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Global to Local Analysis of Systems Sustainability

Future Challenges to Feeding the World

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TECNOLÓGICO DE MONTERREY

Outline

- Factors affecting food demand
  - Population
  - Income growth
  - Biofuels
- Factors affecting food production
  - Crop yield growth and yield gaps
  - Climate change and crop yields
  - R&D-driven productivity growth
- Where are we headed? Projections with SIMPLE
- Trade-offs in SDGs using SIMPLE-G

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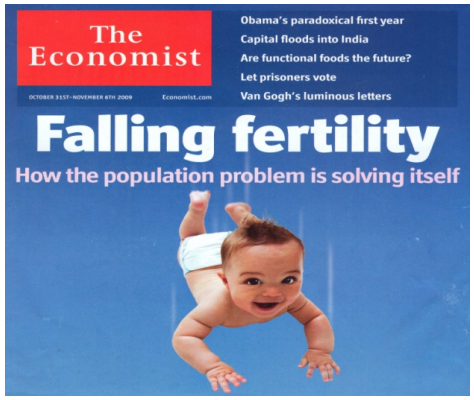
Factors Shaping Demand: Population

- In the late 2000s, *The Economist* argued that the population problem was “solving itself”
- Fertility in many middle-income Asian nations had fallen *below replacement levels* – fertility rates in Africa are expected to follow these trends
- At the time, experts projected that by 2050, global population would be **at 9 billion persons**



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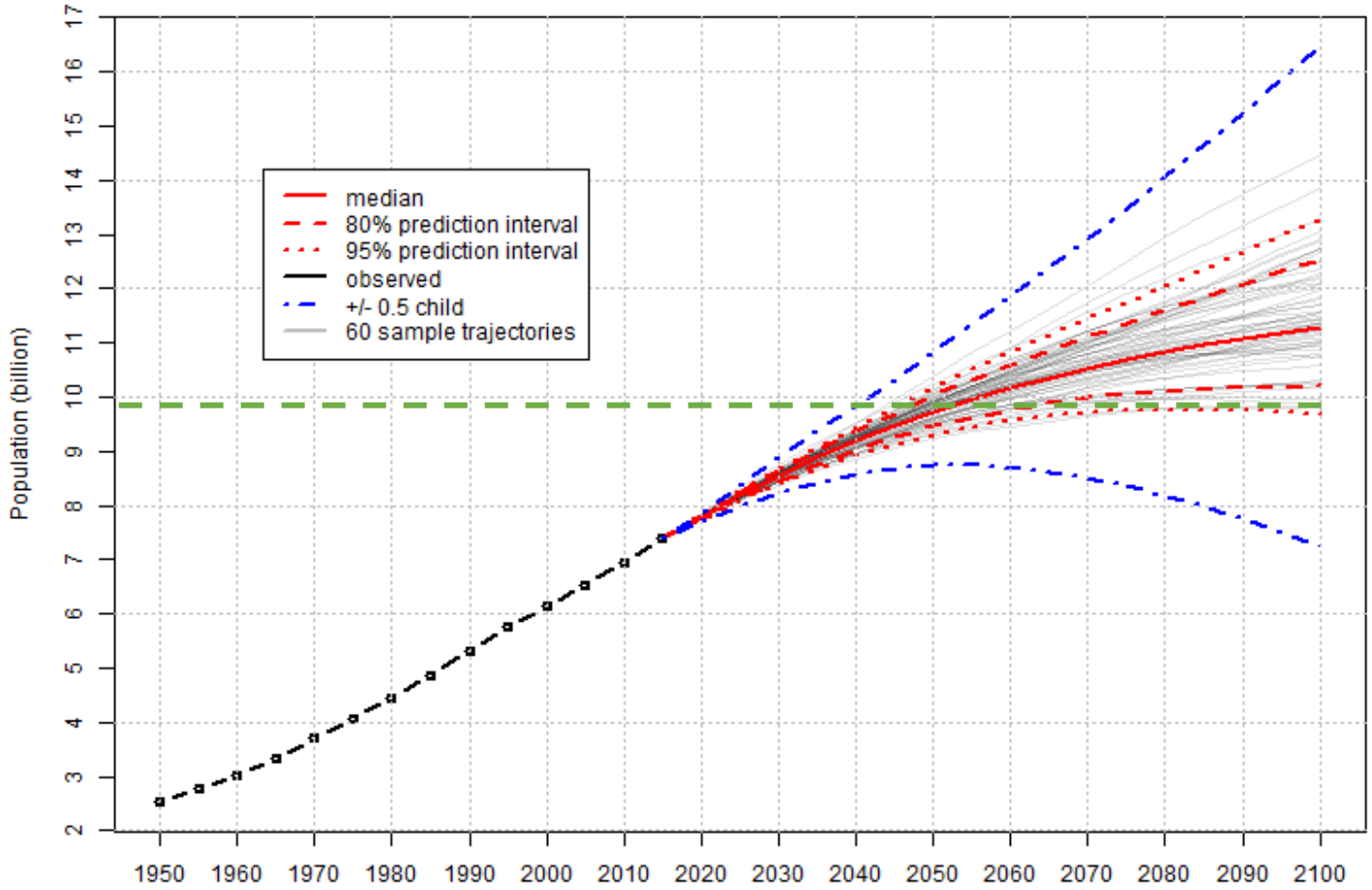
A Recent UN Assessment Has Adjusted This Upwards to 9.8 Billion

