Using ICLUS v2 to characterize global change impacts, vulnerabilities, and adaptation opportunities.

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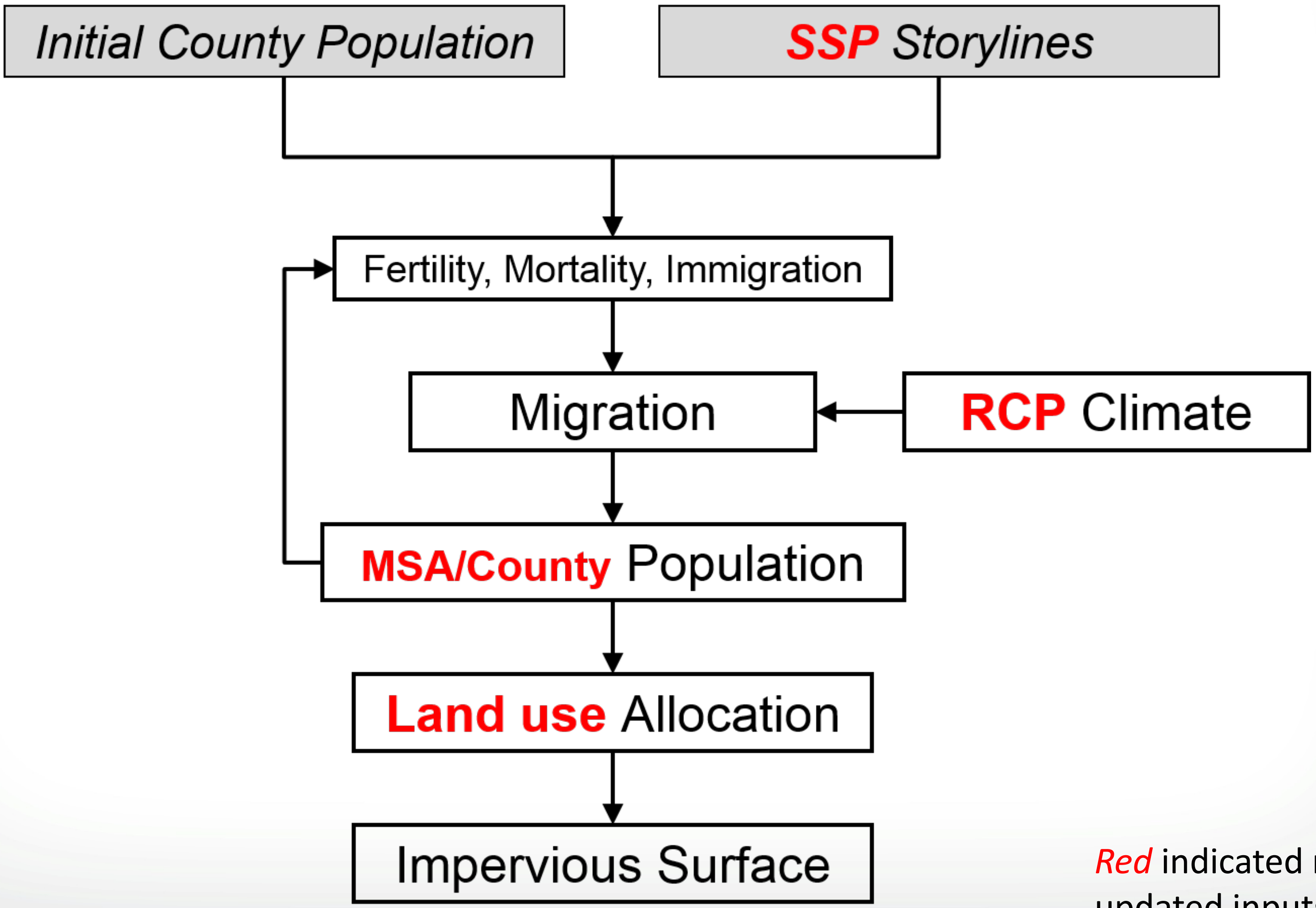
ICLUS version 2



Red indicated new or updated inputs

ICLUS version 2: The Gravity Model

i = origin ICLUS unit

j = destination ICLUS unit

F_{ij} = people migrating from unit i to unit j between year n and $n+1$

D_{ij} = functional distance between unit i and j

P = population density

A = developable land area

SH = mean summer (July) apparent temperature, 10 year running average

SP = mean summer (June, July, August) precipitation, 10 year running average

WH = mean winter (January) apparent temperature, 10 year running average

WP = mean winter (December, January, February) precipitation, 10 year running average

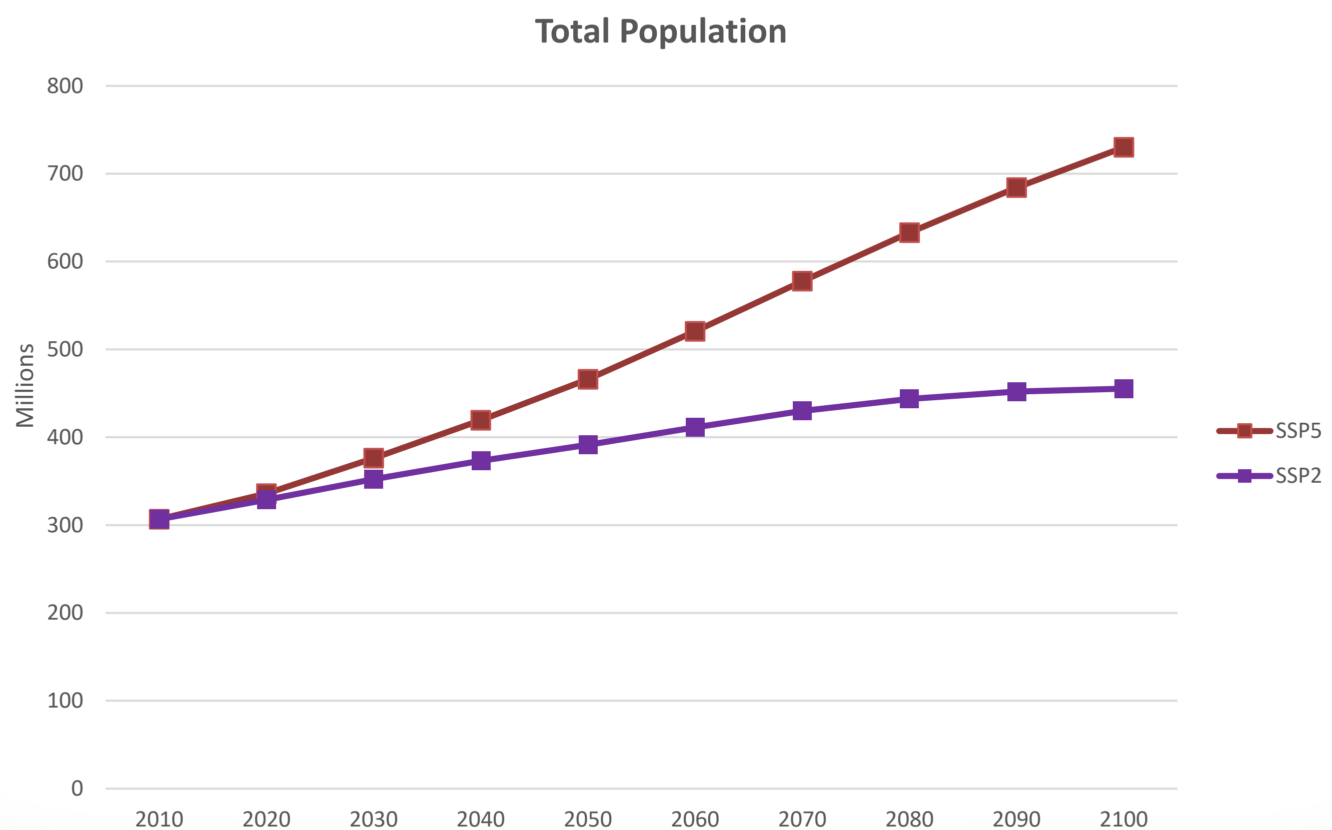
β_k = intercept or slopes quantifying the relationship between the above parameters and number of migrants

$$\ln(F_{ij}) = \beta_0 + \beta_1 * \ln(D_{ij}) + [\beta_2 * \ln(P_i) + \beta_3 * \ln(P_j)] + [\beta_4 * G_i^{-4} + \beta_5 * G_j^{-4}] + [\beta_6 * \ln(A_i) + \beta_7 * \ln(A_j)] +$$

