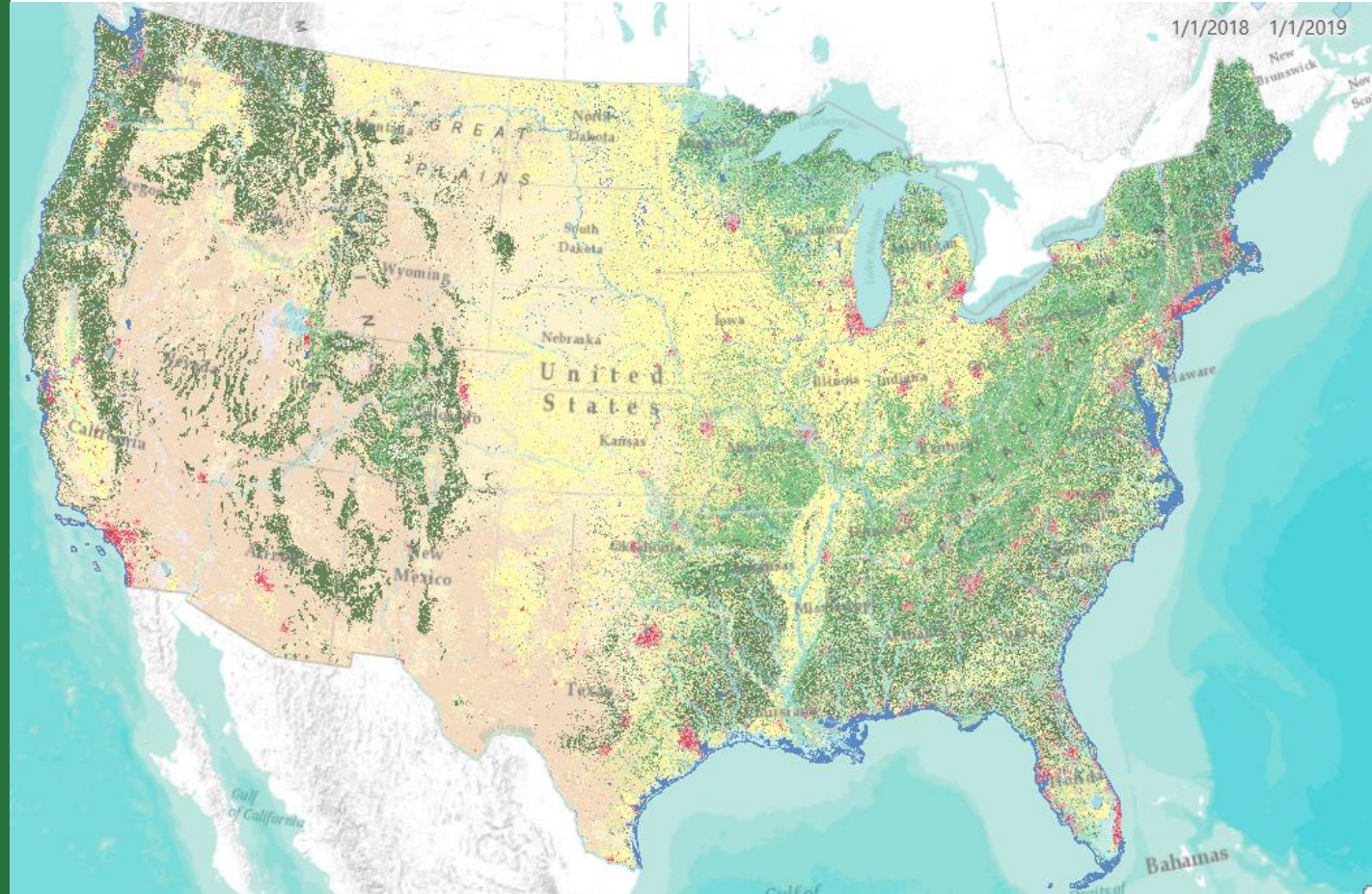


Impacts on Land Use Changes in the United States from Global Forces and Drivers: Searching for Tipping Points in a Multi-System Dynamics Approach

Angelo Gurgel
John Reilly
Elodie Blanc



U.S. DEPARTMENT OF
ENERGY

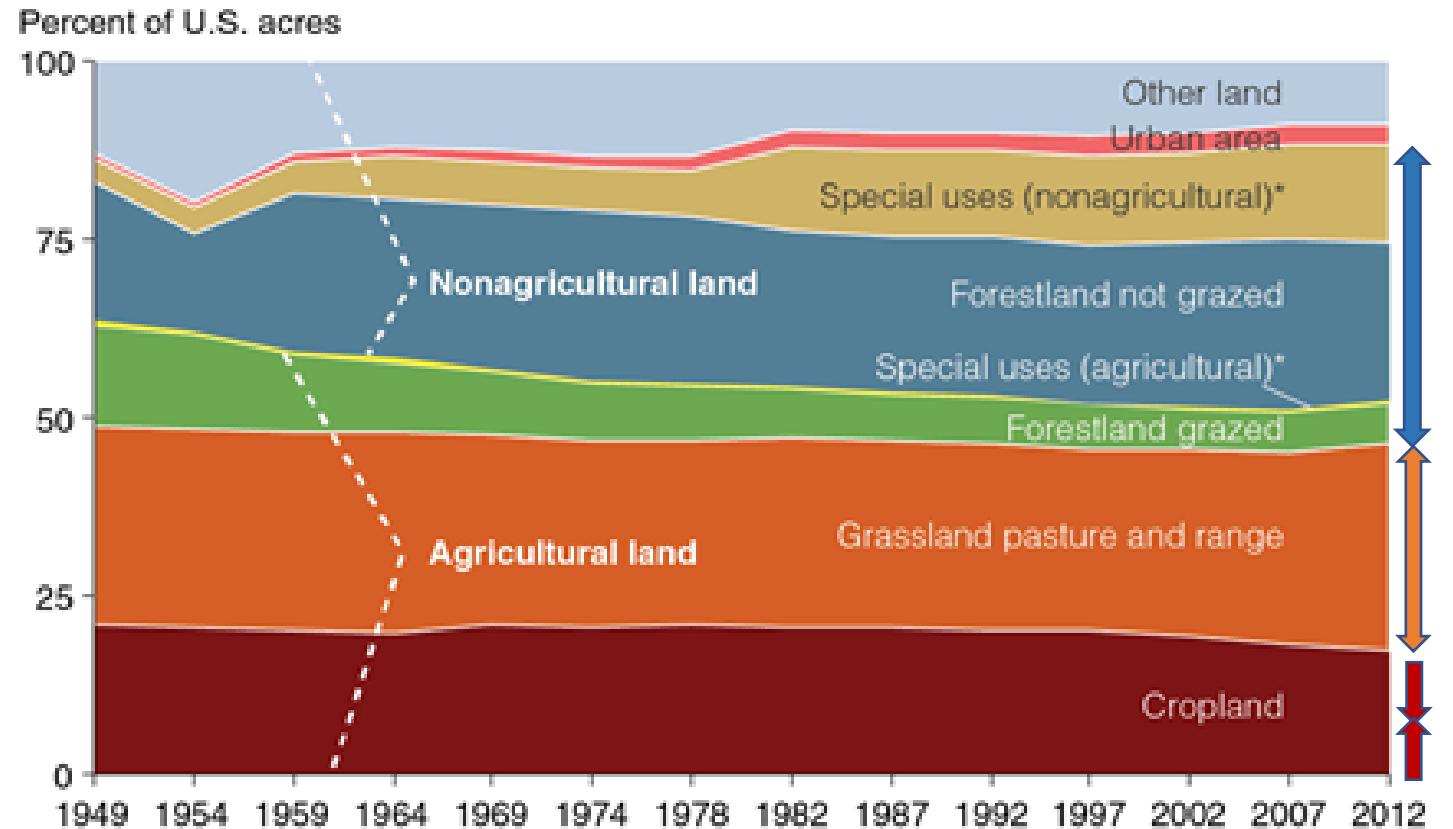
Office of
Science

BIOLOGICAL AND ENVIRONMENTAL RESEARCH
Earth and Environmental System Modeling

Motivation

Land Use in the U.S. has been fairly stable in the last 50-60 years

Share of land used for agricultural purposes has decreased 11 percent since 1949



*Special uses include rural parks and wilderness areas, rural transportation areas, defense/industrial lands (all nonagricultural uses), and farmsteads/farm roads (agricultural uses).
Source: USDA, Economic Research Service calculations using data from USDA, U.S. Department of the Interior, U.S. Department of Commerce, and other sources.