Population projections remain highly uncertain



Source: World Population Prospects: The 2017 Revision

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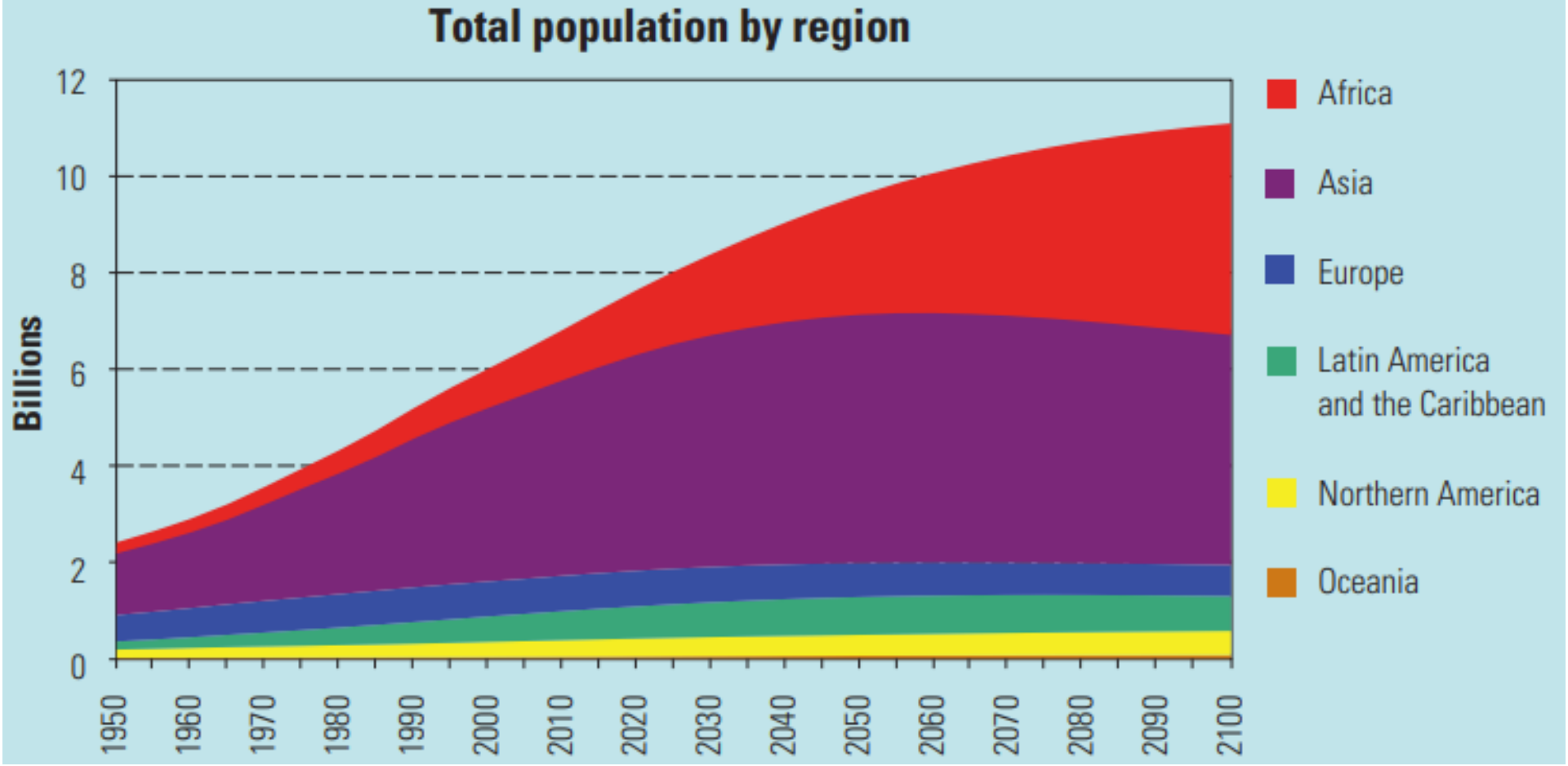
Much of the Growth Will Come from Africa and Asia

Significant proportional growth in Latin America



Source: World Population Prospects: The 2017 Revision

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Alternative Projections of Population Are Based on the IPCC SSP Scenarios

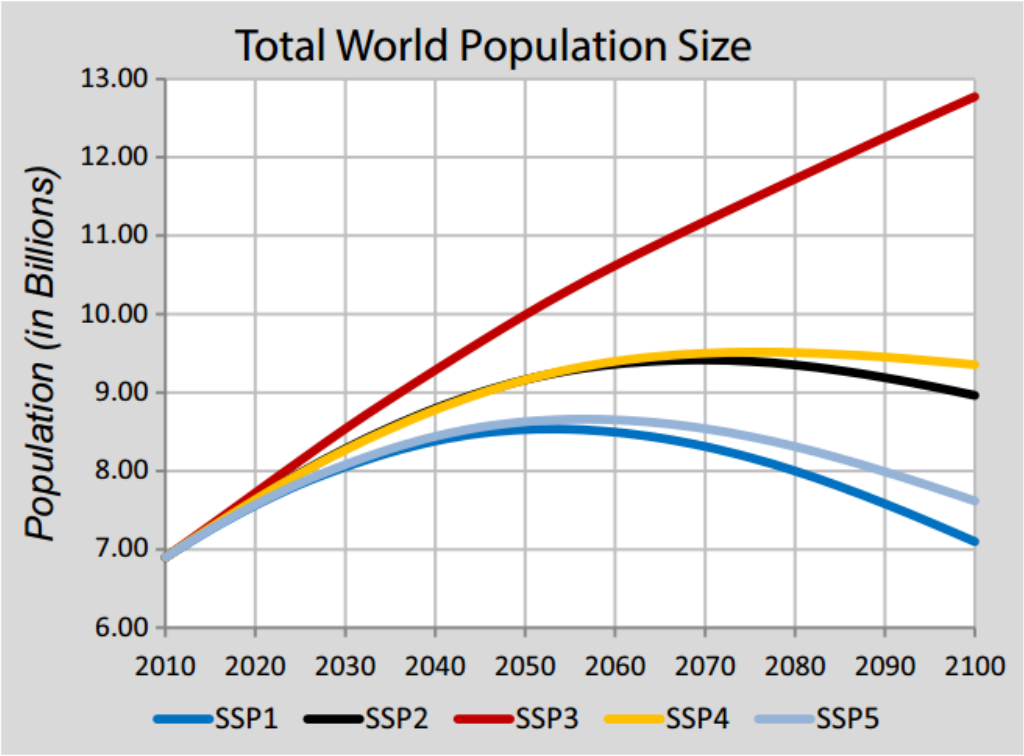

Fig. 1. Trends in total world population size to 2100 according to the five SSPs.

Table 1
Matrix with shared socioeconomic pathways definitions for the demographic and human capital component.

Country groupings	Fertility	Mortality	Migration	Education
SSP1				
HiFert	Low	Low	Medium	High (FT-GET)
LoFert	Low	Low	Medium	High (FT-GET)
Rich-OECD	Medium	Low	Medium	High (FT-GET)
SSP2				
HiFert	Medium	Medium	Medium	Medium (GET)
LoFert	Medium	Medium	Medium	Medium (GET)
Rich-OECD	Medium	Medium	Medium	Medium (GET)
SSP3				
HiFert	High	High	Low	Low (CER)
LoFert	High	High	Low	Low (CER)
Rich-OECD	Low	High	Low	Low (CER)
SSP4				
HiFert	High	High	Medium	CER-10%/GET
LoFert	Low	Medium	Medium	CER-10%/GET
Rich-OECD	Low	Medium	Medium	CER/CER-20%
SSP5				
HiFert	Low	Low	High	High (FT-GET)
LoFert	Low	Low	High	High (FT-GET)
Rich-OECD	High	Low	High	High (FT-GET)

Source: Samir KC, Lutz W. “The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100.”