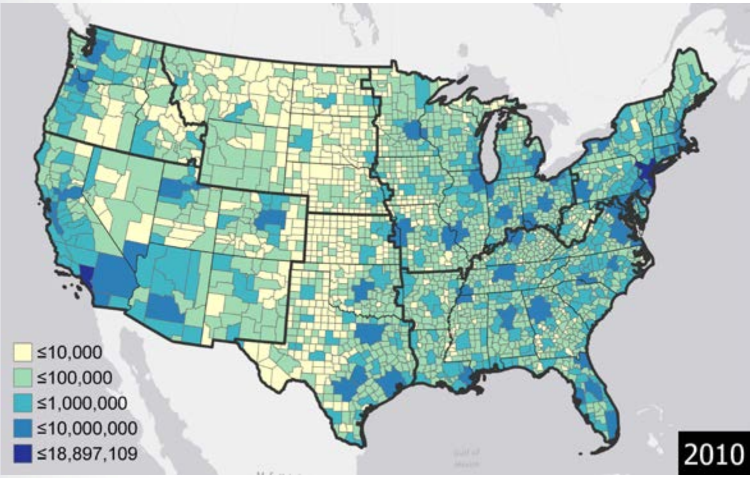
$$[\beta_8 * SH_i + \beta_9 * SH_j] + [\beta_{10} * WH_i + \beta_{11} * WH_j] + [\beta_{12} * SP_i + \beta_{13} * SP_j] + \left[\beta_{14} * WP_i^{1/2} + \beta_{15} * WP_j^{1/2}\right] +$$

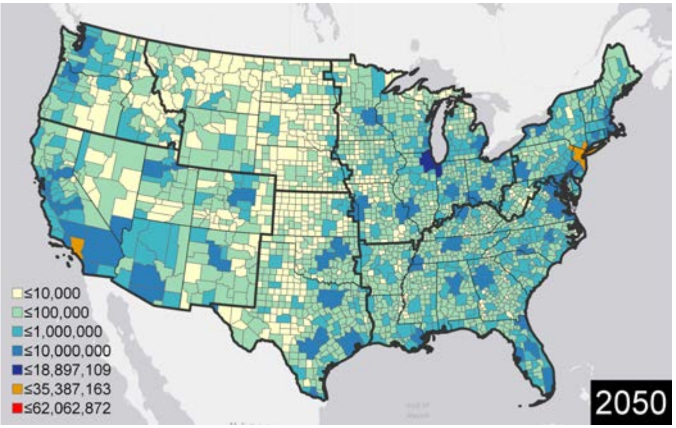
$$[\beta_{16} * SH_i * SP_i + \beta_{17} * SH_j * SP_j] + \left[\beta_{18} * WH_i * WP_i^{1/2} + \beta_{19} * WH_j * WP_j^{1/2}\right]$$

ICLUS version 2: Total population

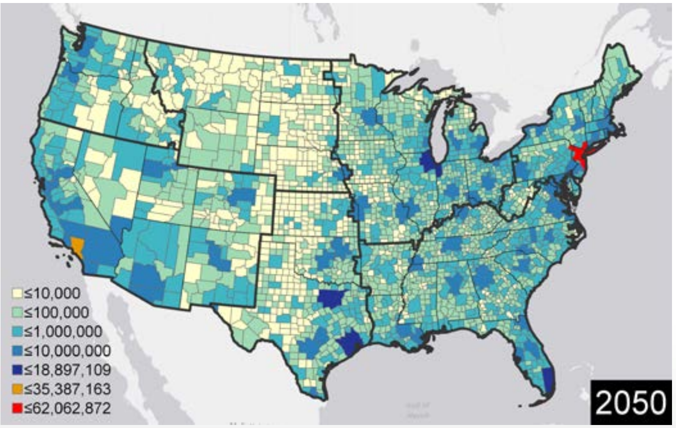


ICLUS version 2: County population



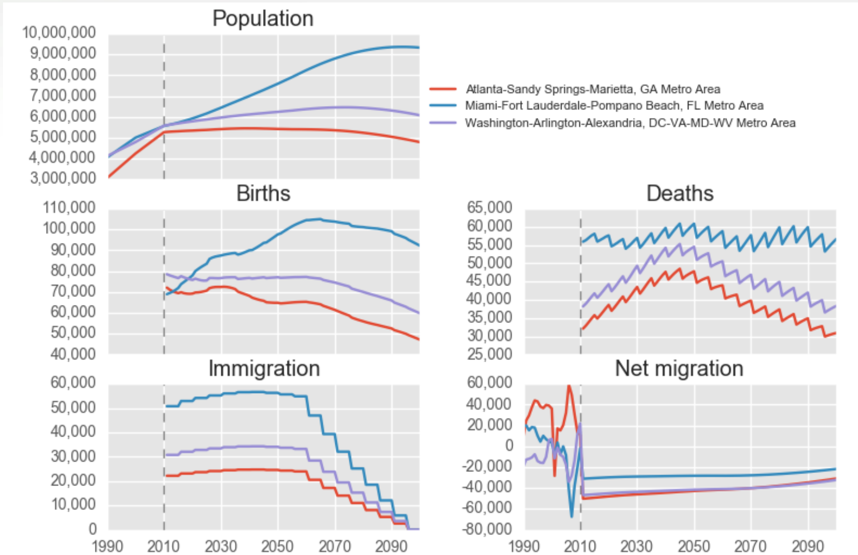


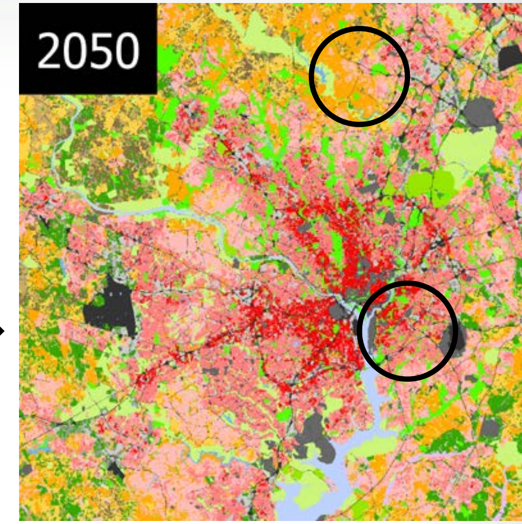
SSP2



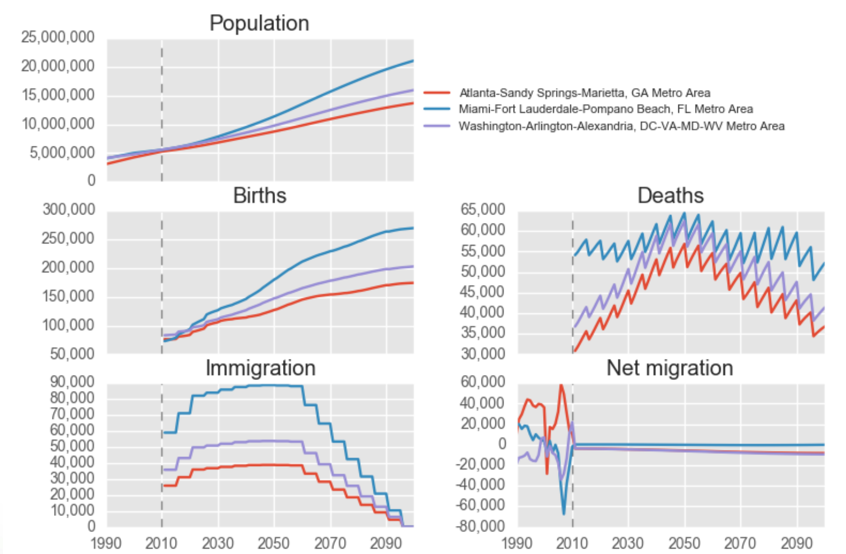
SSP5

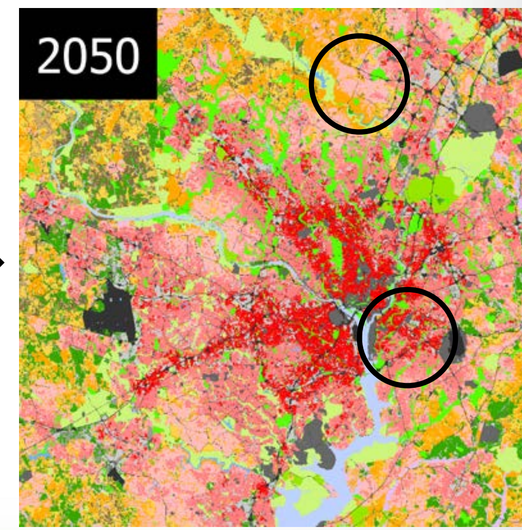
SSP2
Demographic
Assumptions





SSP5
Demographic
Assumptions





Part II: Assessing the future of mobile emissions

Research objective and questions

Quantify trajectories of passenger vehicle emissions under high- and medium-population scenarios.

