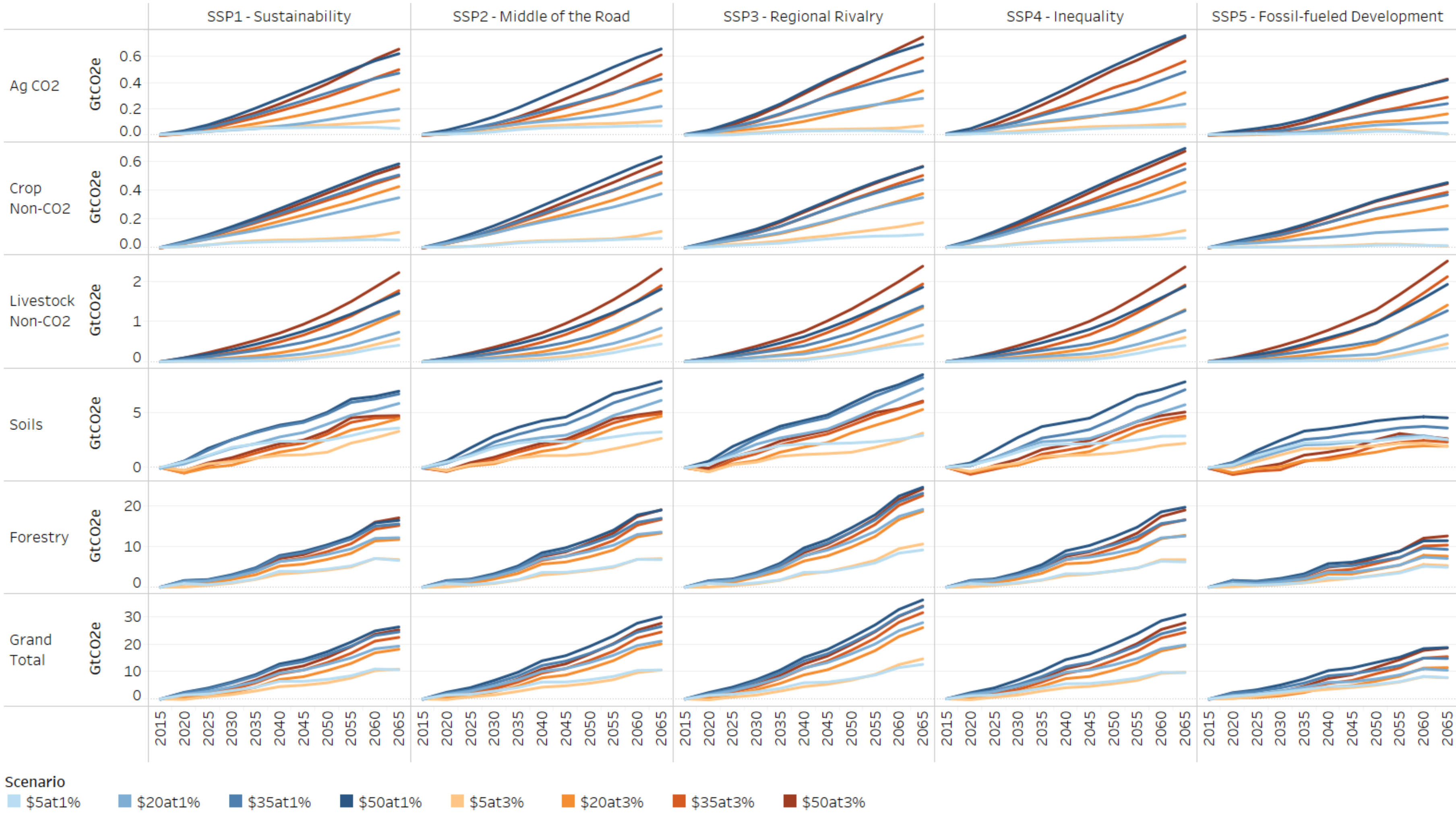

Figure 11: Mitigation potential from agriculture and forestry sectors across all SSPs and all mitigation price scenarios