Source: Bigelow, 2017

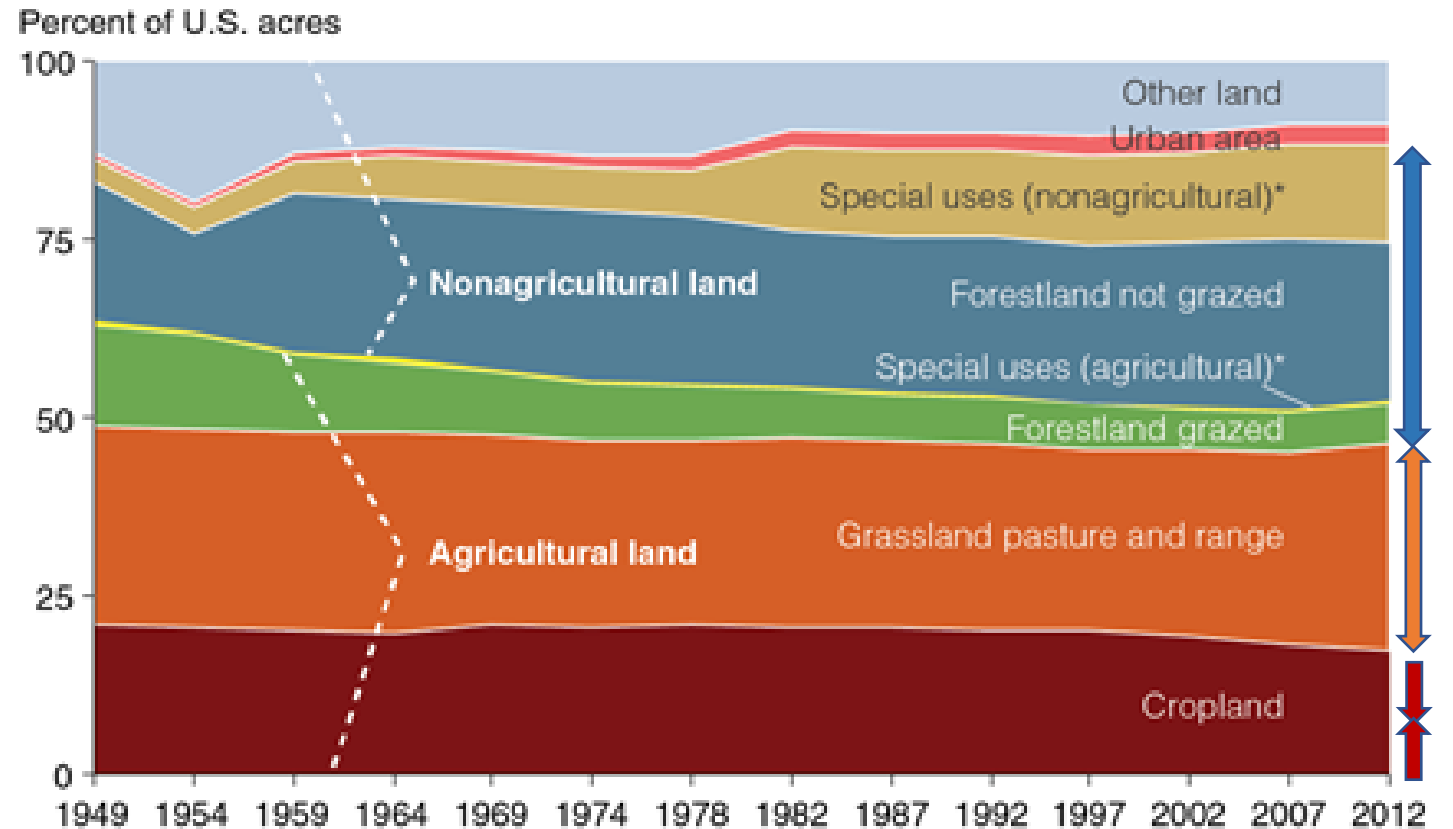
Motivation

Multiple forces influencing land use changes at the global level:

- *income and population growth*
- *yield and productivity improvements*
- *trade policy*
- *climate change*
- *changing diets*

Land use change is critically important for carbon storage, species habitat, biodiversity, and broader ecosystem values!

Share of land used for agricultural purposes has decreased 11 percent since 1949



*Special uses include rural parks and wilderness areas, rural transportation areas, defense/industrial lands (all nonagricultural uses), and farmsteads/farm roads (agricultural uses).
Source: USDA, Economic Research Service calculations using data from USDA, U.S. Department of the Interior, U.S. Department of Commerce, and other sources.

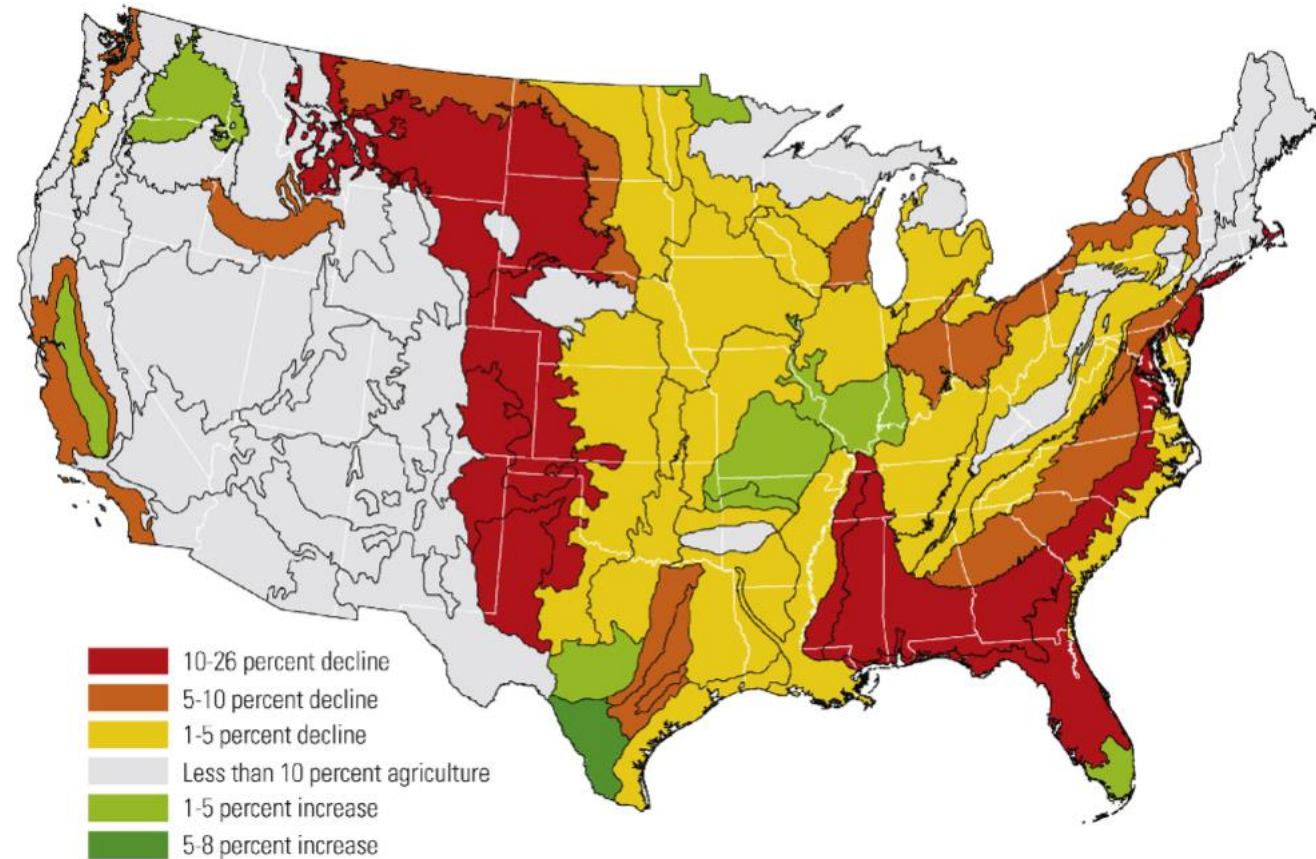
Source: Bigelow, 2017

Motivation

Multiple and compounding forces: is there a tipping point in land use in the US?