- **Examine the interplay between population, land use change and emissions standards with respect to passenger vehicle emissions**
- **Which areas of the country experience notable increases/decreases?**

Modeling & analysis approach

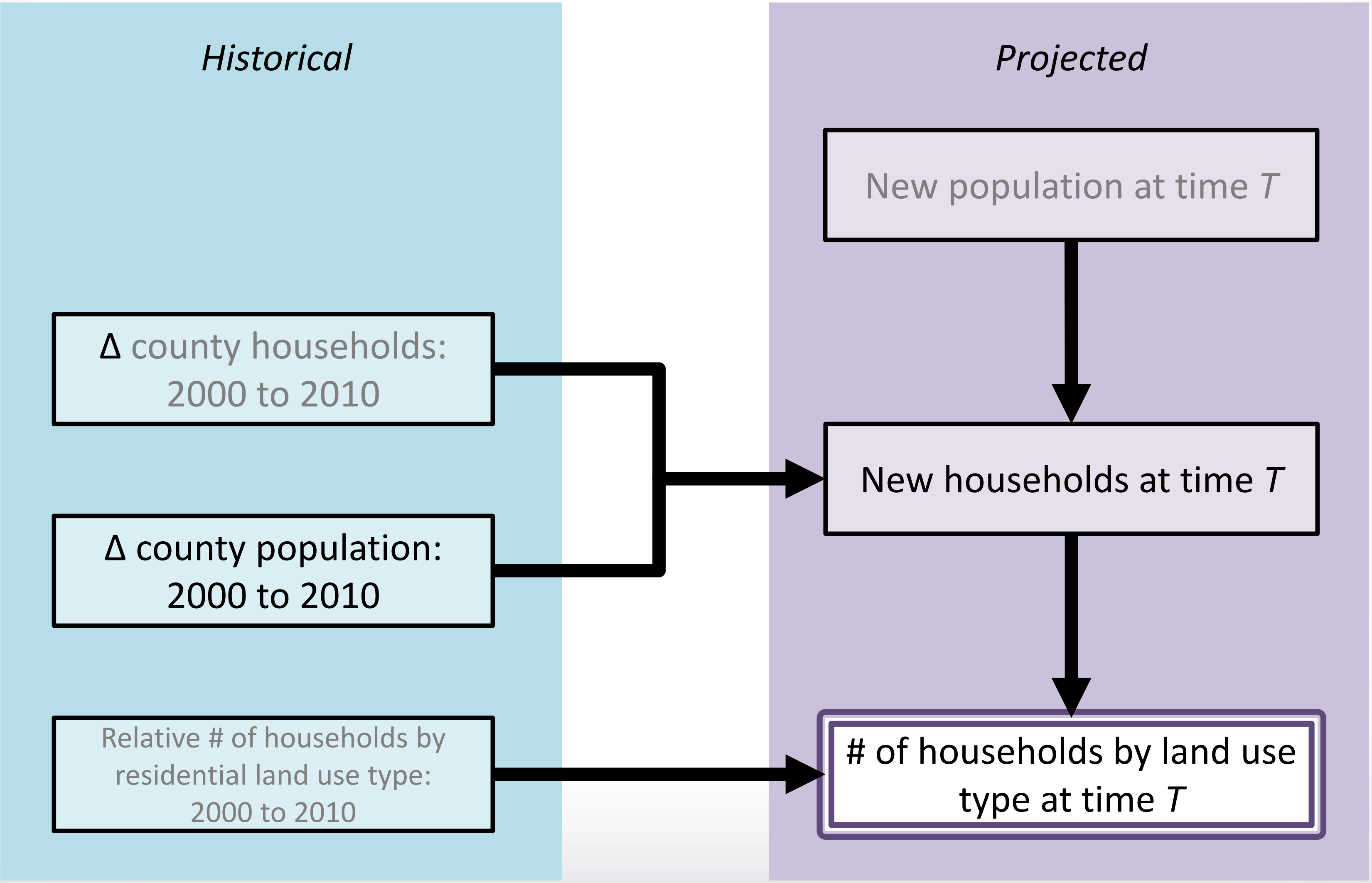
1. **Use ICLUS v2 to model population and land use changes**
   - County-level
   - Decadal to 2100

2. **Allocate households to residential density classes**
   - High-density urban
   - Urban
   - Suburban
   - Exurban
   - Rural

3. **Calculate VMTs per household as a function of residential density**

4. **Use MOVES 2014 to calculate changes in passenger vehicle emissions**
   - Use 2010 as the baseline for comparison

Allocating households to land use types



Generating Vehicle Miles Traveled (VMTs)

Based on the ICLUS model outputs, we are currently relying on a simple model to define VMT per household per year as a function of housing density for each category of housing in ICLUS v2:

$$VMT_i = \sum_j \left(32{,}237 * HD_j^{-0.3135} * HH_{ij}\right),$$

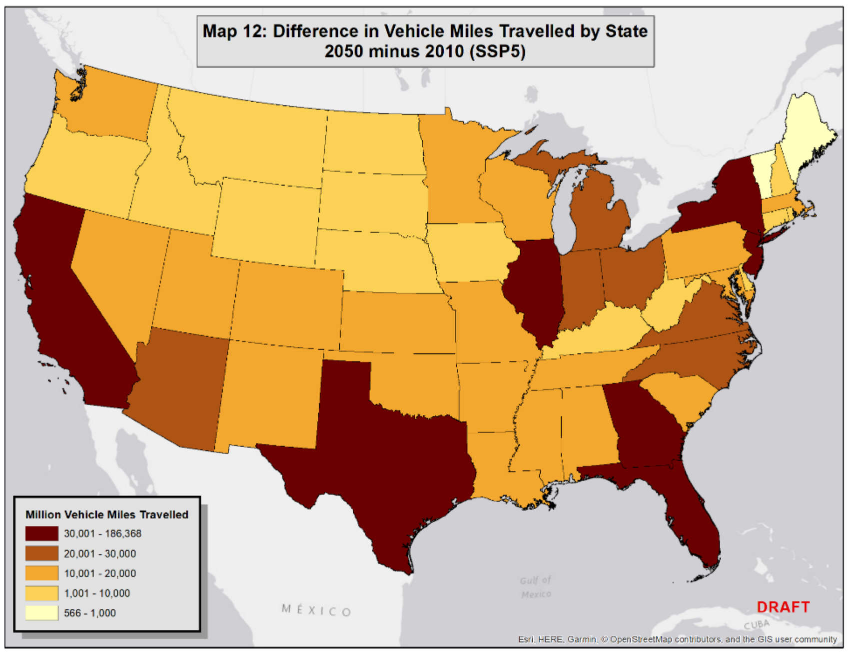
where:

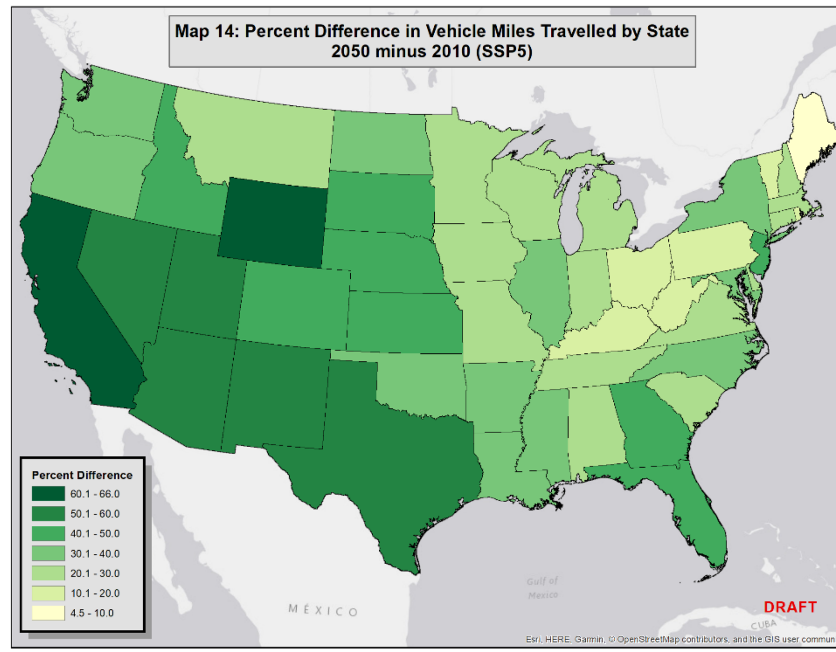
VMT_i = Vehicle Miles Traveled per year by residents of county i,
HD_j = Households per acre for housing type j,
HH_{ij} = Number of households in county i in housing type j.

Source: ICLEI, undated. Density- VMT Calculator. Available at: http://www.icleiusa.org/action-center/tools/resolveuid/4d86e0a42c31474c5d73100200a1c4e0. Accessed June 24, 2014.