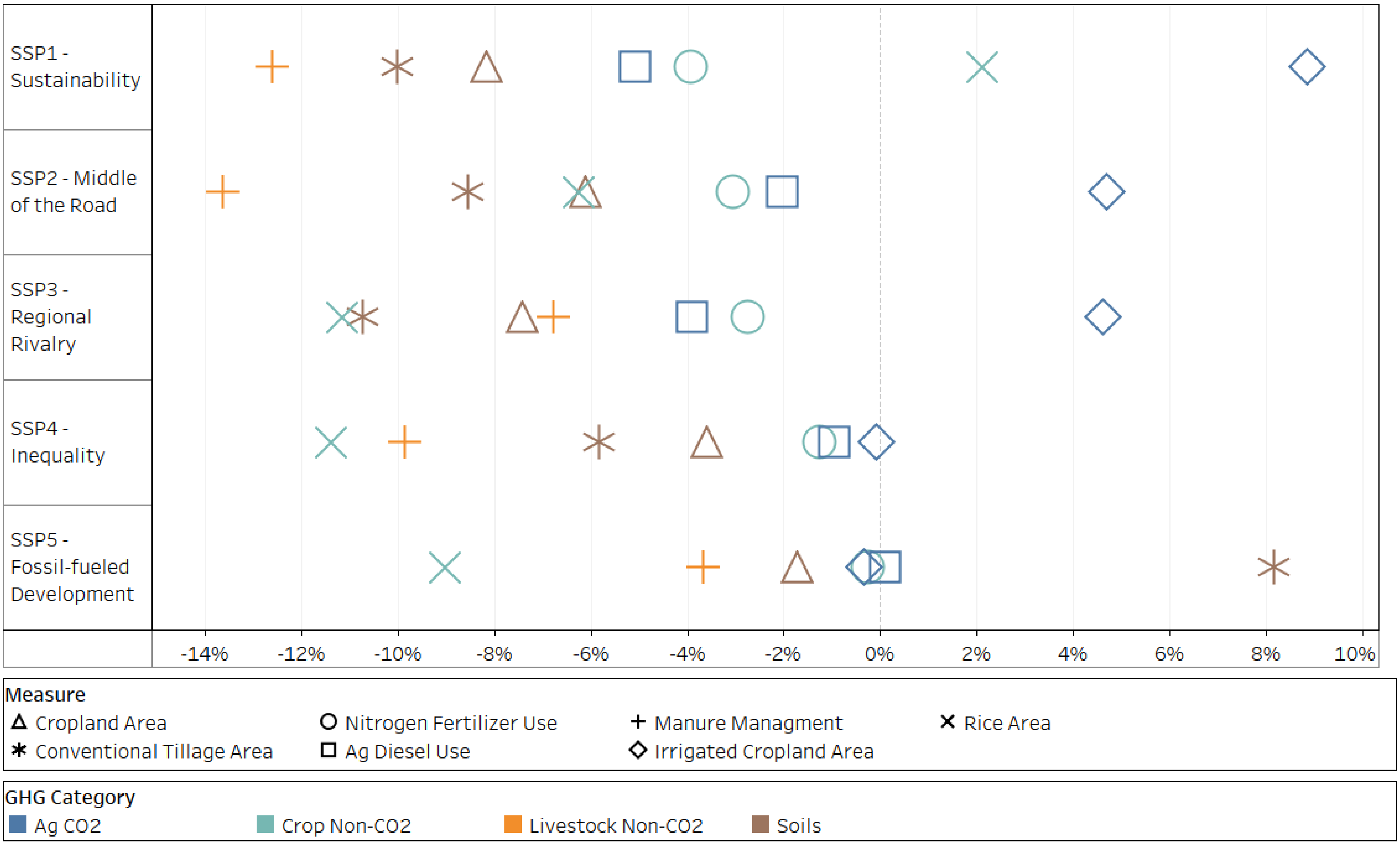

Figure 12: Summary of Land Use Mitigation Activity Changes, Percent difference between Baseline and $20at1% in 2055

Figure 13: Changes in carbon sink (negative values represent carbon sinks) due to changes in demand for agricultural and forestry products (top) and mitigation policy incentives (bottom) in the $20tCO2e^{-1} growing at 3% scenario in 2035, 2055 and 2065.