“Land-cover change in the conterminous United States from 1973 to 2000”

A. Net change in agricultural cover between 1973 and 2000



Source: Sleeter et al. (2013)

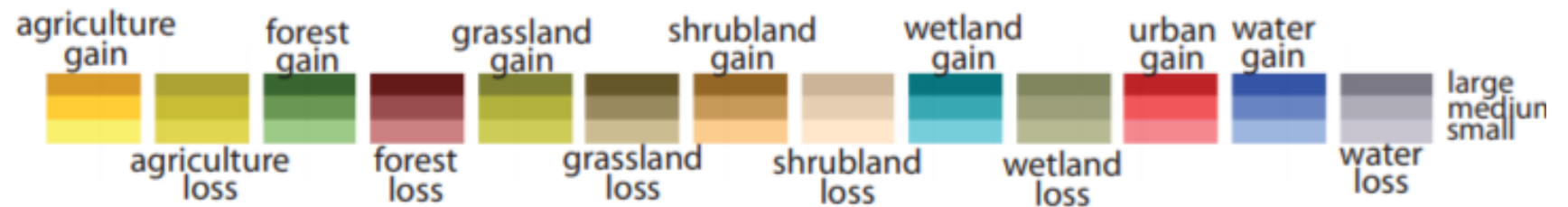
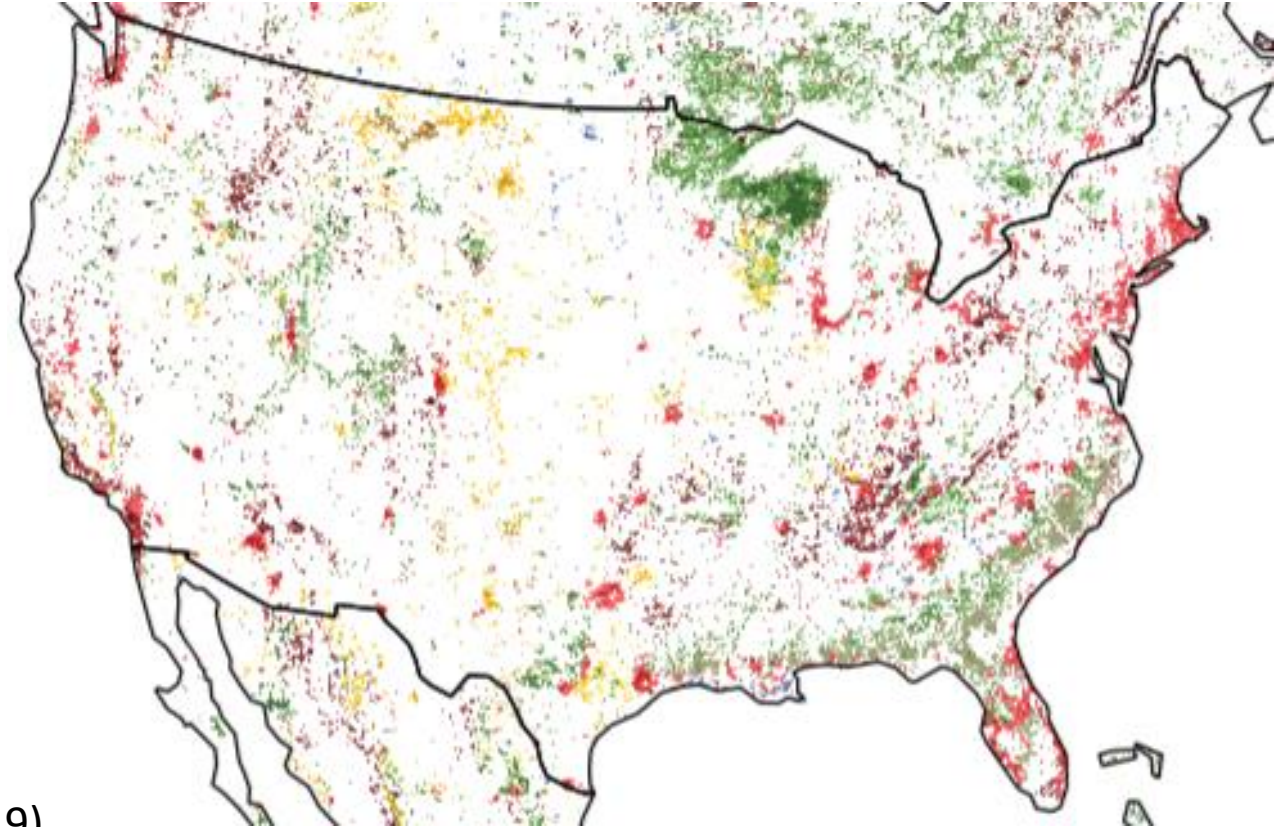
Motivation

“Global assessment and mapping of changes in mesoscale landscapes: 1992–2015”

Multiple and compounding forces: is there a tipping point in land use in the US?

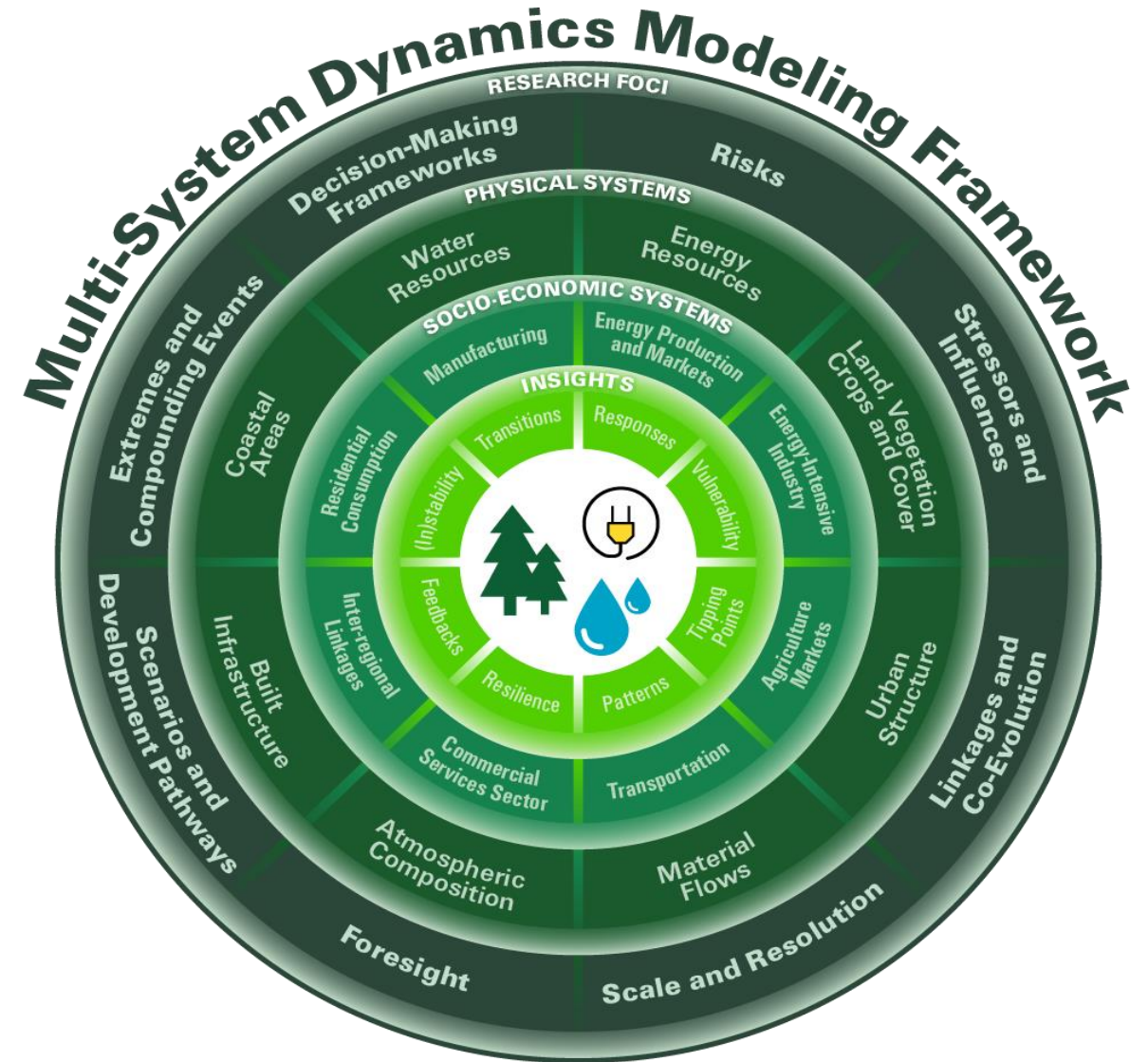
abandonment or *expansion* of land devoted to agriculture?