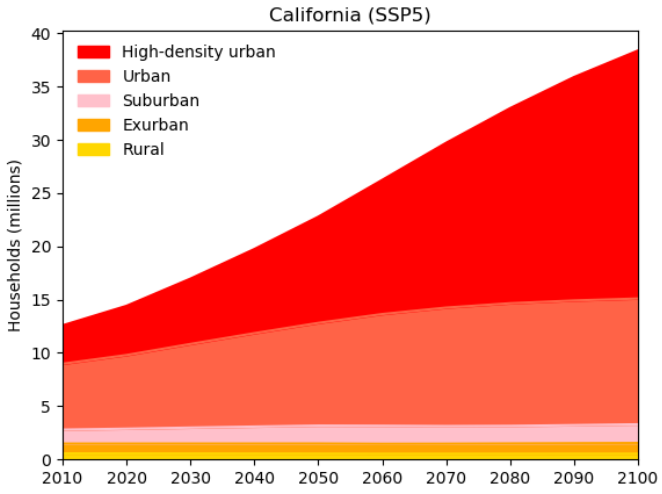
Initial assessment of state-level results

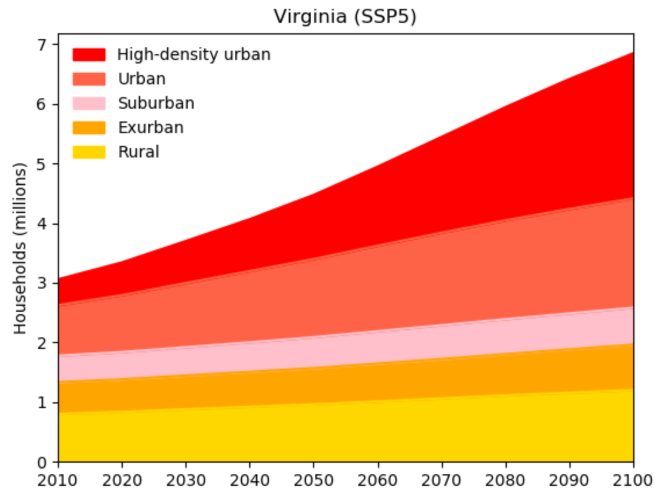
1. **At 2050: VMT increase in all states. Attributed to overall population growth, despite overall densification of human settlements.**





New households, growth and densification



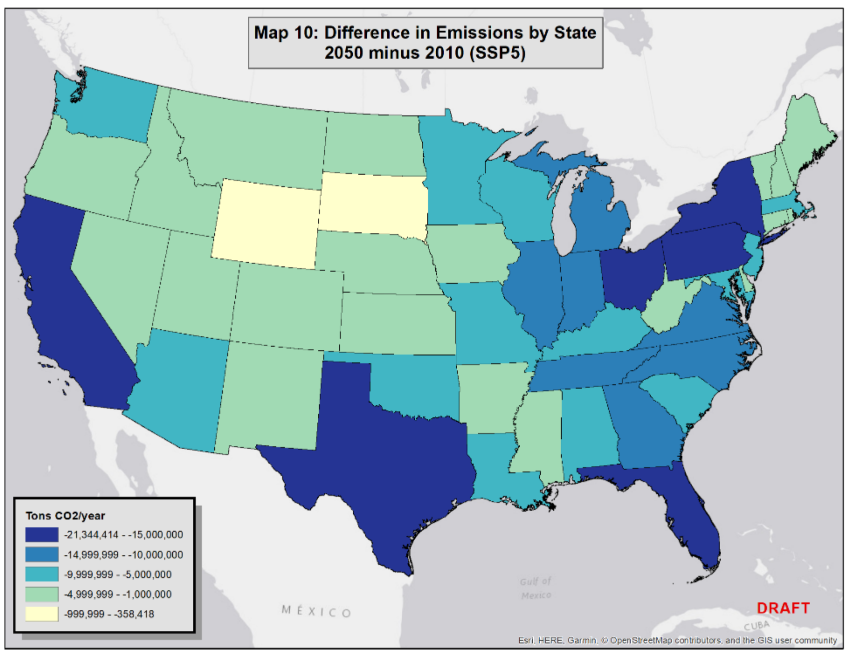


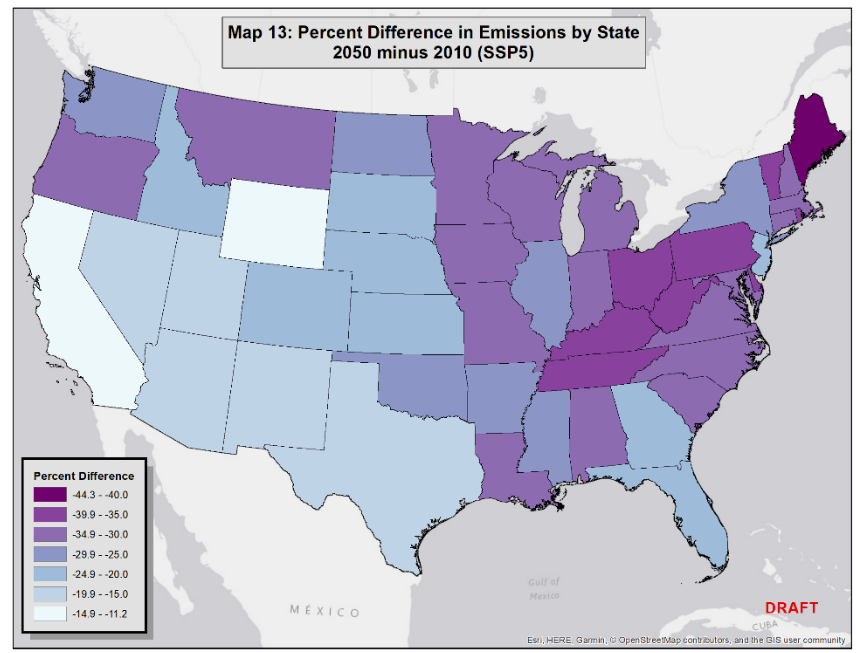
- **The proportion of (High-density) Urban households grows considerably**
- ***Densifying***

- **The proportion of (High-density) Urban households grows.**
- **But the number of households in Exurban and Rural also increases.**
- ***Less densifying?***

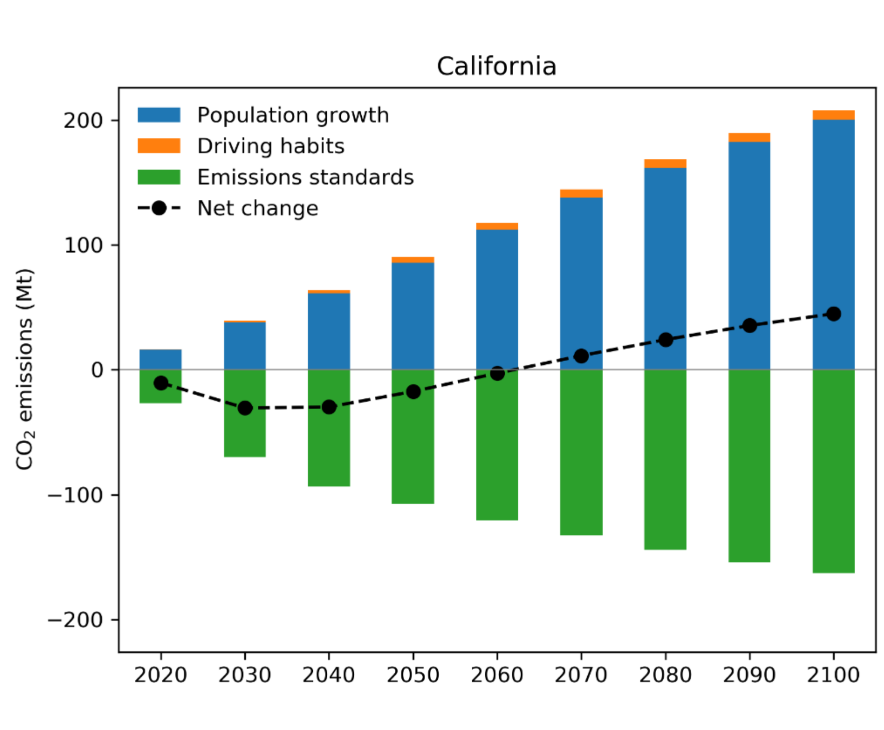
Initial assessment of state-level results