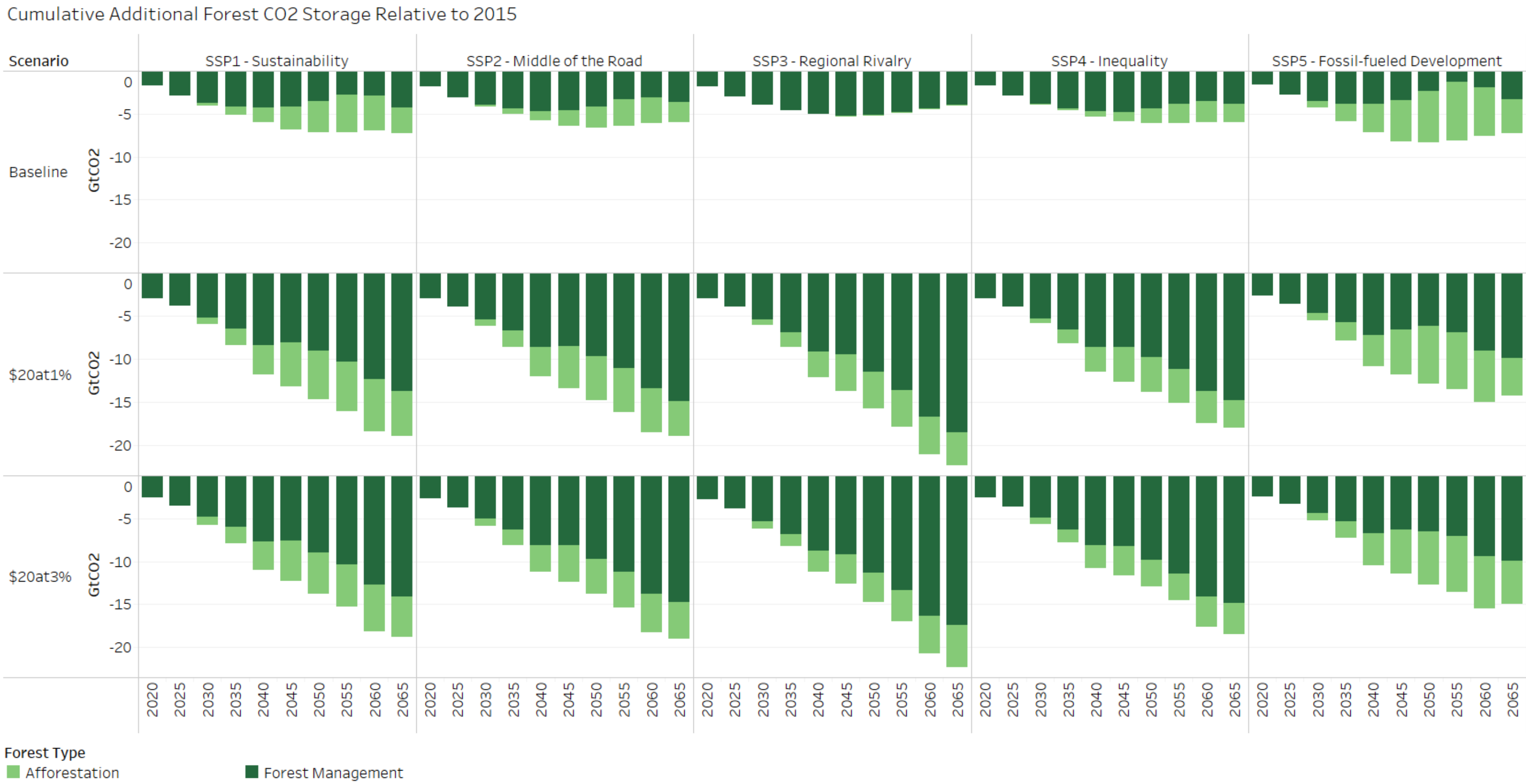

Figure 14: Additional carbon stored in existing forest and new forests relative to 2015 across each SSP for the baseline (no mitigation policy), \$20tCO2e^{-1} growing at 1% scenario, and \$20tCO2e^{-1} growing at 3% scenario.

Table 2: Domestic demand elasticity assumptions for forest products in FASOMGHG.

Product	Demand Elasticity
SW Lumber	-0.14
HW Lumber	-0.10
SW Plywood	-0.65
HW Plywood	-0.29
OSB	-0.65
Other Panels	-0.46
MDF	-0.46
Newsprint	-0.68
P&W Paper	-0.42
Paperboard	-0.23
Tissue	-0.23

Table 3: Mitigation Technologies and Strategies in FASOMGHG.

	Mitigation Options	CO2	CH4	N2O	*Direct*	Indirect
Afforestation	Convert agricultural lands to forest	X				X
Forest Management	Lengthen timber harvest rotation	X				X
	Increase forest management intensity	X	X	X		
	Wood products		X	X		
	Avoided forest conversion	X	X	X		
Cropland Management	Auto-Fertilization			X		
	Nitrification inhibitors	X		X		
	Reduced fertilizer application	X		X		
	Split fertilization			X		
	Residue incorporation	X		X		
	Change from conventional tillage to reduced tillage	X				
	Change from reduced tillage to no-tillage	X				
	Change from conventional tillage to no-tillage	X		X		

Cropland Soil Carbon Sequestration	Crop tillage change	X				
	Crop mix change	X		X		
	Fertilizer usage change	X				
	Grassland conversion	X		X		
Livestock Management non-	Covered lagoon anaerobic digester	X		X		
	Complete mix anaerobic digester	X		X		
	Plug flow digester	X		X		
	Improved Feed Conversion	X		X		
	Antibiotics	X		X		
	Bst	X		X		
	Propionate Precursors	X		X		
	Antimethanogen	X		X		
	Intensive Grazing	X		X		
	Adding Concentrates to Feed			X		
	Adding Oils to Feed			X		
Fossil fuel mitigation from crop production	Crop tillage change	X				
	Crop mix change	X				
	Crop input change	X				
	Irrigated/dry land mix change	X				
Rice Cultivation	Alternating Wet/Dry	X		X		
	Auto-Fertilization	X		X		
	Nitrification Inhibitors	X		X		
	Mid-Season drainage	X		X		
	Dryland rice/direct seeding	X		X		
	Change from conventional tillage to reduced tillage	X				
	Change from reduced tillage to No-tillage	X				
	Change from conventional tillage to No-tillage	X		X		

Supplement 3: FASOMGHG Algebraic Structure

This supplement documents the general algebraic structure of the FASOMGHG model. This analytical model is a simplified version of the full model where we have omitted certain sets that are included in the full version (e.g., regions and management types.

Objective function

$$OBJ = \sum_{t=1}^{tn,T} (1+i)^{-t} * \beta t * \left\{FWELF_t + AWELF_t - LC_t - \sum_g \overline{PGHG_t} * \left(TGHG_{g,t} - TGHGB_{g,t}\right)\right\}$$
eq1.

$$TGHG_{g,t} = \sum_r FGHG_{r,g,t} + \sum_r AGHG_{r,g,t} + \sum_r LGHG_{r,g,t}$$ eq 1.

Where

t: time period from beginning period t_1 (2015) to end period t_n (flexibly defined by users, 2080 in this paper), plus terminal period T (9999)

i: discount rate by period

βt: weight by period, β=5 for t_1 to t_n indicates the welfare is for five-years. β=25 is assumed for terminal period T.

OBJ: objective value

$FWELF_t$: annual welfare value for forest sector

$AWELF_t$: annual welfare value for agricultural sector

LC: cost associated for linkage between forest and agricultural sector for land conversion and commodity movement

$\overline{PGHG_t}$: Exogenous price of GHG emissions (\$/ton CO_2eq)

$TGHG_{g,t}$: Total GHG flux (million tons of CO2eq)

$TGHGB_{g,t}$: Baseline GHG stock (million tons of CO2eq)

$FGHG_{r,g,t}$: Forest ghg stock (million metric tons)

$AGHG_{r,g,t}$: agriculture ghg stock

$LGHG_{r,g,t}$: GHG associated with land conversion.

The objective value OBJ is equal to the sum of presented value of forest sector welfare $FWELF_t$, agricultural sector welfare $AWELF_t$, minus the cost associated with land conversion between land types LC_t over the modeling horizon and terminal period. For the paper, the mitigation price grows differently by scenario and is assigned to $\overline{PGHG_t}$, thus the cost/benefit arise from the difference of emissions between scenario $TGHG_{g,t}$ and the baseline case $TGHGB_{g,t}$ (for this paper, each SSP without a mitigation price represents a baseline scenario). Thus, emissions and sequestration are directly priced in the the objective function, which stimulates adoption of mitigation activities. Eq 2. below defines that total GHG stock $TGHG_{g,t}$, is the sum of GHG stock from forest $\sum_r FGHG_{r,g,t}$, agriculture $\sum_r AGHG_{r,g,t}$, and land use change $\sum_r LGHG_{r,g,t}$.