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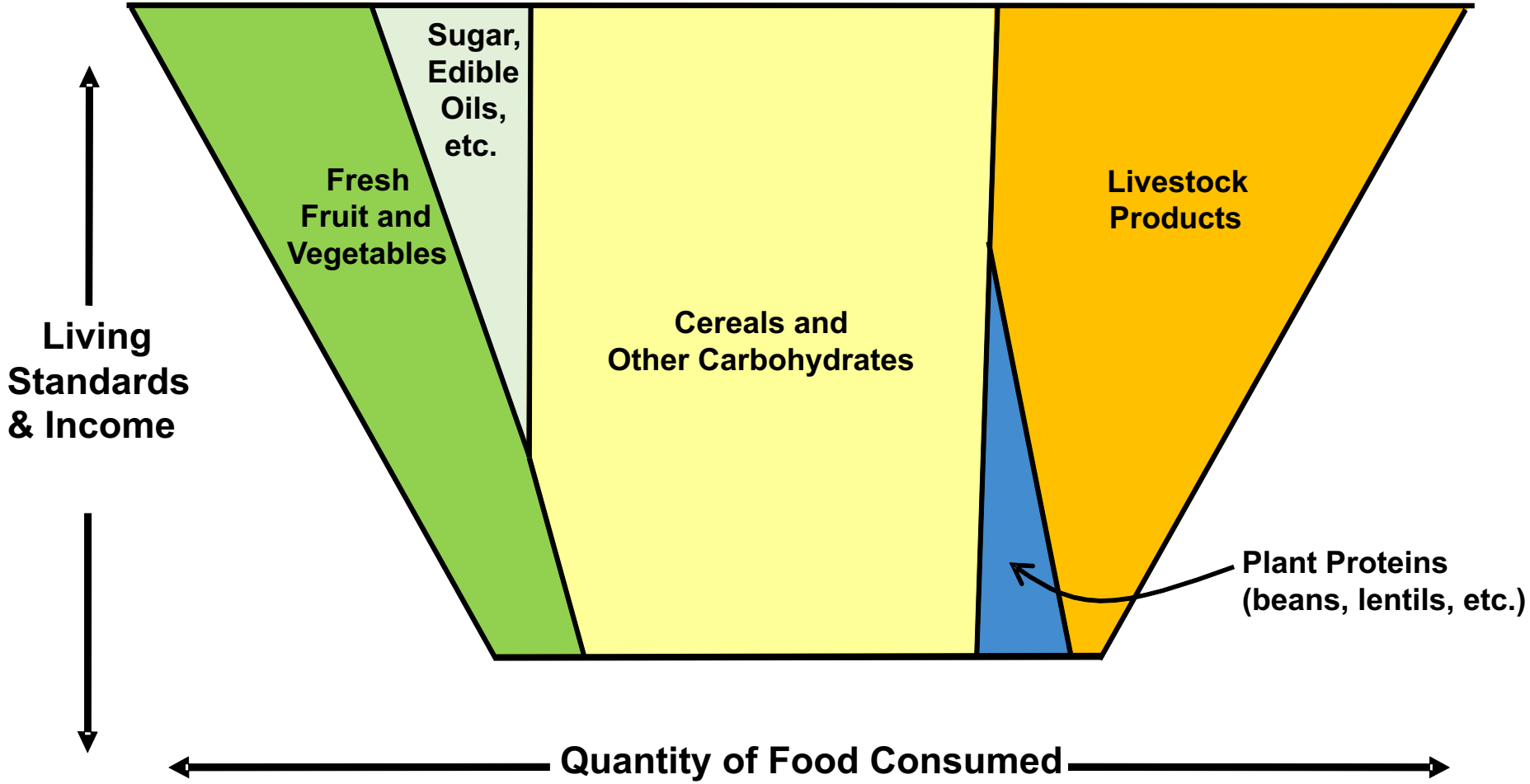
Factors Shaping Demand: Income



Source: Southgate, Graham, and Tweeten (2010).

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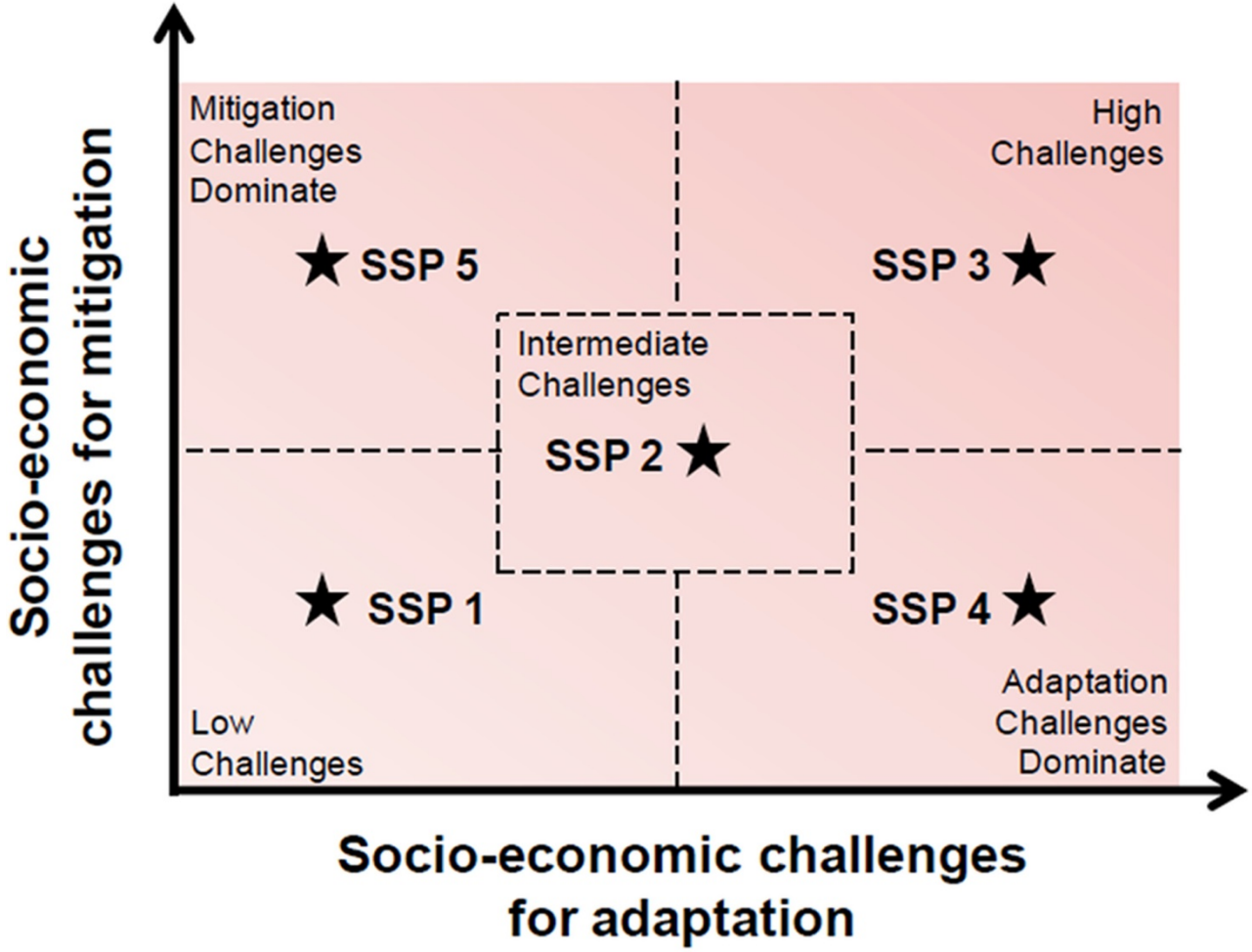
Income Growth Projections Are Also Often Tied to the IPCC SSP Scenarios



Source: ISSP Database – IIASA, OECD (2018), van der Mensbrugghe (2014)