2. Despite increased VMT, emissions *decline* in every state through 2050. Attributed to emissions standards.



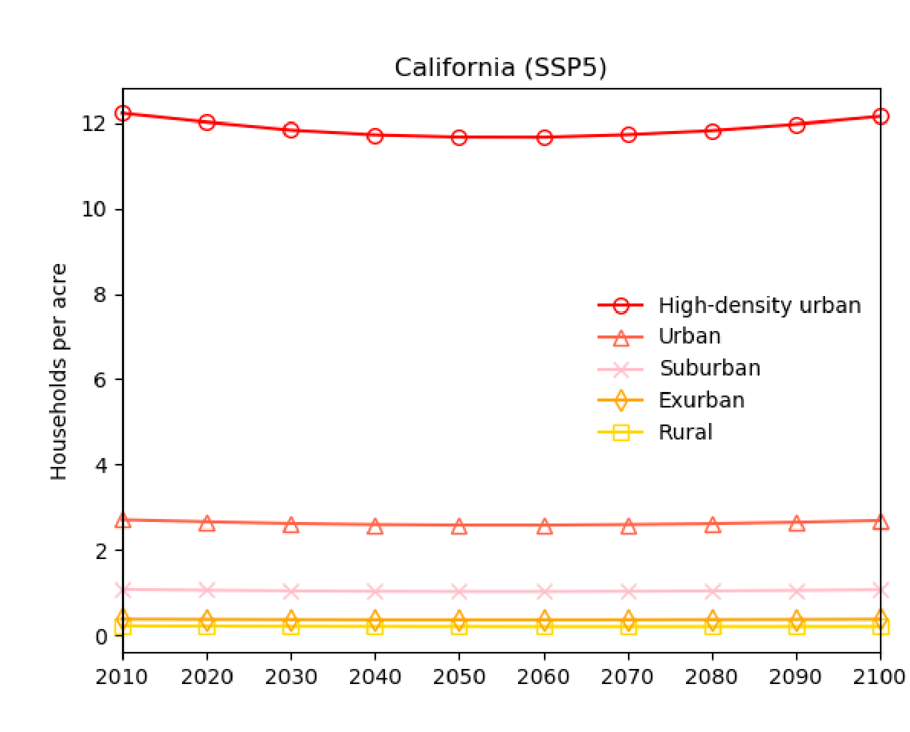


Decomposing the decline in emissions: California



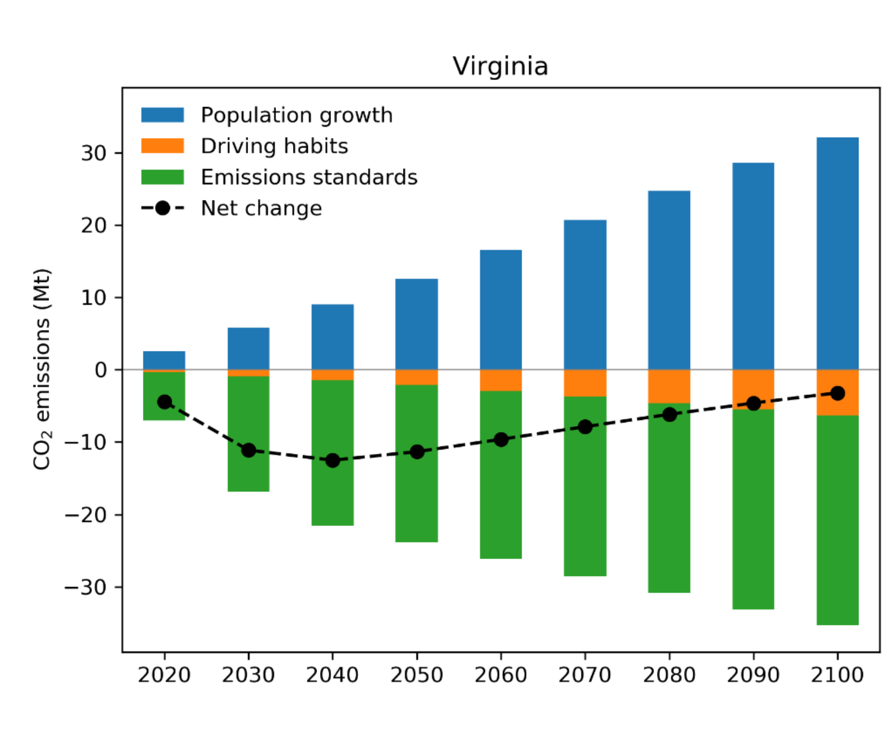
- **Densification should reduce per-person VMT ("Driving habits")**
- **Instead, per-person VMT *<u>increased</u>* in several states**

Sprawl and VMT: California



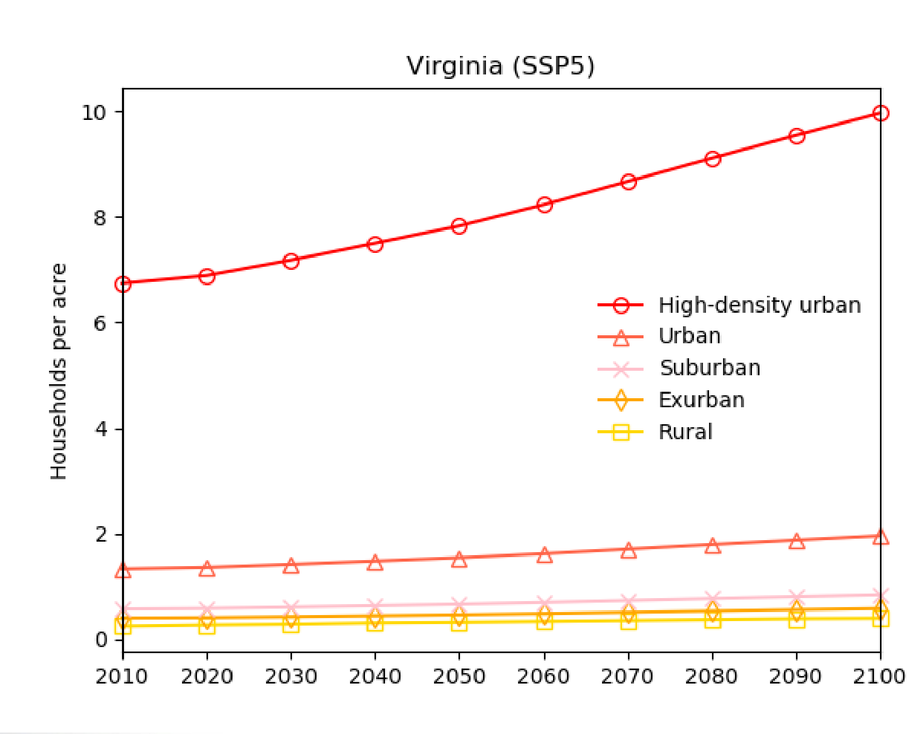
- When development outpaces population growth (sprawl)
  - average density decreases
  - per-person VMT increases
- Sprawl-y development could mean that High-density urban is not as dense in 2030, 2040, … as it was in 2010.

Decomposing the decline in emissions: Virginia



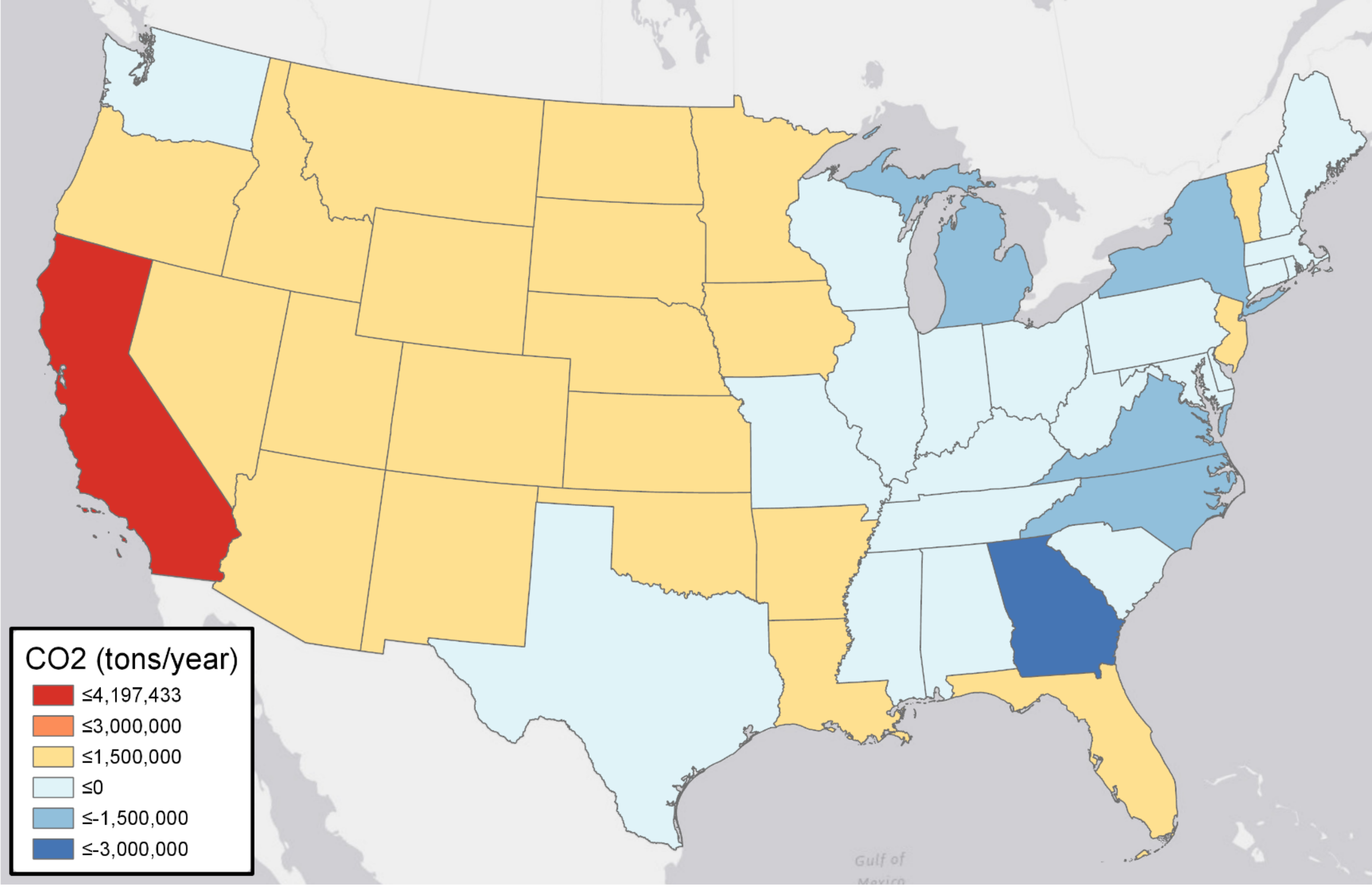
- **In some cases, changing driving habits due to densification help reduce emissions.**
- **It's possible that these factors collectively reduce emissions (relative to 2010) through 2050, or even the end of the century.**