In the remaining sections, we will divide the model structure into three sub-sections:1) forest model structure; 2) agricultural model structure; 3) linkage between forest and agriculture. Variables with overline are exogenous parameters given as data while the variables without overline are decision variables and solved in the model. For example, $\overline{PGHG_t}$ is a parameter while $TGHG_{g,t}$ is a decision variable in Eq 1.

Forest Module

A.1) Forest Sector Welfare Function – sum of producer and consumer surplus in the U.S. forest sector

$$FWELF_t = \sum_f \int PDM_{f,t}(DMD_{f,t})dDMD_{f,t}$$
$$-\sum_{r,f} FCOST_{r,f,t} - \sum_{r,j,n=4} \overline{ESTC_{r,J}} * (NEW_{r,j,t-n,t} + AFF_{r,j,t-n,t}) \qquad \text{eq 2.}$$

Where

f: forest product, e.g.,, sawlogs, pulplogs, lumber, bark (f=33)

r: region (11 regions for US forest and 60 or 11 regions for US agriculture, and some foreign countries with major forest and agriculture commodities import and export)

j: forest type

n: forest age

$DMD_{f,t}$: domestic demand by forest product

$PDM_{f,t}(DMD_{f,t})$: inverse demand of domestic forest demand. In FASOM, it is represented as a step-wise demand function.

$FCOST_{r,f,t}$: cost of forest product

$NEW_{r,j,t-n,t}$: new forest replanted at period t-n then harvested at later periods t; n=4 indicates that forest with at least 20 years old can be harvested (thousand acres).

$AFF_{r,j,t-n,t}$: Afforested land planted at t-n then harvested at t (thousand acres).

$ESTC_{r,j}$: new or afforest establishment cost ($/acre)

Forest net welfare $FWELF_t$ at period t comes from demand surplus $\int PDM_{f,t}(DMD_{f,t})dDMD_{f,t}$, minus the cost from forest production $\sum_{r,f} FCOST_{r,f,t}$, minus the cost to establish new and afforested land $\sum_{r,j,n=4} \overline{ESTC_{r,J}} * (NEW_{r,j,t-n,t} + AFF_{r,j,t-n,t})$.

A.2) Forest cost

For_cost: *r, f, t*

$$FCOST_{r,f,t} = \frac{1}{5} * (\sum_{j,n=4} EST_{r,j,n,t} * \overline{ESTQ_{r,f,J,n,t}} * \overline{HAVC_{r,f,J,n}} + \sum_{j,n=4} NEW_{r,j,t-n,t} * \overline{NEWQ_{r,f,J,n,t}} * \overline{HAVC_{r,f,J,n}} + \sum_{j,n=4} AFF_{r,j,t-n,t} * \overline{AFFQ_{r,f,J,n}} * \overline{HAVC_{r,f,J,n}}) + \sum_{r_2,f_2} F2M_{r,r_2,f,f_2,t} * \overline{F2MC_{r,r_2,f,f_2}} + \sum_{f_2,k} MAN_{r,f_2,k,t} * \overline{MANC_f}$$

Where

$EST_{r,j,n,t}$: Area of existing forest stand type *j* harvested at period *t* at age *n*. Once harvested, it will be replanted at period *t* immediately (thousand acres).

$\overline{ESTQ_{r,f,J,n,t}}$: harvested products *f* (log or log residue) from 1 acre of existing forest stand type *j* at period *t* at age *n* (cubic meters/acre or metric tonnes/acre)

$\overline{NEWQ_{r,f,J,n}}$: harvested products *f* (log or log residue) from 1 acre of new forest land type *j* at age *n*

$\overline{NEWC_{r,J,f,n}}$: harvest cost per cubic meter or per metric ton of forest product ($/cubic meters or $/metric ton)

$\overline{AFFQ_{r,f,J,n}}$: harvested products *f* (log or log residue) from 1 acre of afforested land type *j* at age *n*

$\overline{HAVC_{r,f,J,n}}$: harvest cost per cubic meter or per metric ton of forest product ($/cubic meters or $/metric ton)

$F2M_{r,r_2,f,f2,t}$: products *f* (log or log residue) moved from *r2* to *r* then processed from *f* to *f2* by mill (unit vary by product - either 1000 m3 or 1000 metric tonnes)

$\overline{F2MC_{r,r_2,f,f_2}}$: transportation cost for per unit of products *f* (log or log residue) moved from *r2* to *r* then processed from *f* to *f2* by at the mill level ($/cubic meters or $/metric ton)

K: forest processing technology

$MAN_{r_1,f_2,k,t}$: forest manufacturing by technology and by major product f_2

$\overline{MANC_f}$: per unit of forest manufacturing output cost. f hHere, f stands for both main and multiple by-products.

Forest sector costs includes three components:

1) harvest cost from existing, new and afforest products $(\sum_{j,n=4} EST_{r,j,n,t} * \overline{ESTQ_{r,f,J,n,t}} * \overline{HAVC_{r,f,J,n}} + \sum_{j,n=4} NEW_{r,j,t-n,t} * \overline{NEWQ_{r,f,J,n,t}} * \overline{HAVC_{r,f,J,n}} + \sum_{j,n=4} AFF_{r,j,t-n,t} * \overline{AFFQ_{r,f,J,n}} * \overline{HAVC_{r,f,J,n}}$).
   − n>=4 represents forest that can be harvested must be at least 20 years old;

2) transportation cost for forest log or residue ship to mill $\sum_{r_2,f_2} F2M_{r,r_2,f,f_2,t} * \overline{F2MC_{r,r_2,f,f_2}}$;

3) forest product manufacturing cost $\sum_{f_2,k} MAN_{r,f_2,k,t} * \overline{MANC_f}$.