Source: Nowosad et al. (2019)



Approach/Framework

- **Multisectoral, multisystem dynamics (MSD)** perspective focused on understanding dynamics in complex interdependent systems;
- **Interaction among economic sectors and natural systems;**
- Allows investigating **vulnerability or resilience of systems to compounding forces and stressors;**
- Tool: socio-economic-environmental modeling (**EPPA-Agriculture**)

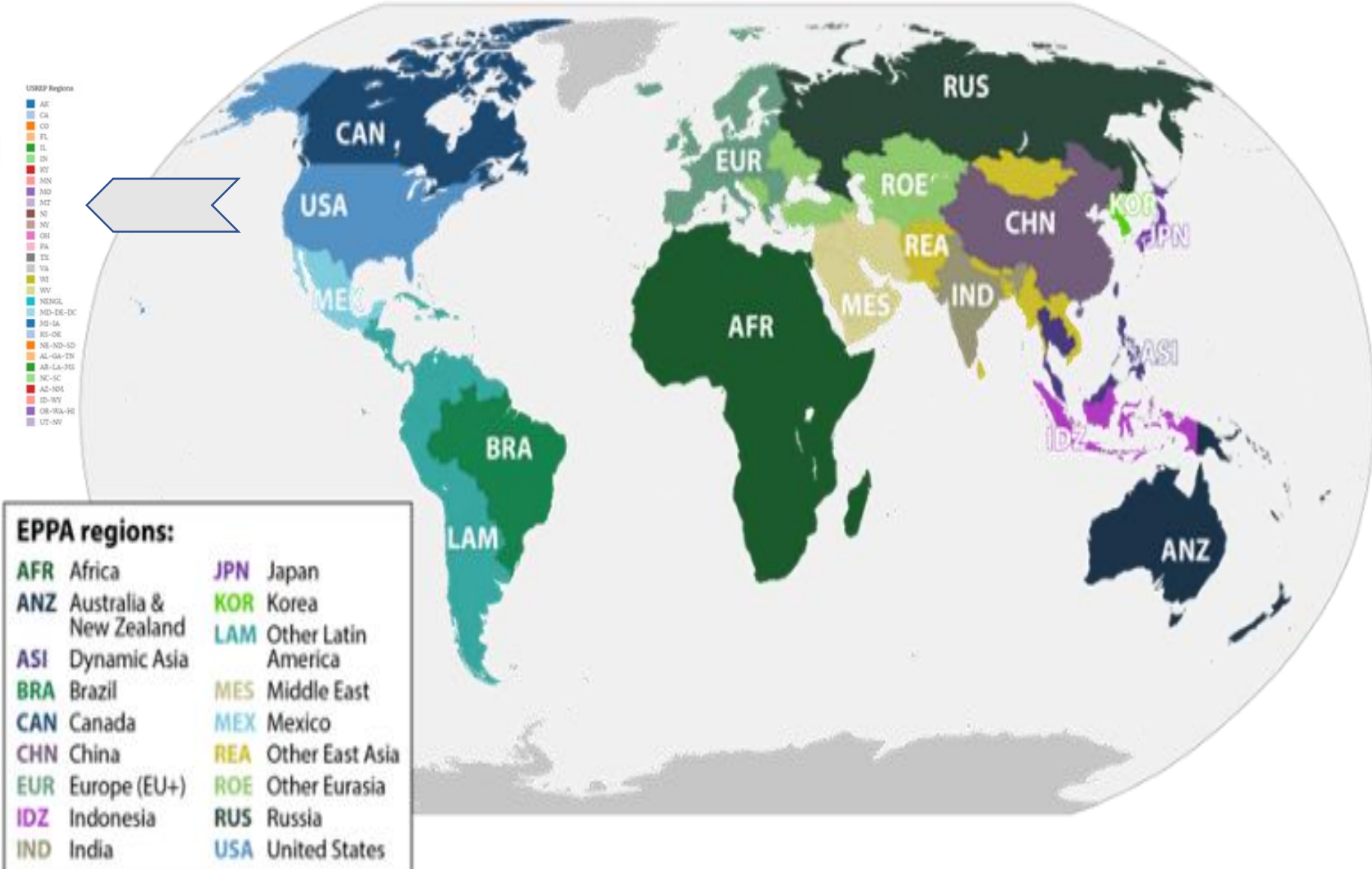


Approach/Framework

Global Drivers and Boundary Conditions



Country- and State-Level
Drivers and
Teleconnections



Approach/Framework

Multi-sectoral representation, natural and economic resources in EPPA-Agriculture

Sectors		Primary Factor Inputs	
Rice	Coal	Depletable Natural Capital	Conventional Oil Resources
Maize	Crude Oil		Shale Oil
Soybean	Refined Oil		Conventional Gas Resources
Wheat	Gas		Unconventional Gas Resources
Sugar Crops	Electricity		Coal Resources
Vegetables & Fruits	Non-Metallic Minerals	Renewable Natural Capital	Natural Forest
Fiber plants	Iron & Steel		Natural Grasslands
Other crops	Non-Ferrous Metals		Solar and Wind Resources
Bovine Cattle	Other Energy-intensive Industries		Hydro Resources
Poultry and Pork	Other Industries	Produced Capital	Conventional Capital (Bldgs & Mach.)
Other Livestock	Construction		Cropland
Forestry	Other Services		Pasture and Grazing Land
Wood Products	Transport		Managed Forest Land*
Food Products	Ownership of dwellings		Labor

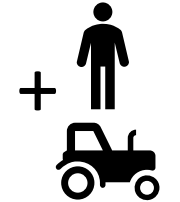
Environmental Resources - Land



Natural grasslands



Natural Forests



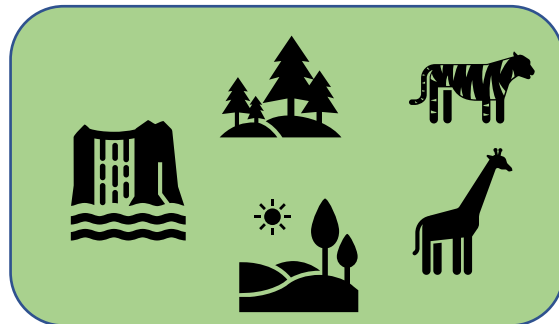
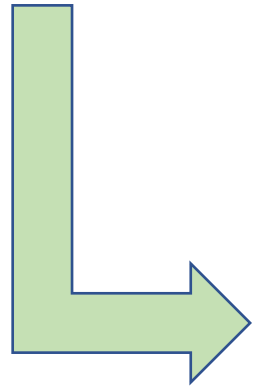
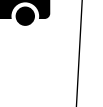
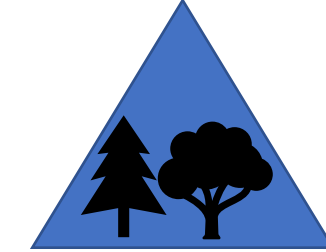
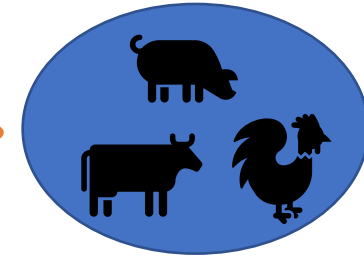
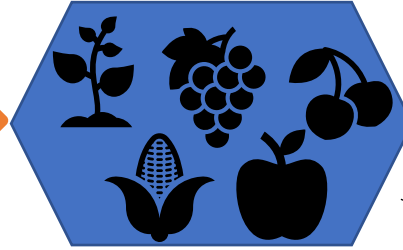
Cropland