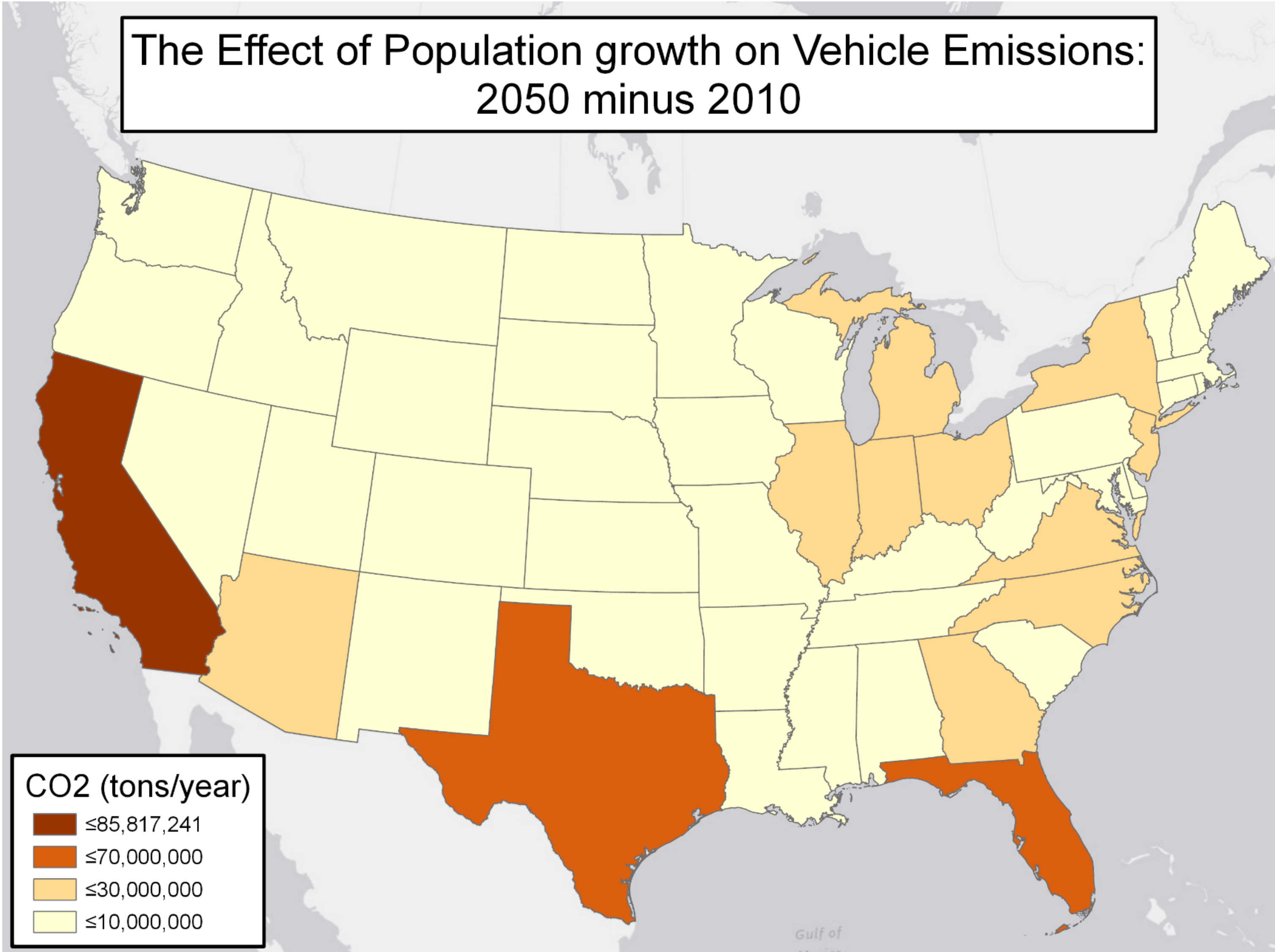
Sprawl and VMT: Virginia

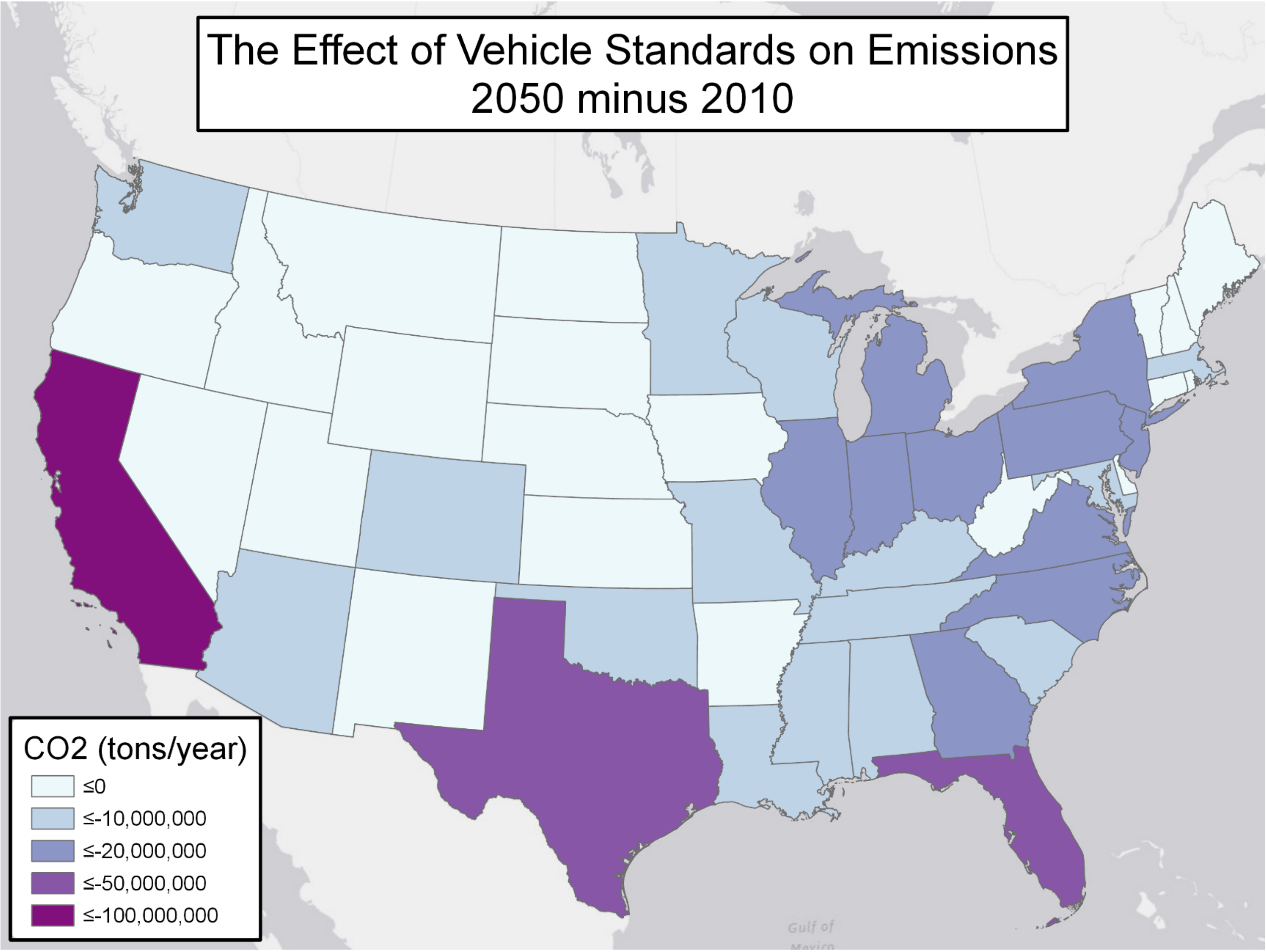


- **All residential land use types become more dense after 2010.**
- **More density → fewer VMT per person**

The Effect of VMT-per-person on Vehicle Emissions: 2050 minus 2010




The Effect of Population growth on Vehicle Emissions:
2050 minus 2010
CO2 (tons/year)
≤85,817,241
≤70,000,000
≤30,000,000
≤10,000,000
Gulf of
Mexico


The Effect of Vehicle Standards on Emissions
2050 minus 2010
CO2 (tons/year)
≤0
≤-10,000,000
≤-20,000,000
≤-50,000,000
≤-100,000,000

Assessing the results

- **Existing emissions standards for passenger vehicles can entirely mitigate population growth – and more – through 2050**

- **After 2050, additional standards may be needed; none of the states densify quickly enough to overcome population growth in our simulations**

- **The role of land use change is complicated; overall density of households needs to increase in order to realize a benefit**

Limitations and unknowns

- Assumptions of stationarity
  - Average household size (by county)
  - Relative proportion of households by land use type (by region)
- Single VMT equation
  - Holding the density of each land use type constant decreases emission even more
- The role of technological innovation
  - Electric cars
  - Self-driving cars

Part III: An integrated assessment of land use/land cover change

Assessing land cover/land use

- Few studies account simultaneously for:
  - Expansion of developed land
  - Market responses of agricultural and forest landowners
  - Interactions between agriculture and forestry land use
- In this study, we combine the projections of developed land use from ICLUS v2 with the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG)
- FASOMGHG is an economic model of the US agriculture and forestry sectors that provides detailed representation of agricultural and forestry management, production, and markets as well as environmental outcomes
- This study expands on existing literature to further explore tradeoffs between agriculture and forest land use under alternative RCP/SSP scenarios while accounting for exogenous land transfers out of agriculture and forest uses into developed uses
  - Consistent reflection of SSP/RCP assumptions across impact categories
  - Exploration of interactions between development and climate change under these scenarios

Research objective and questions

Use temperature and precipitation scenarios to explore interactions between population change, urban growth, agriculture and forestry.