A.3) Forest land use constraints

A.3.1) Existing forest land inventory: r,j,n:

$$\sum_t EST_{r,j,n,t} = \overline{FACRE}_{r,j,n}$$

A.3.2) Existing forest land terminal condition: r,j,n:

$$EST_{r,j,n,T} \geq \overline{FACRER}_{r,j,n}$$

$\overline{FACRE}_{r,j,n}$: Existing area of forest by type, age in thousand acres. The actual model includes more information and vary by cohort, site class, ownership from Strata.

$\overline{FACRER}_{r,j,n}$*:* reserved land area for existing forest by type, age in thousand acres

These equations require the sum of existing forest land harvested over time should be equal to the initial existing land area available.

A.3.3) New forest land balance by region r, forest type j and period t:

$$\sum_{n=4} NEW_{r,j,t,t+n} + \sum_{l1,l2} F2AA_{r,j,l1,l2,t} + F2D_{r,j,t}$$

$$= \sum_{n=4} EST_{r,j,n,t} + \sum_{n=4} NEW_{r,j,t-n,t} + \sum_{n=4} AFF_{r,j,t-n,t}$$

Where

l: Land type for ag and forest. There is only 1 type of forest land

$NEW_{r,j,t,t+n}$: new forest replanted at period *t* then harvested at later periods *t+n* forests with at least 20 years old can be harvested (thousand acres).

$AFF_{r,j,t-n,t}$: Afforested land planted at *t-n* then harvested at *t* (thousand acres).

$F2AA_{r,j,l1,l2,t}$: forestland *l1* converted to ag land type *l2* at period *t* (thousand acres).

$F2D_{r,j,t}$ *: forest land converted to* development at period *t* (thousand acres).

This is the forest land balance equation where new forest replanted at period t then harvested at all later periods $NEW_{r,j,t,t+n}$, plus forest converted to agricultural land $F2AA_{r,j,l1,l2,t}$ and used for crop cultivation.

A.3.4) Afforest land balance constraint by region r, forest type j and period t:

$$\sum_{n=4} AFF_{r,j,t,t+n} = \sum_{l1,l2} A2FF_{r,j,l1,l2,t}$$

$A2FF_{r,j,l1,l2,t}$: Land converted from ag land type l1 to forest type l2 (thousand acres).

This equation indicates that afforested land planted at t which is then harvested at later time periods $AFF_{r,j,t,t+n}$ comes from land converted from agricultural land l2 at period t $A2FF_{r,j,l1,l2,t}$. Note here l1 can be cropland, cropland_pasture, pasture while l2 refers to only one type of forest land.

A.3.5) Forest land converted for development by region r, j, period t

$$F2D_{r,j,t} = \overline{F2D_{r,J,t}}$$

where

$\overline{F2D_{r,j,t}}$: exogenous acreage where forest land is converted for urban land development (thousand acres).

This is the land development constraint where forest land converted for development $F2D_{r,j,t}$is set to equal to an exogenous constraint $\overline{F2D_{r,J,t}}$, as described in the main body of the manuscript.

A.4) Supply and demand balance constraint for forest logs and residues harvested from land (r,f,t)

$$\sum_{j,n=4} EST_{r,j,n,t} * \overline{ESTQ_{r,f,J,n,t}} + \sum_{j,n=4} NEW_{r,j,t-n,t} * \overline{NEWQ_{r,f,J,n}} + \sum_{j,n=4} AFF_{r,j,t-n,t} * \overline{AFFQ_{r,f,J,n}}$$

$$\geq 5 * \sum_{r2,f2} F2M_{r,r_2,f,f2,t} + 5 * F2P_{r,f,t} + 5 * \sum_{r_{2,a}} M2A_{r,r_2,f,a,t} + 5 * Waste_{r,f,t}$$

Where

$F2P_{r,f,t}$: Harvested log or residue moved to port for export

$M2A_{r,r_2,f,a,t}$: Harvested log or residue moved to ag for bioenergy process (thousand short ton with 33% moisture content)

$Waste_{r,f,t}$: Logs left behind in the forest (thousand m3)

The left side of equation is the sum of total forest log or residue products harvested from existing forest land, $\sum_{j,n=4} EST_{r,j,n,t} * \overline{ESTQ_{r,f,J,n,t}}$, from new forest land $\sum_{j,n=4} NEW_{r,j,t-n,t} * \overline{NEWQ_{r,f,J,n}}$, and from afforested land $\sum_{j,n=4} AFF_{r,j,t-n,t} * \overline{AFFQ_{r,f,J,n}}$. The right side of equation is the sum of forest products from demand from various sources:

A.5) supply and demand and balance constraint for forest manufacturing input and output (unit dependent on forest product - either 1000 m3 or 1000 metric tonnes):

A.5.1) supply and demand and balance constraint for forest manufacturing input

$$\sum_{r_2} F2M_{r,r_2,f_1,f_2,t} + \sum_{r_2,f_3} M2M_{r_1,r_2,f_1,f_2,f_3,t} + REC_{r,f_1,f_2,t} + P2M_{r,f_1,f_2,t}$$

$$= \sum_{k} MAN_{r,f_2,k,t} \overline{MANIN_{f_1,f_2,k}}$$

where

$M2M_{r_1,r_2,f_1,f_2,f_3,t}$: forest by-product input f_1 for f_2 shipped from *r2* to *r* to produce f_3 (1000 metric tonnes)