Pasture



Managed Forest



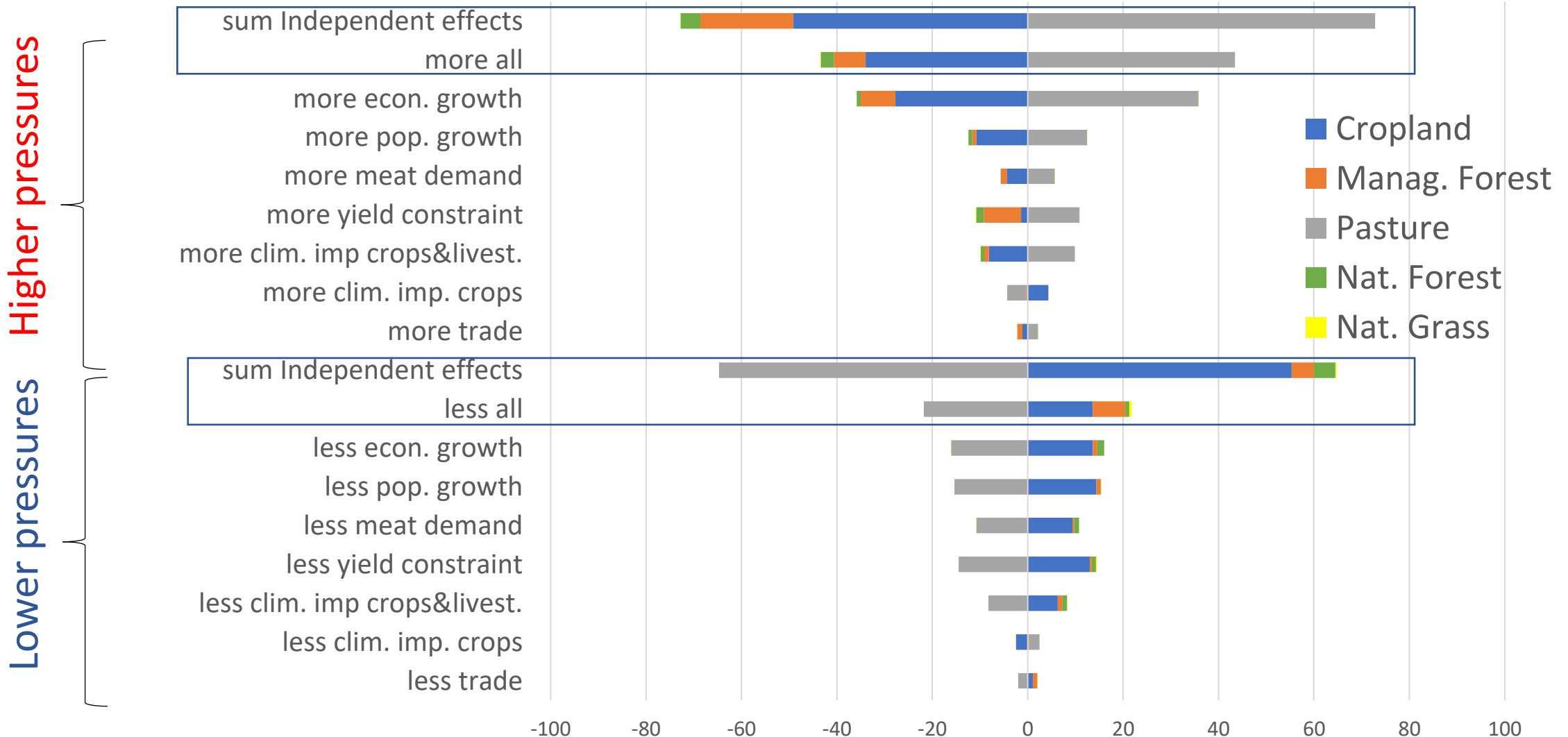
Approach/Framework

Scenarios to explore multiple and compounding global stressors and possible tipping points

Baseline (BAU) – no “stressors”				
Lower pressures	higher tariffs (50%)	Trade	lower tariffs (50%)	Higher pressures
	positive yield impacts	Climate impacts on crops	negative yield impacts	
	positive yield impacts	Climate impacts on crops&Lives.	negative yield impacts	
	1.5% per year gains	Yield gains	0.5% per year gains	
	lower income elasticities	Meat demand	higher income elasticities	
	1% per year lower	Population growth	1% per year higher	
	20% lower	Economic growth	20% higher	
	less all	All	more all	

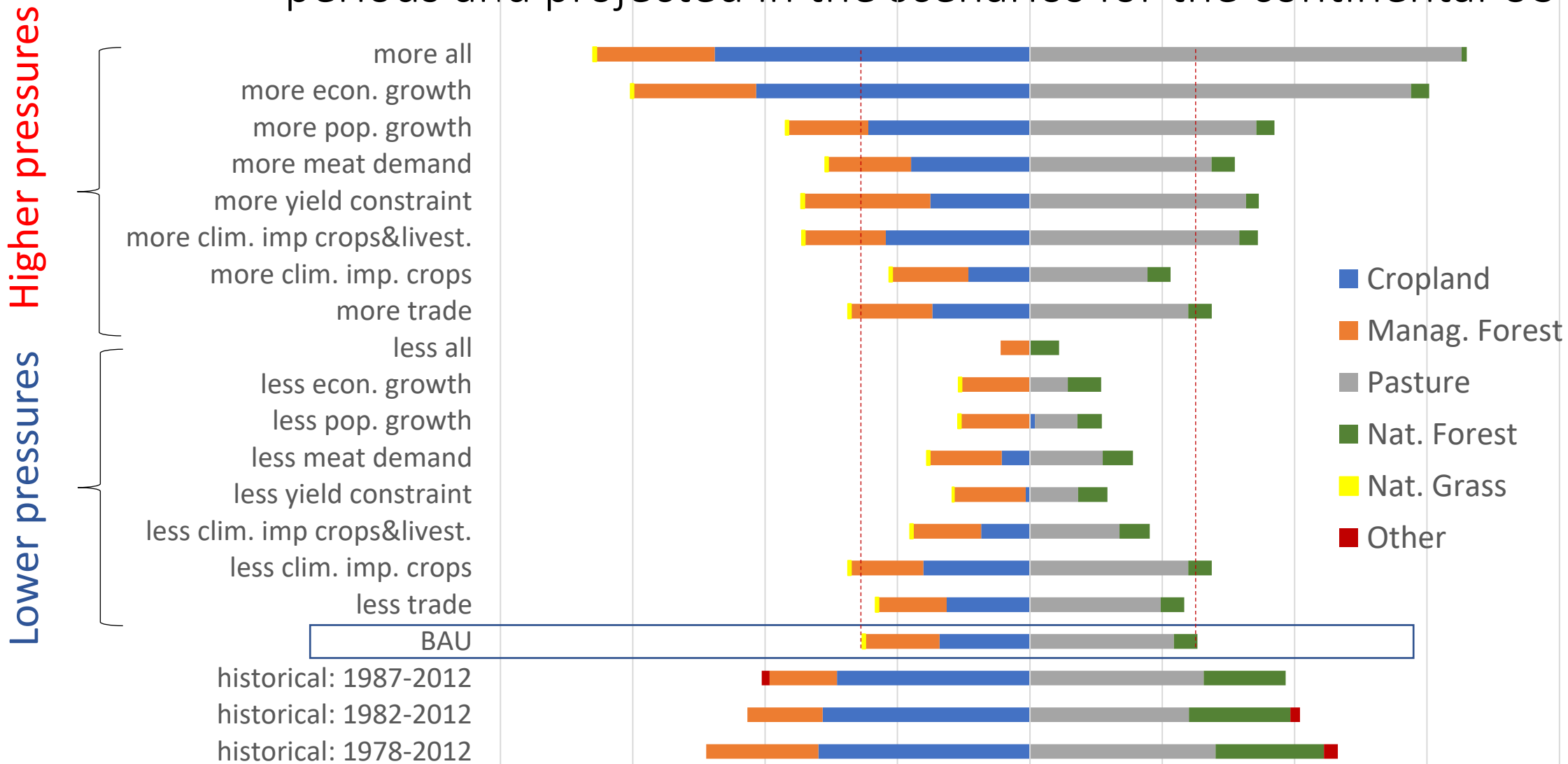
Results

Land use changes in 2050 relative to BAU in US (Mha)



Results

Cumulative Land use changes from 2015 to 2050 in some historical periods and projected in the scenarios for the continental US (Mha)



*Other: urban, defense, transportation and others

Results

Changes in US output, exports and imports in 2050 relative to BAU (%)

MSD approach:
multisectoral
impacts and
interdependences
Lower (higher)
pressures
decrease
(increase) output
and trade in all
sectors

Higher pressures Lower pressures Higher pressures Lower pressures Higher pressures Lower pressures