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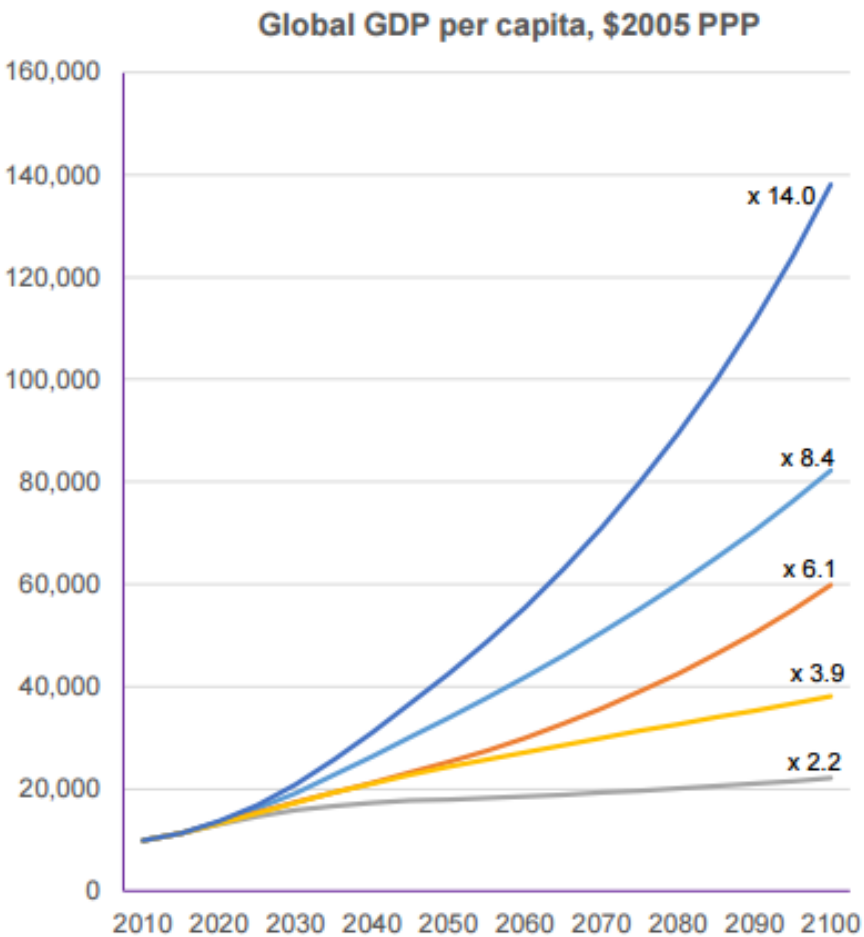

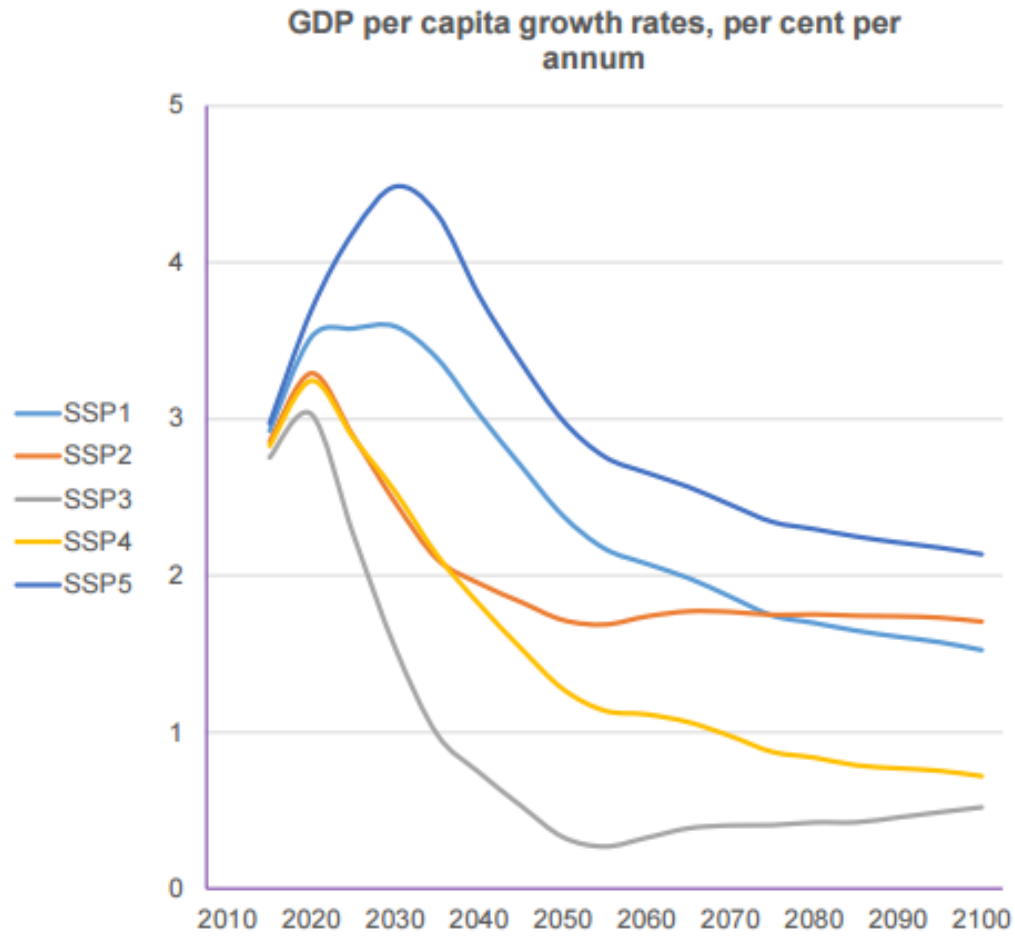

Source: ISSP Database – IIASA, OECD (2018), van der Mensbrugghe (2014)