$REC_{r,f_1,f_2,t}$: recycled inputs where *f1* is pulp_recyle and *f2* is forest products made from the recycled paper

$P2M_{r,f_1,f_2,t}$: forest products import f1 then used to make *f2*

K: forest manufacturing technology

$MAN_{r_1,f_2,k,t}$: Forest manufacturing by technology

$\overline{MANIN_{f_1,f_2,k}}$: Parameter defines forests manufacturing input demand *f1* for per unit of output *f2*

Equation A.5.1 defines the supply and demand balance constraint for forest manufacturing processes. It uses input *f1* to produce major product *f2*. *f3* stands for both major and multiple by-products in the process. For example, 2.58 m^3 *SW_SawLogs* can produce 1 m^3 *SW_lumber*. Along with the major product, processes represent supply of industrial byproducts: For example, producing a m3 of *SW_lumber* produces 0.348 metric tonnes of *SW_MillChips*, 0.084 metric tonnes of *SW_Sawdust*, 0.093 metric tonnes of *SW_Shavings*, 0.127 metric tonnes of *SW_Bark*, 0.013 metric tonnes of *SW_Hogfuel*.

The left side of equation represents the supply side of forest manufacturing input:

1) log or residue harvested from region *r2* and then processed from *f1* to *f2* by mills $\sum_{r_2} F2M_{r,,r_2,f_1,f_2,t}$;

2) Forest byproducts input supply that is created from processing then moving from mill *r2* to mill *r*, $\sum_{r_2,f_3} M2M_{r_1,r_2,f_1,f_{2,},f_3,t}$;

3) recycled pulpwoods used for further processing $REC_{r,f_1,f_2,t}$;

4) forest products import *f1* used for manufacturing *f2*, $P2M_{r,f_1,f_2,t}$. The right side of the equation represents total manufacturing input demand from all technologies which is multiplication of process and the input requirement per unit of the process, $\sum_k MAN_{r_1,f_2,k,t}\,\overline{MANIN_{f_1,f_2,k}}$.

A.5.2) Demand and supply balance constraint for forest manufacturing output (unit dependent on forest product - either 1000 m3 or 1000 metric tonnes):

$$\sum_{f_2,k} MAN_{r,f_2,k,t}\,\overline{MANOUT_{f,f_2,k}}$$

$$= \sum_{r_2,f_1,f_2} M2M_{r,r_2,f_1,f_{2,}f,t} + M2D_{r,f,t} + M2P_{r,f,t} + WST_{r,f,t} + \sum_{r_{2,a}} M2A_{r,r_2,f,a,t}$$

where

$\overline{MANOUT_{f_1,f_2,k}}$: Parameter defines forests manufacturing output f for per unit of processing *f2*

$M2D_{r,f,t}$: Products sent to US domestic final demand by region and period

$M2P_{r,f,t}$: Product sent for export

$WST_{r,f,t}$: byproducts not used then wasted.

In the equation, the left side is total forest product output at mill, the multiplication of the process level and output per unit of process, proving the domestic supply of forest products. The right side is the processed forest product demand from :1) demand from mill *r2* to mill *r*, $\sum_{r_2,f_3} M2M_{r_1,r_2,f_1,f_{2,},f_3,t}$; 2) send to domestic final demand $M2D_{r,f,t}$; 3) send for export $M2P_{r,f,t}$; 4) not really used $WST_{r,f,t}$; 5) send to agriculture side for biofuel and bioelectricity processing $\sum_{r_{2,a}} M2A_{r,r_2,f,a,t}$.

A.6) Forest product domestic demand and their sources (1000 m3)

For_MRT: *f,t*

$$DMD_{f,t} = \sum_{r} M2D_{r,f,t} + P2D_{f,t}$$

Where

$DMD_{f,t}$: domestic final demand by forest product by period *t*

$P2D_{f,t}$: direct demand supplied from import by forest product by period *t*

In this equation, the left side is the domestic final demand $DMD_{f,t}$ which must be equal to total supply from two sources: 1) products directly from mill for all regions $\sum_r M2D_{r,f,t}$; 2) direct import $P2D_{f,t}$.

A.7) Constraint for harvested wood moving to a mill for process:

$$\sum_{r_1,f_1,f_2} F2M_{r_1,r_2,f_1,f_2,t} \geq \sum_{r_1,f_1,f_2} F2M_{r_1,r_2,f_1,f_2,t-1}$$

This constraint indicates that total harvest forest products at region *r2* which is moved to region *r1* at period *t*, $\sum_{r_1,f_1,f_2} F2M_{r_1,r_2,f_1,f_2,t}$ must be at least greater or equal to the harvest products at region *r2* which is moved to region *r1* at previous period *t-1*, allowing for an upper trend of regional harvested forest product for mill production.

A.8) Trade constraint

A.8.1) Forest import constraint by f, t

Trade-Import: *f,t*

$$\sum_{r,f_2} P2M_{r,f,f_2,t} + P2D_{f,t} = \overline{FIM_{f,t}}$$

where

$\overline{FIM_{f,t}}$ Parameter for forest import by product and period *t*

A.8.2) Forest export constraint by *f, t*

$$\sum_{r} F2P_{r,f,t} + \sum_{r} M2P_{r,f,t} = \overline{FEX_{f,t}}$$

where

$\overline{FEX_{f,t}}$ Parameter for forest export by product and period t

The above two equations specify forest product trade constraints where import and export must be equal to the exogenous quantity $\overline{FIM_{f,t}}$ and $\overline{FEX_{f,t}}$ respectively. The import is used by demand for mill processing $\sum_{r,f_2} P2M_{r,f,f_2,t}$ and direct final demand $P2D_{f,t}$. The export is supplied by harvest forest products directly shipped to port $\sum_r F2P_{r,f,t}$, plus processed forest products shipped to port $\sum_r M2P_{r,f,t}$.