	Crop			Livestock			Food			Fors&Lum			Energy Intensive Ind.			Other Industries		
	Output	Export	Import	Output	Export	Import	Output	Export	Import	Output	Export	Import	Output	Export	Import	Output	Export	Import
less trade	0	-2	-6	-2	-7	-8	-1	-12	-8	1	0	-3	-1	-8	-2	1	0	-5
less clim. imp. crops	0	-4	-1	1	0	3	0	-2	0	0	0	0	0	0	0	0	0	0
less clim. imp crops&livest.	2	-3	-10	-7	-27	-13	-1	-9	-2	0	-3	0	0	2	1	0	1	2
less yield constraint	13	5	-24	-5	-34	-26	-1	-11	-4	1	-11	3	0	1	2	0	1	2
less meat demand	2	2	-5	-12	-29	-19	-2	-9	-4	0	-1	0	0	1	1	0	1	1
less pop. growth	-4	-8	-29	-23	-44	-37	-23	-26	-22	-28	-30	-23	-27	-23	-21	-29	-26	-21
less econ. growth	-6	-23	-32	-25	-64	-56	-14	-27	-21	-13	-34	-15	-14	-16	-19	-14	-15	-21
less all	-13	-41	-52	-46	-92	-85	-34	-57	-43	-37	-57	-34	-38	-39	-36	-38	-35	-40
sum of independent effects	7	-30	-107	-74	-204	-158	-42	-96	-61	-40	-79	-38	-41	-43	-38	-42	-38	-42
more trade	0	2	8	2	7	10	1	14	12	-1	-2	4	4	20	3	-2	-2	6
more clim. imp. crops	3	13	8	-2	-1	0	0	2	1	0	1	-1	0	-1	-1	0	0	-1
more clim. imp crops&livest.	1	8	16	15	63	27	3	21	5	0	2	-1	-1	-4	-3	-1	-2	-3
more yield constraint	-10	-3	32	3	39	23	1	14	6	-3	6	-3	0	-2	-2	0	-1	-3
more meat demand	-1	-1	5	9	28	20	2	9	4	0	-1	1	0	-1	-1	0	-1	-1
more pop. growth	4	7	44	26	65	48	29	35	28	37	47	28	36	30	25	37	32	23
more econ. growth	7	36	78	54	222	143	21	58	38	15	61	22	16	18	27	16	16	30
more all	1	81	215	55	520	341	69	279	131	47	97	85	57	59	49	57	43	46
sum of independent effects	0	50	183	109	423	270	57	151	93	48	115	51	55	62	49	51	42	52
	Energy			Refined Oil			Electricity			Services			Construction			Transportation		
	Output	Export	Import	Output	Export	Import	Output	Export	Import	Output	Export	Import	Output	Export	Import	Output	Export	Import
less trade	0	1	-1	-1	-2	-2	0	0	0	0	1	-2	1	3	0	0	1	0
less clim. imp. crops	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
less clim. imp crops&livest.	1	2	3	-1	1	1	0	1	0	0	2	-1	0	2	0	0	3	1
less yield constraint	1	3	4	-1	2	2	0	1	0	0	2	-1	0	3	0	0	4	1
less meat demand	0	1	2	0	1	1	0	1	0	0	1	0	0	2	0	0	2	1
less pop. growth	-16	-31	-26	-15	-24	-25	-11	-38	-38	-24	-19	-16	-31	-30	-10	-25	-22	-21
less econ. growth	-13	-26	-22	-6	-18	-18	-7	-24	-20	-14	-9	-21	-13	-11	-8	-13	-10	-20
less all	-25	-46	-42	-16	-39	-37	-17	-50	-48	-35	-24	-33	-40	-34	-15	-34	-27	-36
sum of independent effects	-27	-50	-40	-23	-40	-40	-18	-58	-57	-38	-22	-41	-44	-31	-18	-37	-22	-38
more trade	0	-2	0	1	1	1	0	0	1	0	-4	1	-1	-5	-1	0	-4	2
more clim. imp. crops	0	-1	-1	0	-1	-1	0	0	0	0	-1	0	0	-1	0	0	-1	1
more clim. imp crops&livest.	-1	-4	-4	1	-3	-3	0	-1	-1	0	-3	-1	0	-5	-1	-1	-6	0
more yield constraint	-1	-4	-5	1	-3	-3	0	-2	-1	0	-2	0	0	-4	-1	0	-4	1
more meat demand	0	-1	-2	0	-1	-1	0	0	0	0	-1	-1	0	-2	0	0	-2	1
more pop. growth	20	40	35	17	35	33	27	36	36	32	23	20	43	38	11	32	25	31
more econ. growth	16	36	32	6	28	26	14	20	18	16	3	38	15	5	10	13	0	44
more all	31	54	43	31	52	46	47	51	53	53	14	60	64	12	25	43	-7	95
sum of independent effects	33	65	57	26	57	52	41	53	54	48	15	57	57	27	19	43	9	79

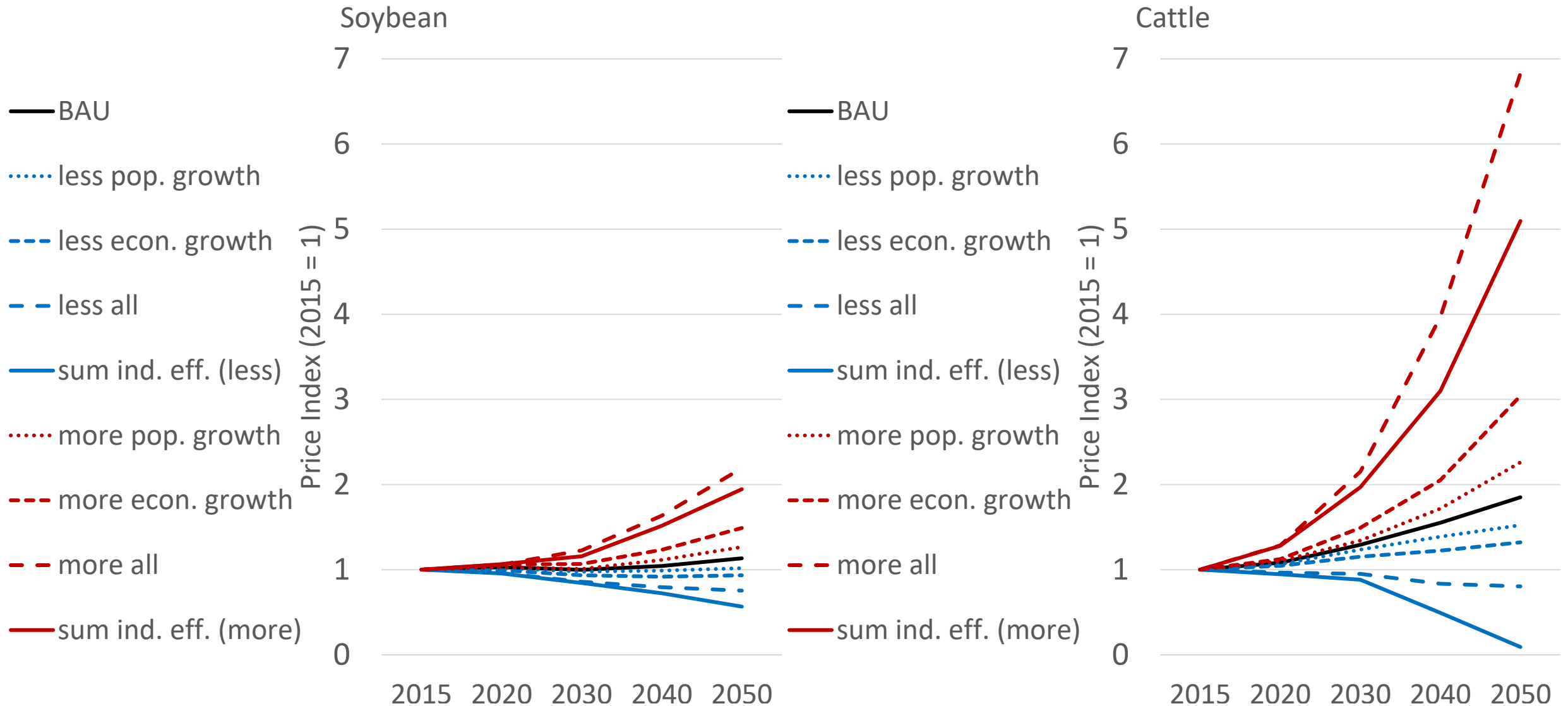
Results

Changes in US output, exports and imports in 2050 relative to BAU (%)