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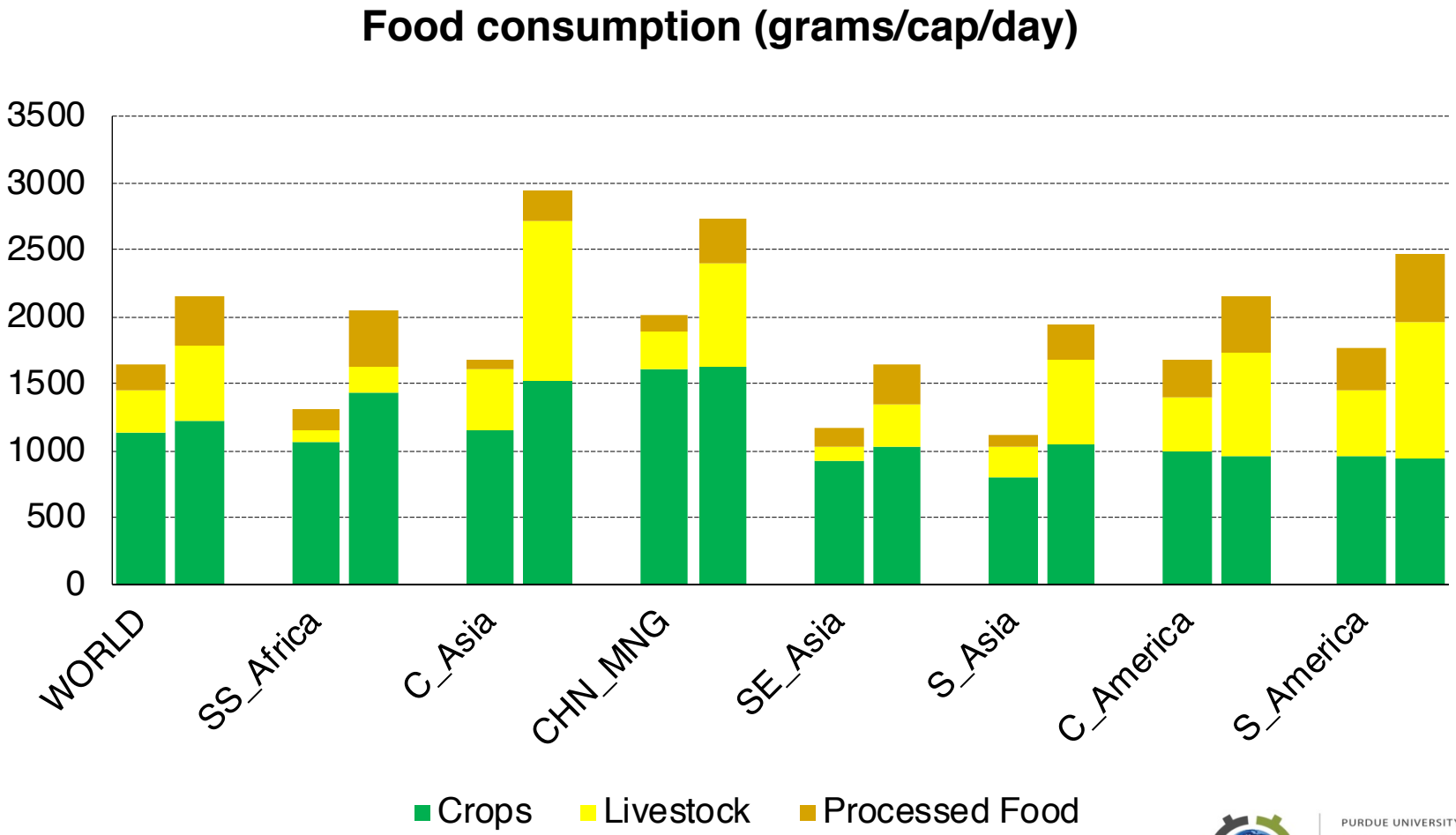
Income Growth Significantly Changes Food Consumption and Composition

2006 (left) versus 2050 (right) due only to income growth (SSP2)



Source: Baldos and Hertel (2014).

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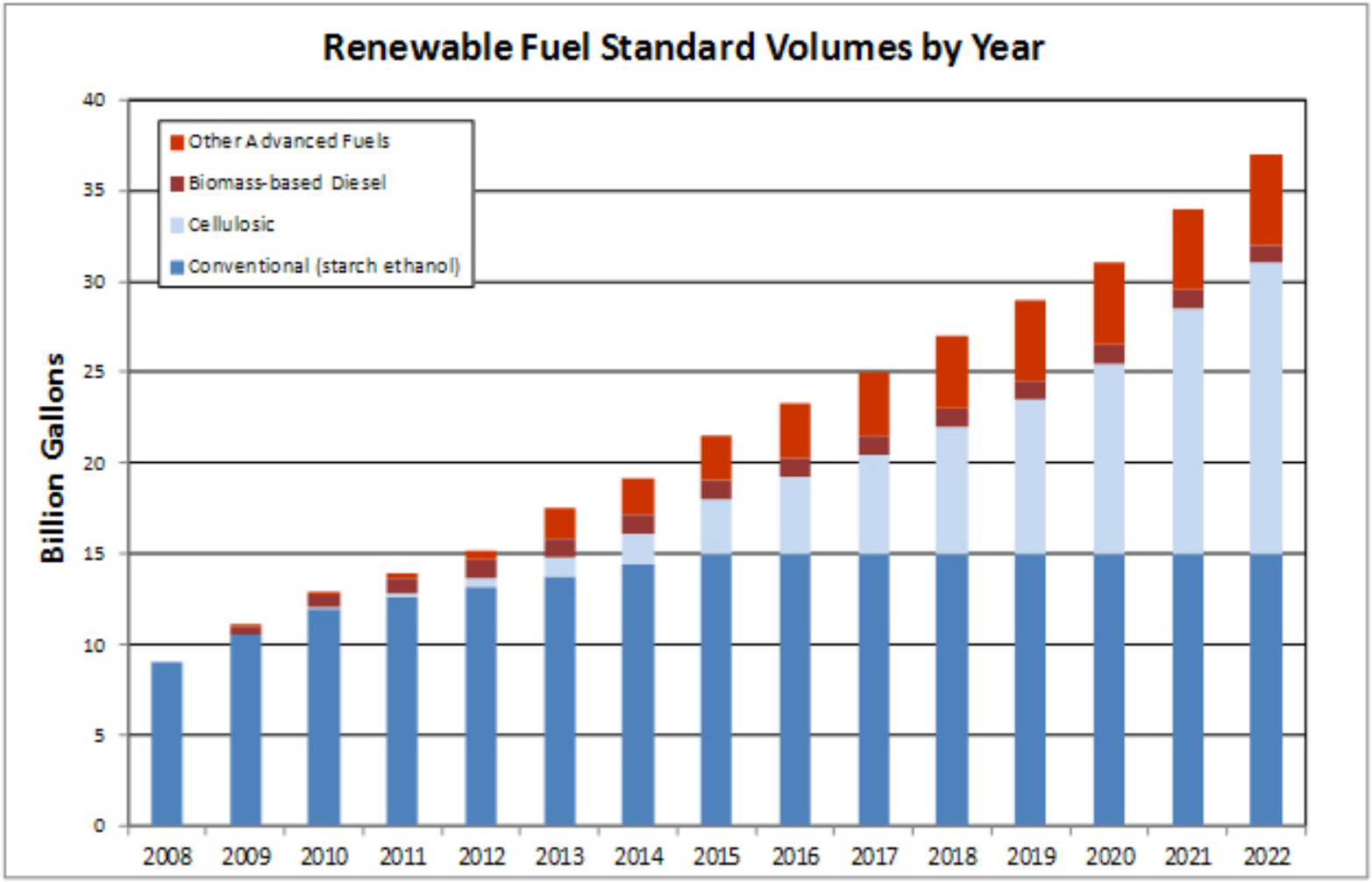
Factors Shaping Demand: Biofuels

- Renewable fuel mandates during the early 2000s increased demand for crops as a feedstock for bioenergy production
- Subsidies and government mandates have played an important role in this expansion but are gradually being rolled back
- Future growth is unlikely – unless oil prices rise

Factors Shaping Demand: Biofuels



Source: U.S. Renewable Fuel Standards (RFS2).