- Simultaneously account for climate amenities as a driver of migration, urban growth, yield and productivity changes, and market responses from land owners
- Explore sensitivities from scenario assumptions and climate models choice
- Which areas of the country may be subject to the largest changes?

Modeling & analysis approach

1. **Identify four projections of future temperature and precipitation that describe divergent future conditions**
    - Two scenarios
        - SSP2 (medium population) and RCP4.5 (medium emissions)
        - SSP5 (high population) and RCP8.5 (high emissions)
    - Two climate models
        - GISS-e2-r (lower sensitivity to CO_2 increases)
        - HadGEM2-ES (higher sensitivity to CO_2 increases)

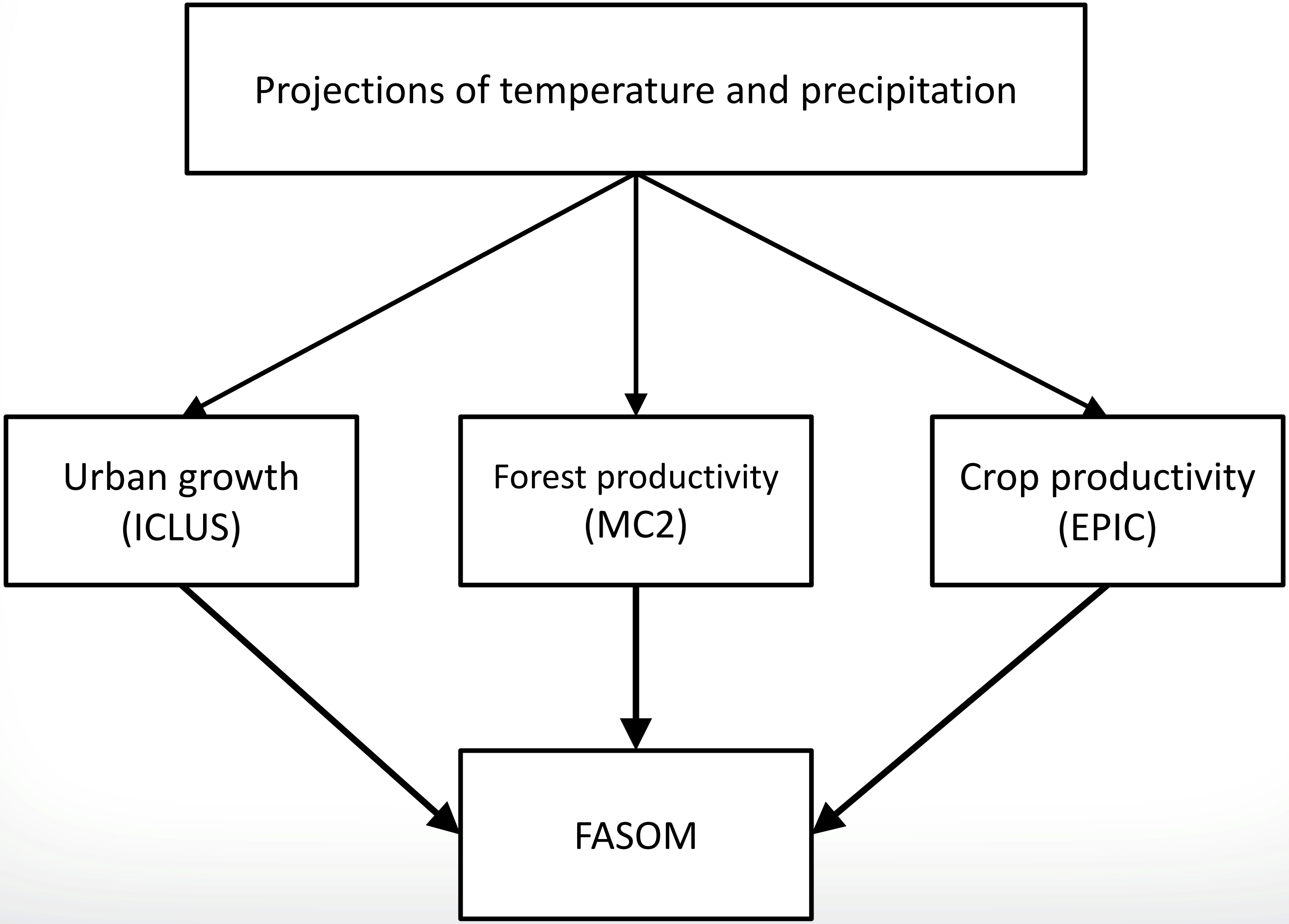
2. **Use those projections as drivers of:**
    - Urban growth (*via* migration amenities and population change)
    - Changing crop yields
    - Changing forestry productivity

3. **Use FASOM to simulate potential land use changes arising from interactions**
    - Use the default FASOM projection as a baseline for comparison
        - o Urban growth projections from Alig et al. (2004)
        - o No temperature or precipitation changes

Input model overviews

- Urban development
  - ***Integrated Climate and Land Use Scenarios* (ICLUS)**
  - Climate is an amenity; people move to nice weather
  - More people → more urban growth
- Changing crop yields
  - ***Environmental Policy Integrated Climate model* (EPIC)**
  - Yield effects for nine crops; irrigated and dryland
- Changing forestry productivity
  - ***Modified version of the CENTURY model* (MC2)**
  - Softwood and hardwood

Modeling overview



Forestry and Agricultural Sector Optimization Model (FASOM)

- **Linked model of the U.S. agriculture and forest sectors**
  - **Land can move between agriculture and forestry**
  - **Also captures crop and livestock production**

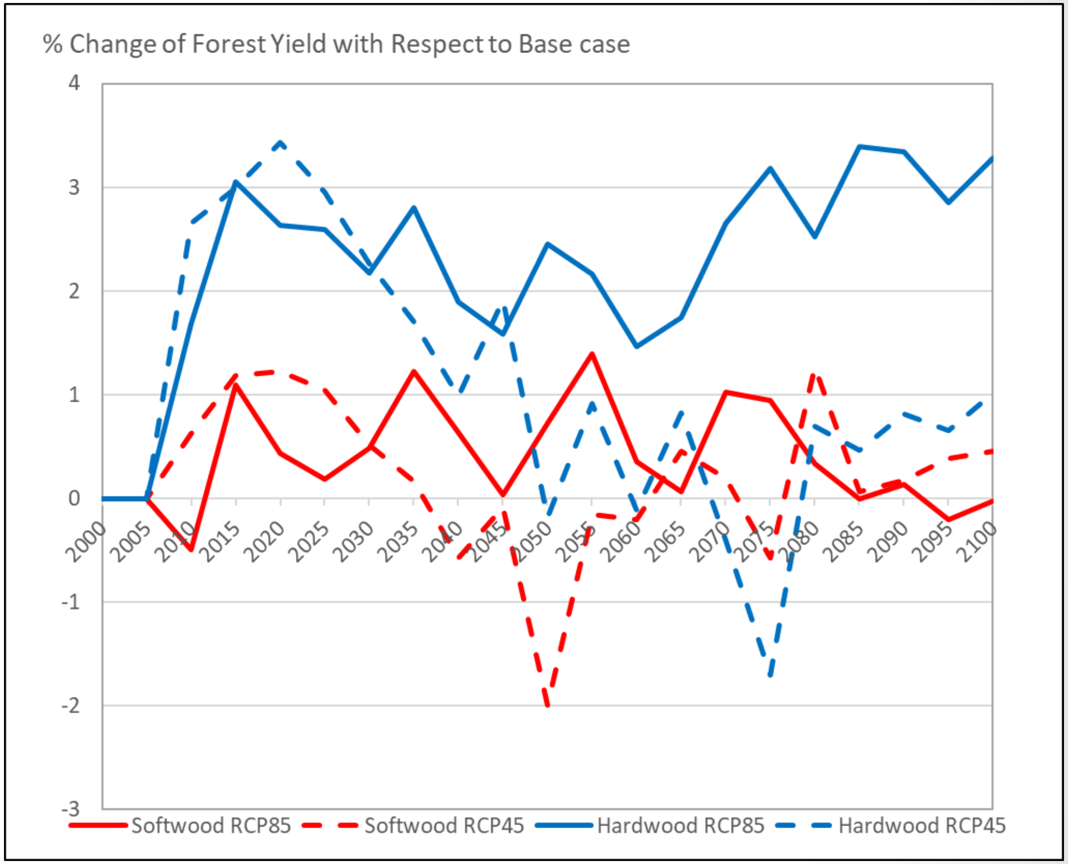
- **Tracks a variety of agriculture and forestry resource conditions and management actions**