		Crop			Livestock			Food		
		Output	Export	Import	Output	Export	Import	Output	Export	Impo
Higher pressures	less trade	0	-2	-6	-2	-7	-8	-1	-12	-8
	less clim. imp. crops	0	-4	-1	1	0	3	0	-2	0
	less clim. imp crops&livest.	2	-3	-10	-7	-27	-13	-1	-9	-2
	less yield constraint	13	5	-24	-5	-34	-26	-1	-11	-4
	less meat demand	2	2	-5	-12	-29	-19	-2	-9	-4
	less pop. growth	-4	-8	-29	-23	-44	-37	-23	-26	-22
	less econ. growth	-6	-23	-32	-25	-64	-56	-14	-27	-21
	less all	-13	-41	-52	-46	-92	-85	-34	-57	-43
	sum of independent effects	7	-30	-107	-74	-204	-158	-42	-96	-61
Lower pressures	more trade	0	2	8	2	7	10	1	14	12
	more clim. imp. crops	3	13	8	-2	-1	0	0	2	1
	more clim. imp crops&livest.	1	8	16	15	63	27	3	21	5
	more yield constraint	-10	-3	32	3	39	23	1	14	6
	more meat demand	-1	-1	5	9	28	20	2	9	4
	more pop. growth	4	7	44	26	65	48	29	35	28
	more econ. growth	7	36	78	54	222	143	21	58	38
	more all	1	81	215	55	520	341	69	279	131
	sum of independent effects	0	50	183	109	423	270	57	151	93

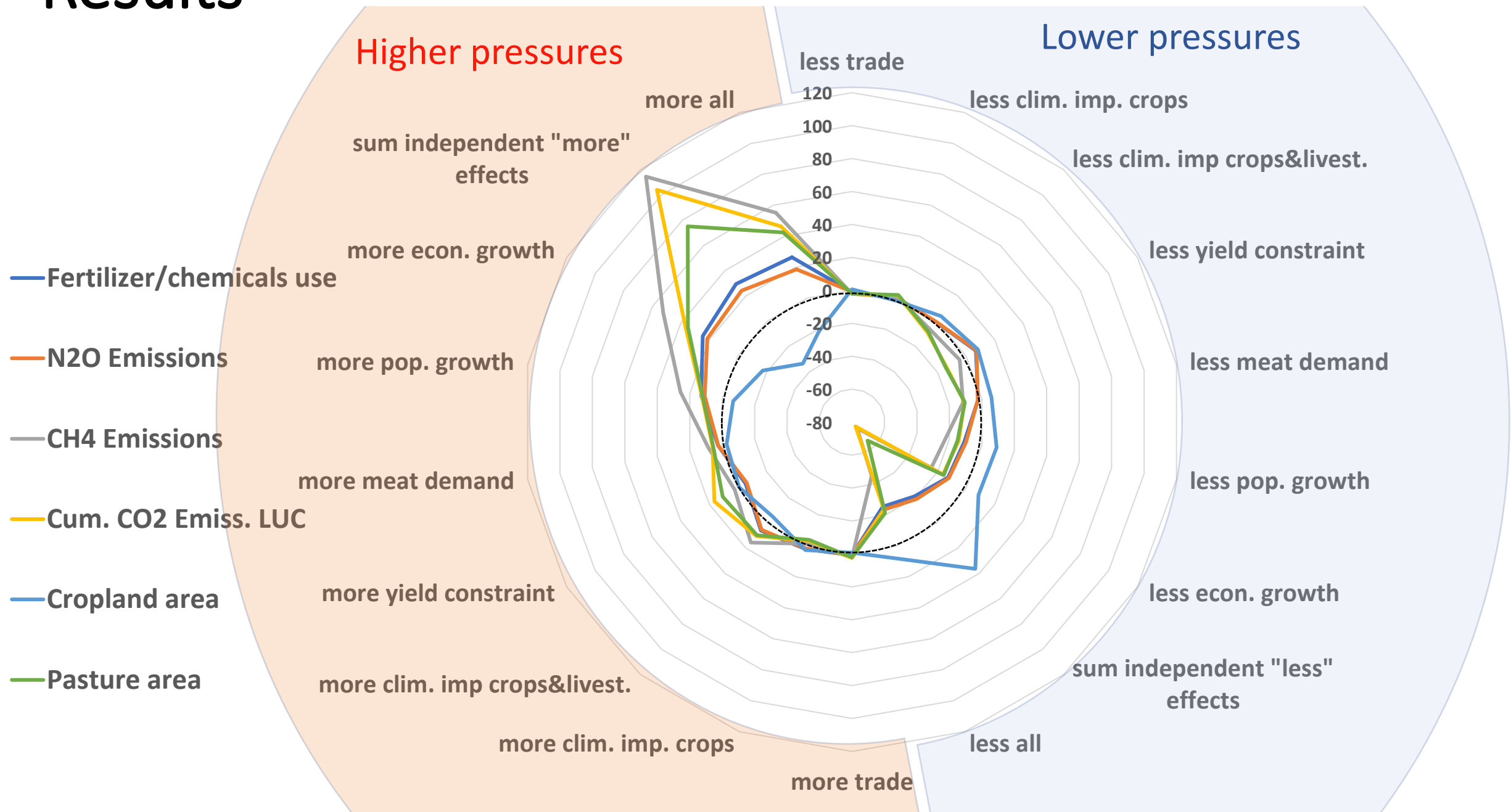
Results

Global agricultural and food price indexes under alternative scenarios: livestock is more impacted than crops