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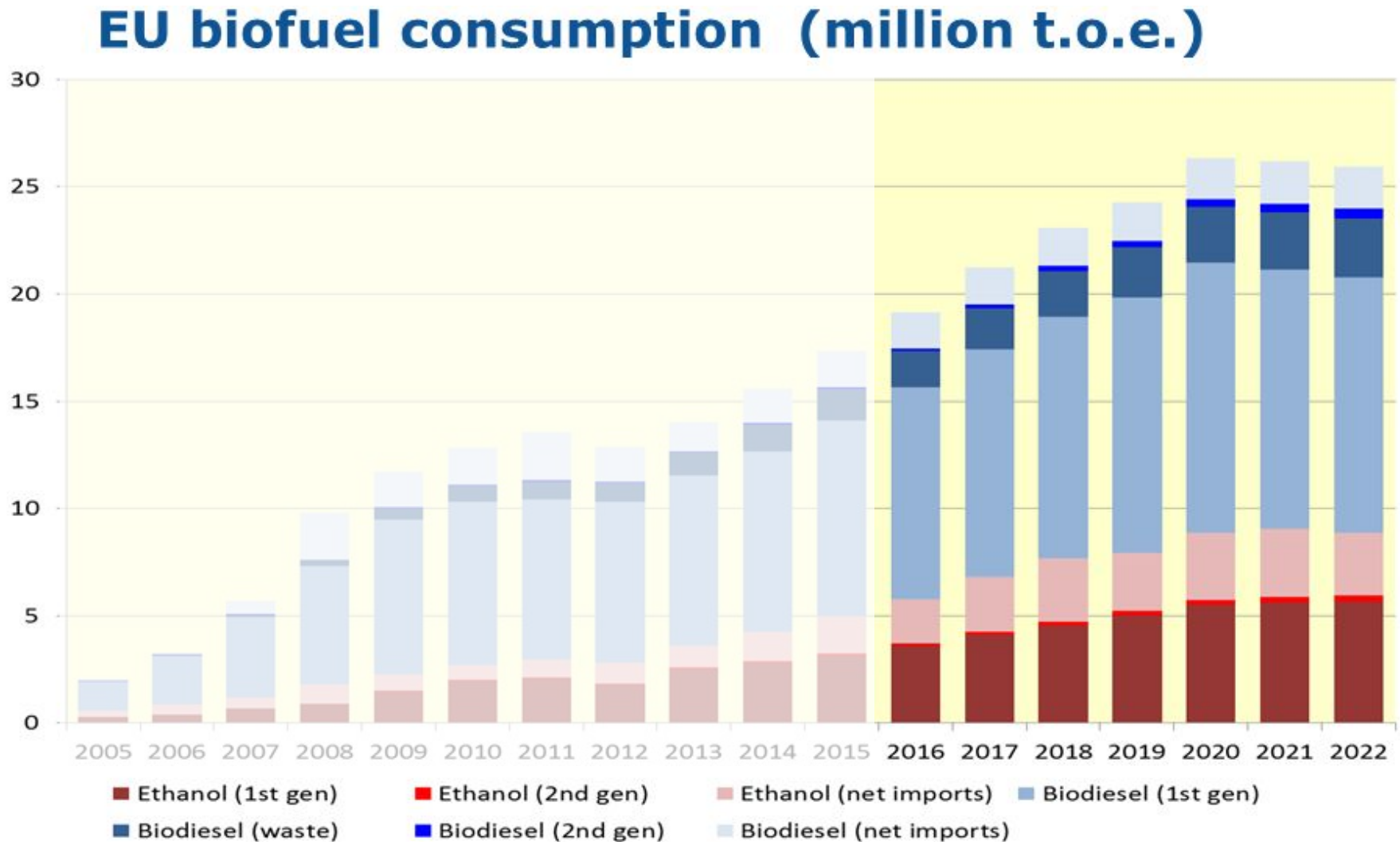

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Factors Shaping Supply: Crop Yields

- FAO estimates over the past 50 years (Bruinsma, 2009):
  - 77% of production growth from yields
  - 9% from increased cropping intensity
  - *Just 14% from area expansion*
  - **Can this be maintained for the next 40 years?**
- But yield growth has been slowing
  - Wheat and rice 3-5%/yr in 80's, but just 1-2%/yr in last decade (Byerlee and Deininger, 2010)
  - Yield growth in 2 dozen breadbasket regions has slowed to less than 0.5%/yr (Fischer, Byerlee and Edmeades, 2009)

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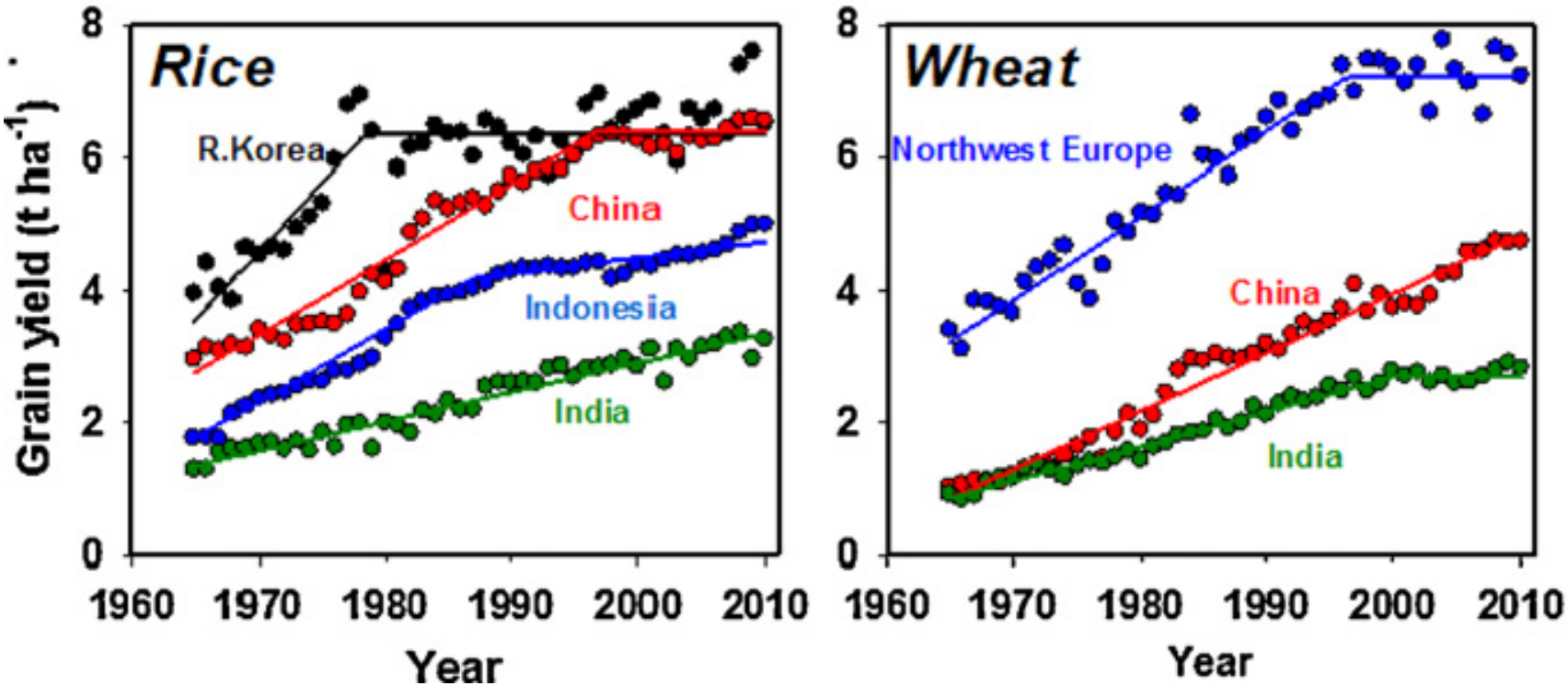
Crop Yield Trends for Major Rice, Wheat and Maize-Producing Countries