A.9) Constraint for recycled paper by period t

Recycle: ***t***

$$\sum_{f,t} DMD_{f,t} * \overline{RECRATE} + \overline{RECIM} - \overline{RECEX} - \sum_{r,f_1,f_2} REC_{r,f_1,f_2,t} - WSTP_t = 0$$

Where

$REC_{r,f_1,f_2,t}$: recycled inputs where *f1* is *pulp_recyle* and *f2* is forest products made from the recycled paper

$\overline{RECRATE}$: proportion (66%) of final consumption of forest products can be recycled for certain products

$\overline{RECIM}$: import of recycled paper

$\overline{RECEX}$: export of recycled paper

$WSTP_t$: wasted paper at period *t*

In this equation, 66% of some paper related products *f* such as *Newsprint*, *P_W_Paper*, *Paperboard* in the household consumption $DMD_{f,t}$, along with net import of recycled paper ($\overline{RECIM} - \overline{RECEX}$) can be either recycled for use at mill, $\sum_{r,f_1,f_2} REC_{r,f_1,f_2,t}$ or eventually wasted $WSTP_t$.

A.10) Forest GHG accounting by r,g,t

For_carbon*: r, g, t*

$$FGHG_{r,g,t} = \sum_{t_2,j,m} F2D_{r,j,t_2} * \overline{F2D_{g,m}} + FGHGS_{r,g,t} + FGHGI_{r,g,t}$$

$$FGHGS_{r,g,t} = \sum_{j,t_3,n=4,m} EST_{r,j,n,t_3} * \overline{FSOIC_{r,g,m}} + \sum_{j,t_3,n=4,m} NEW_{r,j,t_3,t_{3+n}} * \overline{FSOIC_{r,g,m}}$$

$$FGHGI_{r,g,t} = \sum_{j,t_3,n=4,m} EST_{r,j,n,t_3} * \overline{FGHGI_{r,g,m}} * \ \overline{ESTQ_{r,f,J,n,t}}$$
$$+ \sum_{j,t_3,n=4,m} NEW_{r,j,t_3,t_{3+n}} * \overline{FGHGI_{r,g,m}} * \ \overline{NEWQ_{r,f,J,n}}$$
$$+ \sum_{j,t_3,n=4,m} AFF_{r,j,t_3,t_{3+n}} * \overline{FGHGI_{r,g,m}} * \ \overline{AFFQ_{r,f,J,n}}$$

where

g: ghg types (CO_2, CH_4, N_2O)

m: ghg category separated by sources, For example, live tree aboveground, live tree underground, litter for forest and from

$FGHG_{r,g,t}$: Forest ghg stock by region, type and period. Only CO_2 is considered in forest sector in FASOM, so g here refers to CO_2.

$FGHGS_{r,g,t}$: Forest carbon stock from soil at period *t*

$FGHGI_{r,g,t}$: Forest carbon stock from standing trees at period *t*

$\overline{F2D_{g,m}}$: CO_2 stock at period *t* for one acre of forest land converted to urban development at period t_2 (metric tones of CO_2), thus $t \geq t_2 \geq 0$

$\overline{m}$: forest soil carbon stock by category for one acre of live trees

$\overline{FGHGI_{r,g,m}}$: forest carbon stock by category for one acre of live trees

Forest GHG accounting is only available for CO_2 but not CH_4, N_2O or others. The forest stock in FASOM $FGHG_{r,g,t}$ at period t is composed of three parts:

1) forest carbon stock from forestland transferred to urban development from all previous periods t
2) 2, $\sum_{t_2,j,d} F2D_{r,j,t_2} * \overline{F2D_{g,m}}$ where $t \geq t_2 \geq 0$; forest soil carbon stock $FGHGS_{r,g,t}$ from existing trees or new planted trees;
3) 3) Forest carbon stocks for standing trees at period t $FGHGI_{r,g,t}$. In the forest soil carbon stock, $\sum_{j,t_3,n=4,d} EST_{r,j,n,t_3} * \overline{FSOIC_{r,g,m}}$ defines the existing trees harvested from all previous period t_3 where $t \geq t_3 \geq 0$. $\sum_{j,t_3,n=4,m} NEW_{r,j,t_3,t_{3+n}} * \overline{FSOIC_{r,g,m}}$ defines the new forest soil carbon stock at period t is from all new forest replanted at period t_3 then harvested at later periods t_3+*n* where $t_{3+n} \geq t \geq t_3 \geq 0$. Note here forest soil carbon stock from afforestation is not accounted here but would be accounted in the part for land conversion.

Similarly, forest carbon sequestration from standing trees at period t includes stocking for standing existing trees, $\sum_{j,t_3,n=4,m} EST_{r,j,n,t_3} * \overline{FGHGI_{r,g,m}} * \ \overline{ESTQ_{r,f,J,n,t}}$, harvest then replanted new trees,

$\sum_{j,t_3,n=4,m} NEW_{r,j,t_3,t_{3+n}} * \overline{FGHGI_{r,g,m} *}\ \overline{NEWQ_{r,f,J,n}}$, and afforested trees $\sum_{j,t_3,n=4,m} AFF_{r,j,t_3,t_{3+n}} * \overline{FGHGI_{r,g,m} *}\ \overline{AFFQ_{r,f,J,n}}$. Again, $t \geq t_2 \geq 0$ and where $t_{3+n} \geq t \geq t_3 \geq 0$.