Results

Changes (%) in input use, emissions and agric. areas

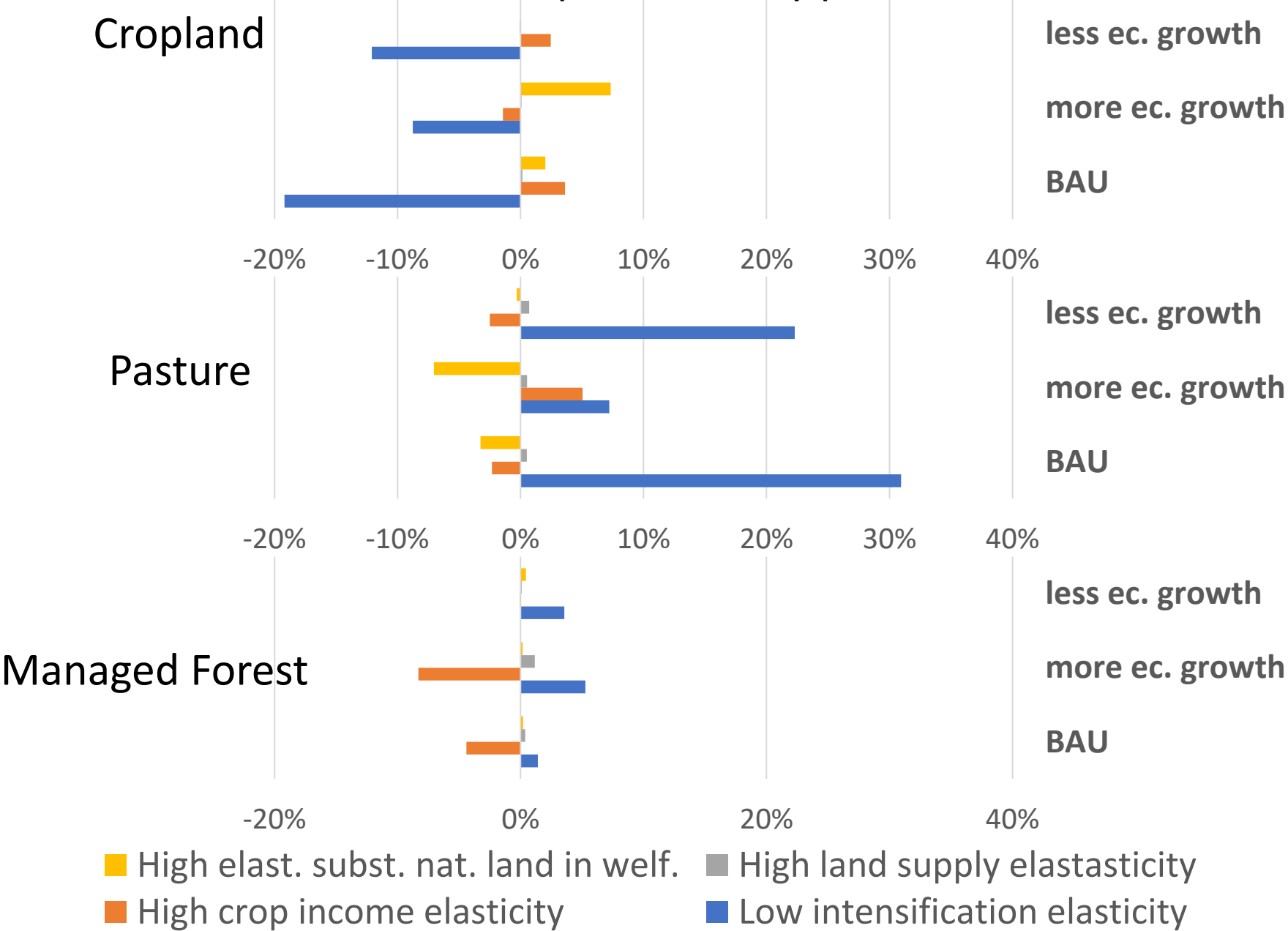


Results

Sensitivity analysis on land use parameters

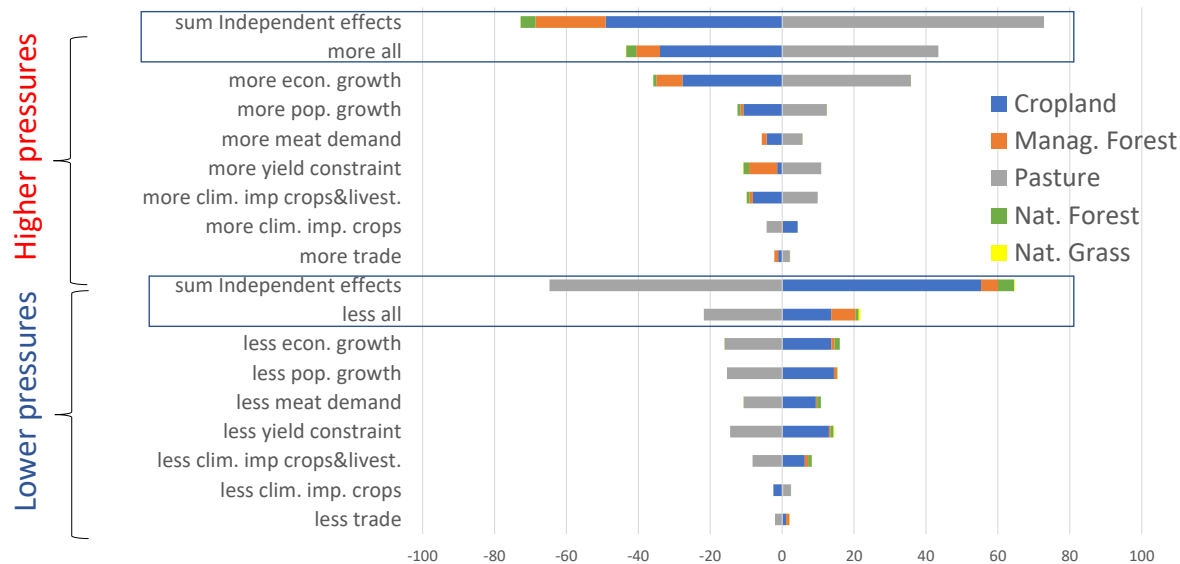
Under limited intensification in livestock production, cropland conversion to pastureland is amplified

Changes in land use in the U.S. by 2050 in selected scenarios under alternative assumptions on key parameters.

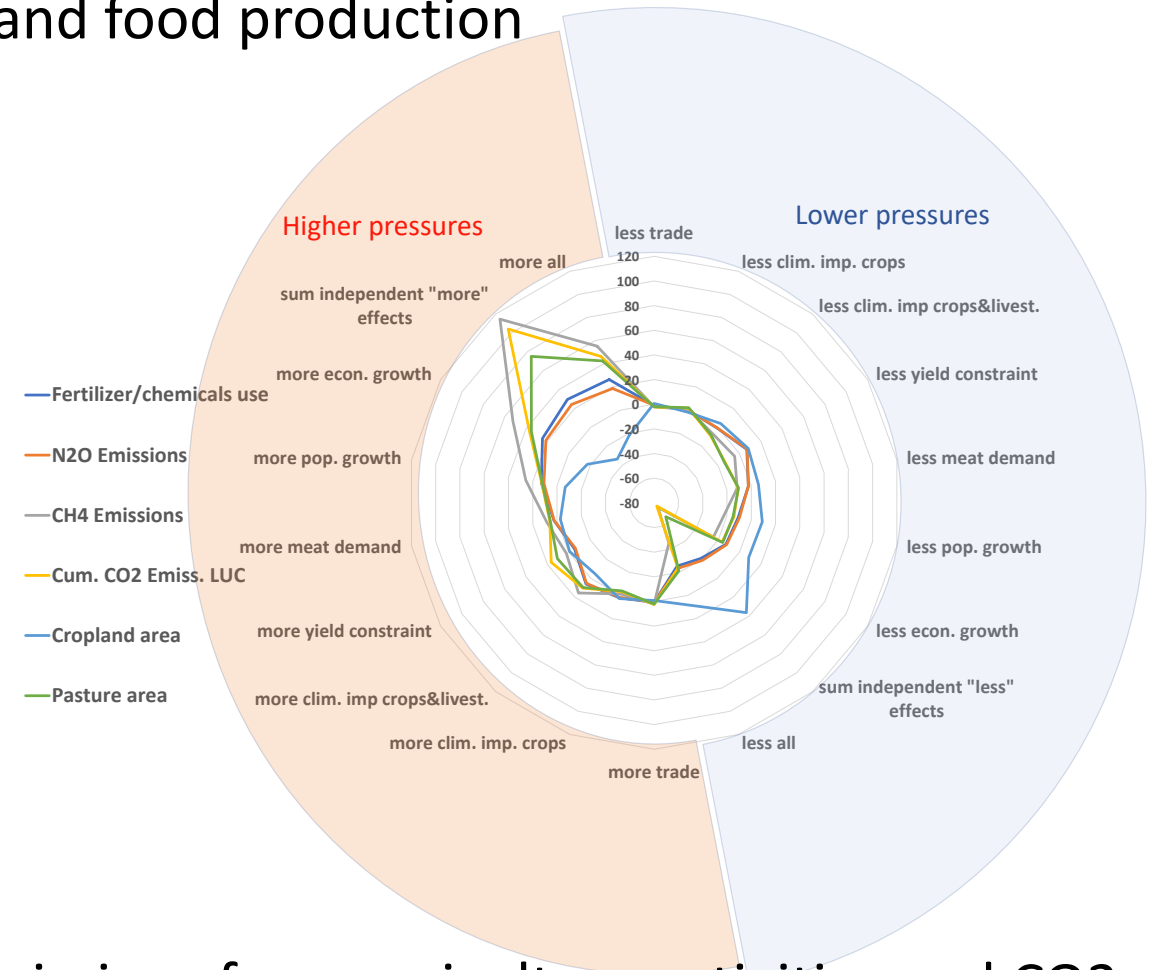


Conclusions

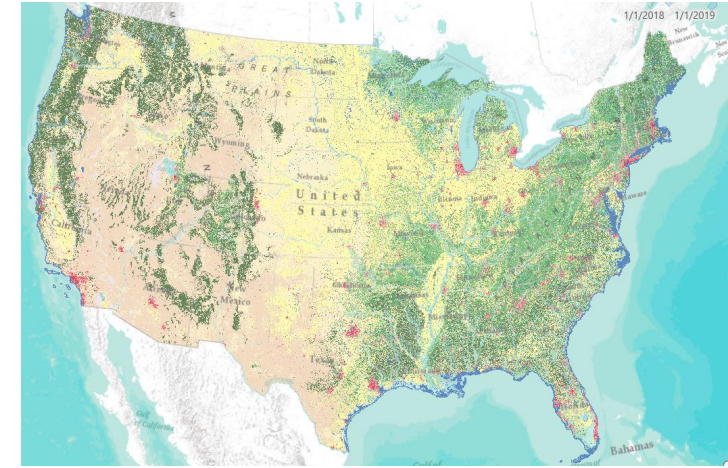
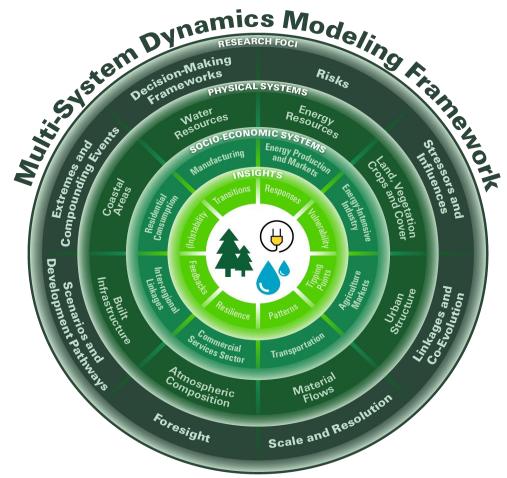
No evidence of tipping points on land use changes in the U.S. from global forces



Current trends are intensified under higher pressures for agricultural land and food production



However, fertilizer use, N2O and CH4 emissions from agriculture activities and CO2 emissions from land use changes are substantially impacted under several land use forcing scenarios.



Thanks for your attention!

gurgel@mit.edu