- **Detailed commodity markets**
  - **Primary and secondary agricultural products**
  - **Primary and secondary forestry products**
  - **Bioenergy**

- **Results summarized for seven U.S. regions**

Forest productivity changes

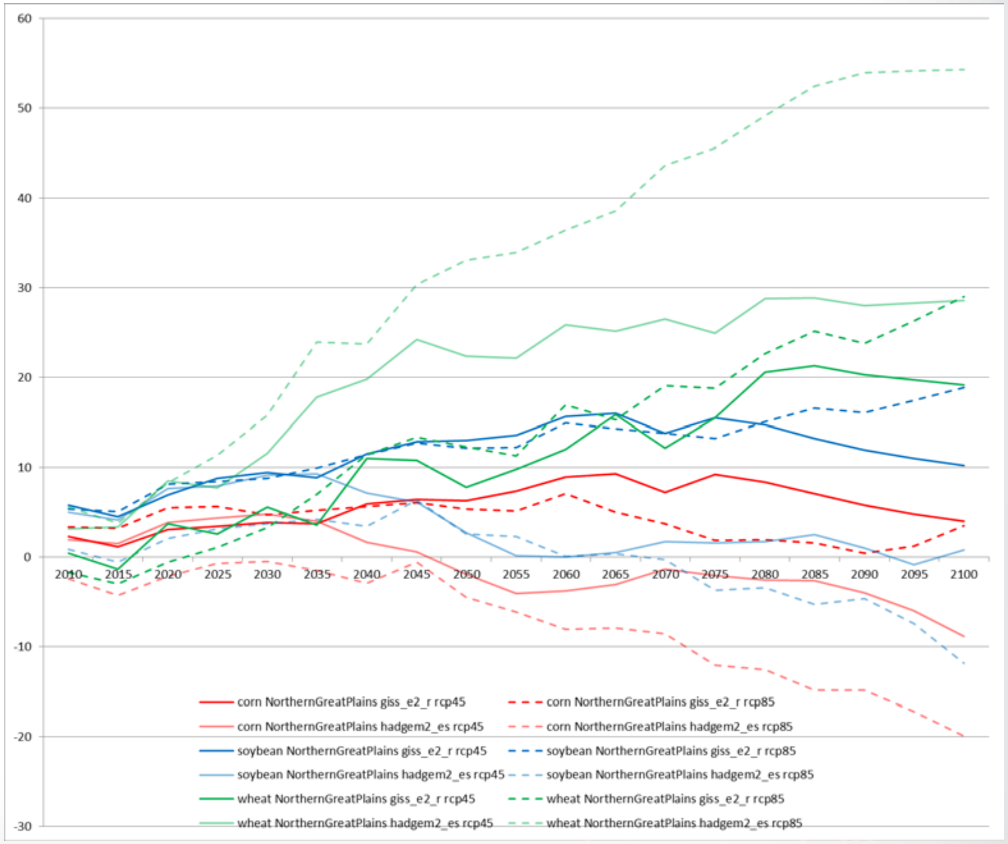
- Detailed categories in MC2 are aggregated to ‘Hardwood’ and ‘Softwood’ for input into FASOM
- Forest productivity is generally higher relative to the baseline projection.



Changing crop yields

- In the Northern Great Plains, yields generally increased
- But, model choice alone <u>can</u> determine the sign of change
    - e.g., corn under RCP8.5

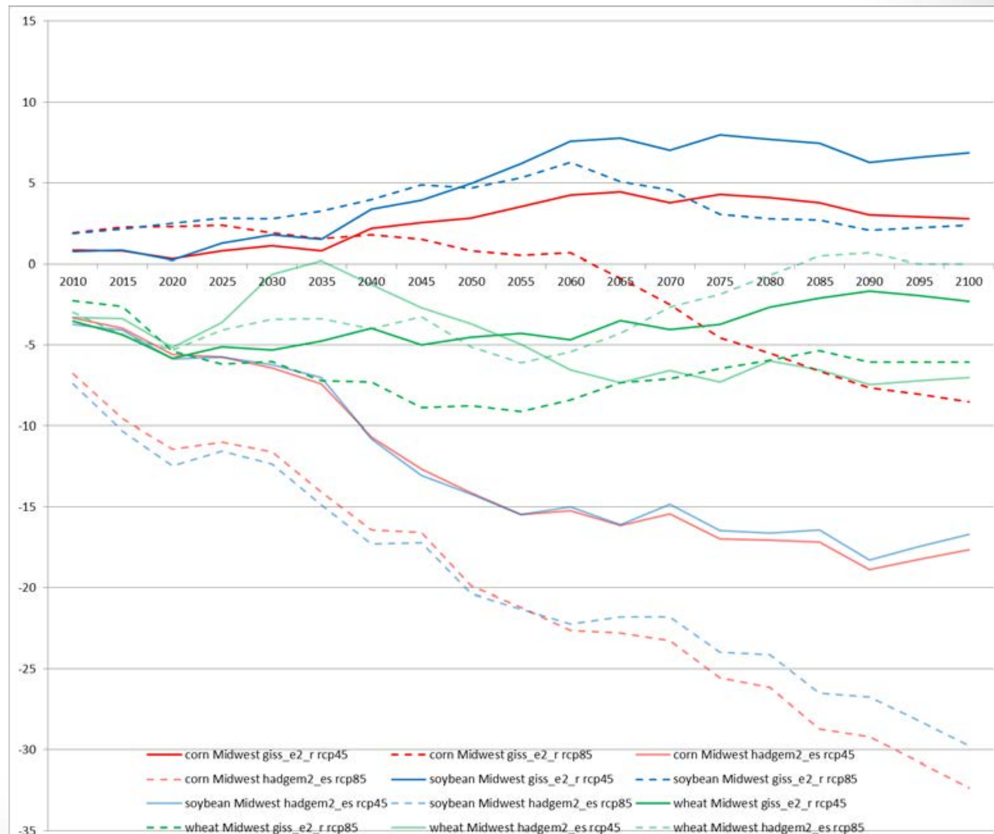
Northern Great Plains



Changing crop yields

- Unlike in NGP, yields generally *decrease*
- Only GISS-e2-r results increased yields, and mostly under RCP4.5
  - Soybean yields increase under RCP8.5

Midwest



Change in Cropland in 2100 relative to base scenario (acres)

	GISS_e2r_RCP45	GISS_e2r_RCP85	Hadgem2_es_RCP45	Hadgem2_es_RCP85
Western US	2,191,900	2,191,900	2,191,900	2,191,900
Plains	43,460,600	31,317,348	31,341,869	31,343,522
Southern US	(122,300)	(242,600)	(268,200)	(293,700)
Midwest	(349,400)	(391,000)	501,800	2,228,200
Northeast	336,400	286,700	947,500	977,700
National	45,517,200	33,162,348	34,714,869	36,447,622

- **Due to overall reductions in yields, more cropland is projected under all four scenarios by 2100, relative to the baseline projection.**
- **Increases correspond to ~9 to ~12 percent of current cropland area (~365 million acres)**
- **Most land moved into production is in the Plains region**

Change in N fertilizer use in 2100 relative to base scenario (tons)

	GISS_e2r_RCP45	GISS_e2r_RCP85	Hadgem2_es_RCP45	Hadgem2_es_RCP85
Western US	328,790	278,744	390,407	456,890
Plains	1,149,939	1,011,940	1,388,952	1,393,519
Southern US	(87,819)	(119,219)	(149,451)	(193,335)
Midwest	(712,766)	(226,902)	(758,406)	(719,769)
Northeast	193,509	182,799	177,445	17,030
National	871,654	1,127,363	1,048,947	1,111,335

- **Fertilizer use increases nationally under all four scenarios by 2100, relative to the baseline projection.**
- **These changes correspond to 13-17% increase in fertilizer use relative to the baseline FASOMGHG scenario**
- **In regions where yields generally declined, fertilizer use decreased (i.e., Southern U.S. and the Midwest).**
- **Increases are greater under RCP8.5 for both GCMs, reflecting greater cropland expansion with lower overall average yields under RCP8.5 relative to RCP4.5**

Assessing the results

- After accounting for urban growth, temperature and precipitation changes, and land use shifts between forestry and agriculture, our results suggest the extent of cropland will increase through 2100.
- This is a larger increase than the baseline projection in FASOM.
- The primary driver of this trend is decreasing yields nationally, although some crop-region-scenario combinations could experience higher yields.
- Forestry yields are generally 1-3% higher than baseline, with some years dipping lower than the baseline projection.
- Choices regarding emissions scenario and climate model remain an important factor in these types of analyses; sign and magnitude of change may depend on those decisions.

Also available from FASOM

- **Besides the summary of results provided here, additional outputs produced include:**
  - **Shifts between crops for each region**
  - **Changes in agricultural production practices (e.g., tillage)**
  - **Changes in forest management by region (e.g., rotation length, management intensity)**
  - **GHG emissions**
  - **Biofuels production and feedstock mix (heavily influenced by policy assumptions)**

Contact information

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