Source: FAOSTAT; Cassman, *et al* (2010).

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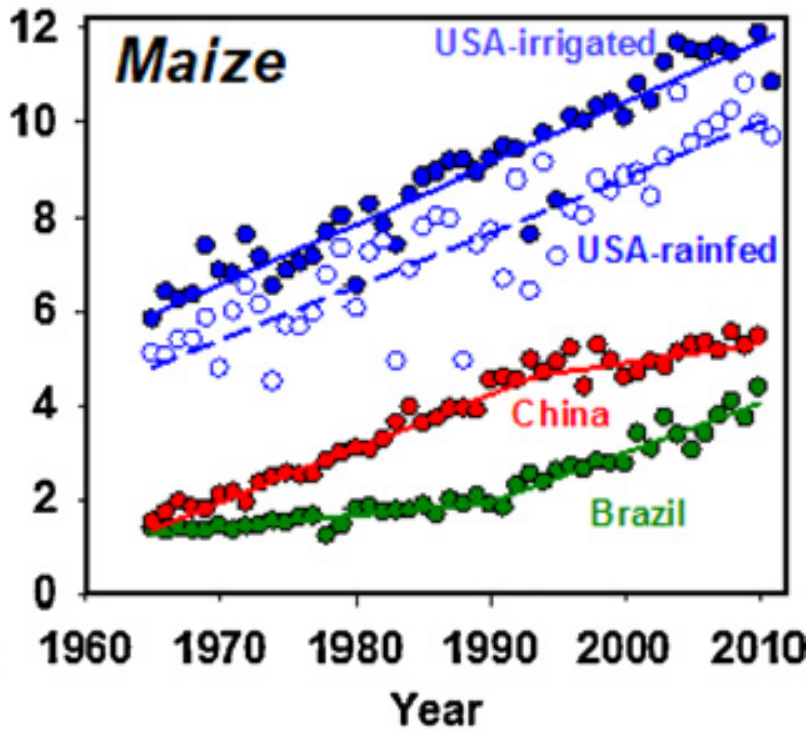

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  - Yield growth in 2 dozen breadbasket regions has slowed to less than 0.5%/yr (Fischer, Byerlee and Edmeades, 2009)
- **On average, yield might be slowing, but not for all regions**

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Yield Gaps Remain Large for Key Field Crops, Including in Mexico

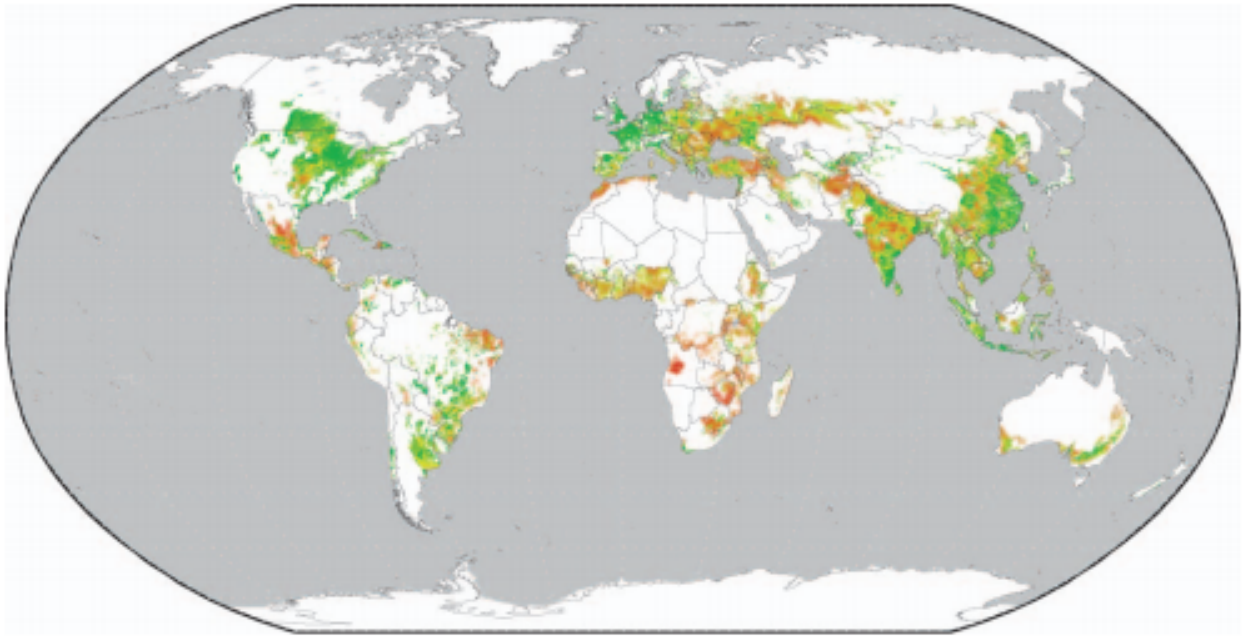
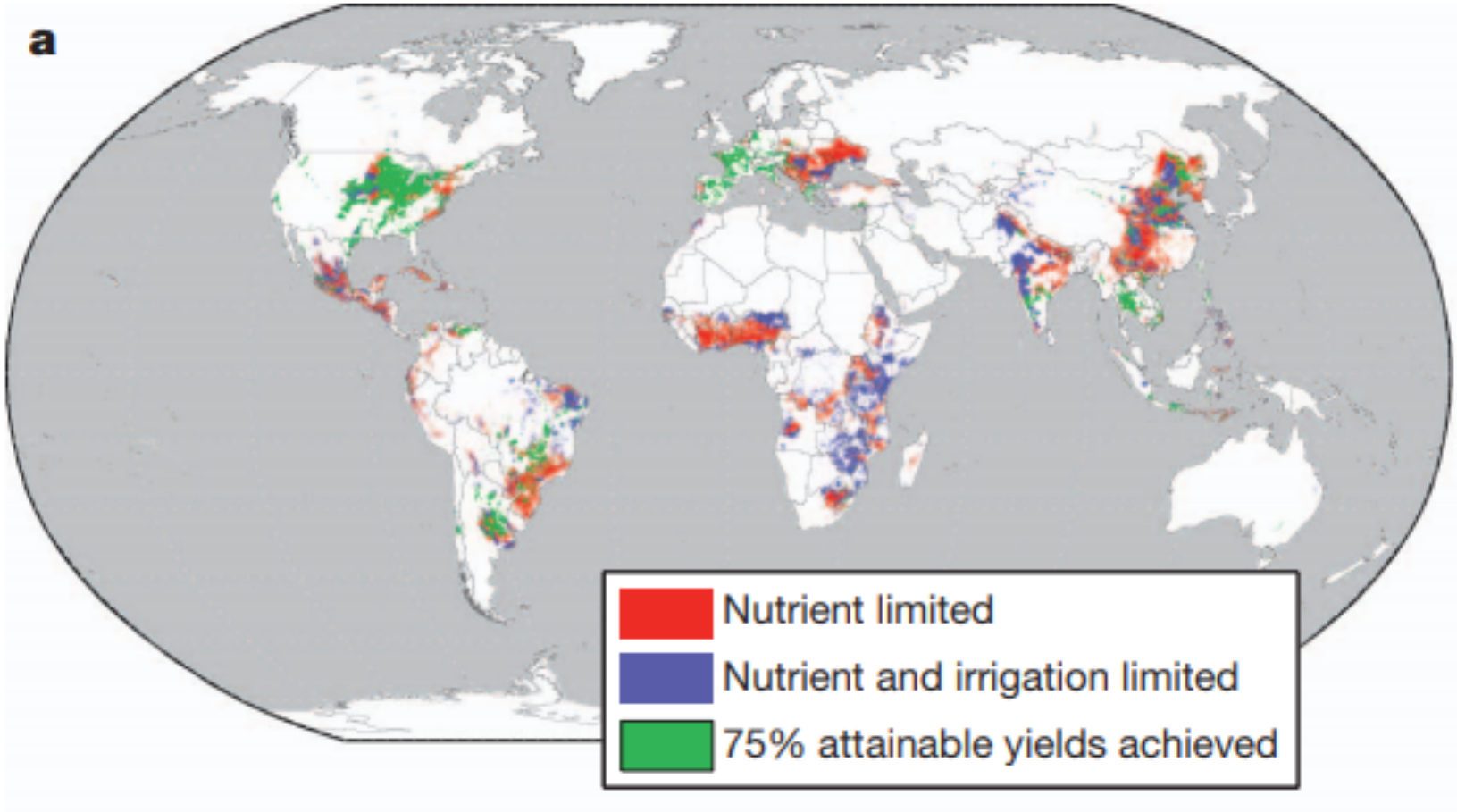