Agricultural Module

B.1) Ag welfare: t

$$AWELF_t = \sum_{a,d} \int ADP_{a,d,t}(AD_{a,d,t}) dAD_{a,d,t} - \sum_{a,s} \int ASP_{a,s,t}(AS_{a,s,t}) dAS_{a,s,t}$$

$$- \sum_{r,l_1,l_2} ALTA_{r,l_1,l_2,t} \overline{* ALTAC_{r,l_1,l_2}} - \sum_{r,w} \int APR_{r,w,t}(AR_{r,w,t}) dAR_{r,w,t}$$

$$- \sum_{r,c,l,k} APP_{r,c,l,k,t} * \overline{APPC_{r,c,l,k,t}} - \sum_{r,k} APC_{r,k,t} * \overline{APCC_{r,k,t}} - \sum_{r_1,r_2,a} ATR_{r_1,r_2,a,t} * \overline{ATRC_{r_1,r_2,a,t}}$$

where

a: ag commodity

d: demand type separated by domestic demand, oversea-demand and export

s: supply type separated by domestic supply, oversea-supply and import

l: land type (cropland, cropland_pasture, pasture, forest and so on)

w: resources used in agriculture (water and labor)

c: crop and livestock type

$AD_{a,d,t}$: final demand for by type for ag commodities.

$ADP_{a,d,t}(AD_{a,d,t})$: constant price elasticity of demand curve where its elasticity varies by ag commodities.

$AS_{a,s,t}$: supply by ag commodity for oversea-supply and import

$ASP_{a,s,t}(AS_{a,s,t})$: constant price elasticity of supply curve for oversea-supply and import where its elasticity varies by ag commodities.

$ALTA_{r,l_1,l_2,t}$: land conversion cost from land type l_1 to land type l_2 within agriculture

$\overline{ALTAC_{r,l_1,l_2}}$: cost of one acre of land conversion from land type l_1 to land type l_2 within agriculture.

$AR_{r,w,t}$: resource demand in agriculture

$APP_{r,c,l,k,t}$:   domestic crop or livestock production

$\overline{APPC_{r,c,l,k,t}}$: unit cost of domestic crop or livestock production

$APC_{r,k,t}$: domestic ag process

$\overline{APCC_{r,k,t}}$: unit cost of domestic ag process

$ATR_{r_1,r_2,a,t}$: ag commodify trade from region *r₁* to region *r₂*

$\overline{ATRC_{r_1,r_2,a,t}}$: unit cost of ag commodity trade from r_1 to r_2

Welfare in agriculture $AWELF_t$ includes:

1) consumer surplus $\sum_{a,d} \int ADP_{a,d,t}(AD_{a,d,t})dAD_{a,d,t}$ from all types of demand for all commodities minus the cost of supply from oversea and import $\sum_{a,s} \int ASP_{a,s,t}(AS_{a,s,t})dAS_{a,s,t}$,
2) domestic cost land conversion$\sum_{r,l_1,l_2} ALTA_{r,l_1,l_2,t} * \overline{ALTAC_{r,l_1,l_2}}$, from resource demand $\sum_{r,w} \int APR_{r,w,t}(AR_{r,w,t})dAR_{r,w,t}$,
3) production $\sum_{r,c,l,k} APP_{r,c,l,k,t} * \overline{APPC_{r,c,l,k,t}}$, process $\sum_{r,k} APC_{r,k,t} * \overline{APCC_{r,k,t}}$ and trade associated cost $\sum_{r_1,r_2,a} ATR_{r_1,r_2,a,t} * \overline{ATRC_{r_1,r_2,a,t}}$.

B.2) supply-demand balance constraint for ag commodity production and process

Agprodbal: *r, a, t*

$$\sum_{r,c,l,k} APP_{r,c,l,k,t} * \overline{APPY_{r,c,l,k,a}} + \sum_{r_2} ATR_{r_2,r,a,t} + \sum_{r_2,f} M2A_{r_2,r,f,a,t} \geq \sum_{k} APC_{r,k,t}\, \overline{APCI_{r,k,a}} + \sum_{r_2} ATR_{r,r_2,a,t}$$

where

$\overline{APPY_{r,c,l,k,a}}$:   crop or livestock yield per unit of production

$\overline{APCI_{r,k,a}}$: crop or livestock input demand per unit of process

This equation sets up the supply-demand balance of crop and livestock. The left defines the supply of crop and livestock which comes from:

1) domestic production $\sum_{r,c,l,k} APP_{r,c,l,k,t} * \overline{APPY_{r,c,l,k,a}}$;
2) import from other regions $\sum_{r,c,l,k} APP_{r,c,l,k,t} * \overline{APPY_{r,c,l,k,a}}$;
3) shipment from forest to ag $\sum_{r_2,f} M2A_{r_2,r,f,a,t}$.

The right side defines the demand from two parts:

1) ag process $\sum_{k} APC_{r,k,t}\, \overline{APCI_{r,k,a}}$,
2) export to other regions $\sum_{r_2} ATR_{r,r_2,a,t}$. Total supplies of ag commodity must be greater than or equal to its total demand.

B.3) Ag resource constraint

B.3.1) Ag resource balance: *r, w, t*

$$\sum_{c,l,k,w} APP_{r,c,l,k,t}\,\overline{APPW_{r,c,l,k,w}} \leq AR_{r,w,t}$$

where

$\overline{APPW_{r,c,l,k,w}}$: resource requirement per unit of production

B.3.2) Ag resource max constraint: *r, w, t*

$$AR_{r,w,t} \leq \overline{ARM_{r,w,t}}$$

where

$\overline{ARM}$: maximum amount of resource available

The total resource used in all production must be less or equal to the resource used, which is then less than the maximum resource available.