Figure 1 | Average yield gaps for maize, wheat and rice. These were measured as a percentage of the attainable yield achieved circa the year 2000. Yield gap in each grid cell is calculated as an area-weighted average across the crops and is displayed on the top 98% of growing area.

Source: Mueller, *et al* (2012), *Nature*.

Yield Gaps Commonly Result from Nutrient or Irrigation Constraints



Maize

Source: Mueller, *et al* (2012), *Nature*.

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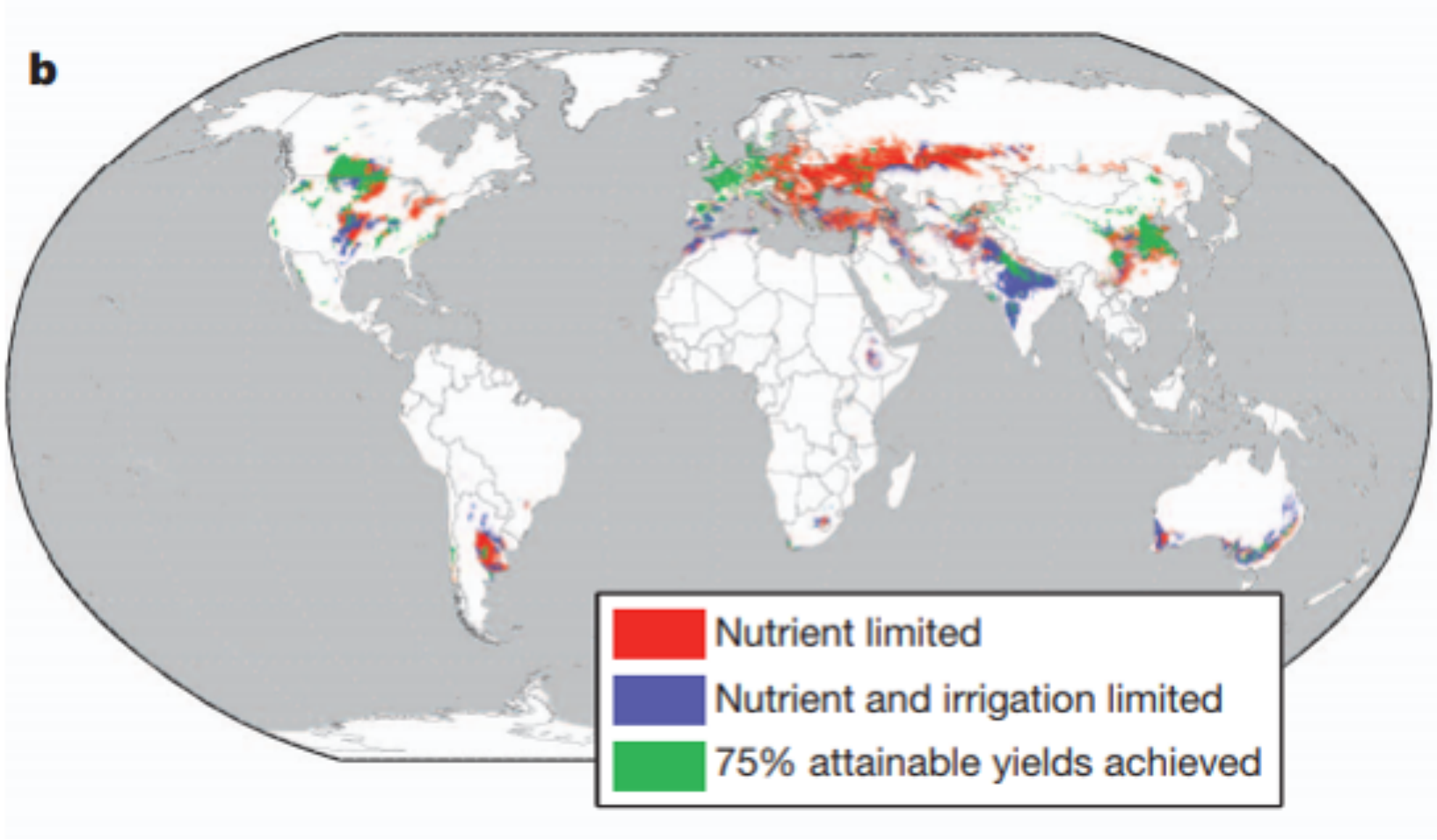

Wheat

Source: Mueller, *et al* (2012), *Nature*.

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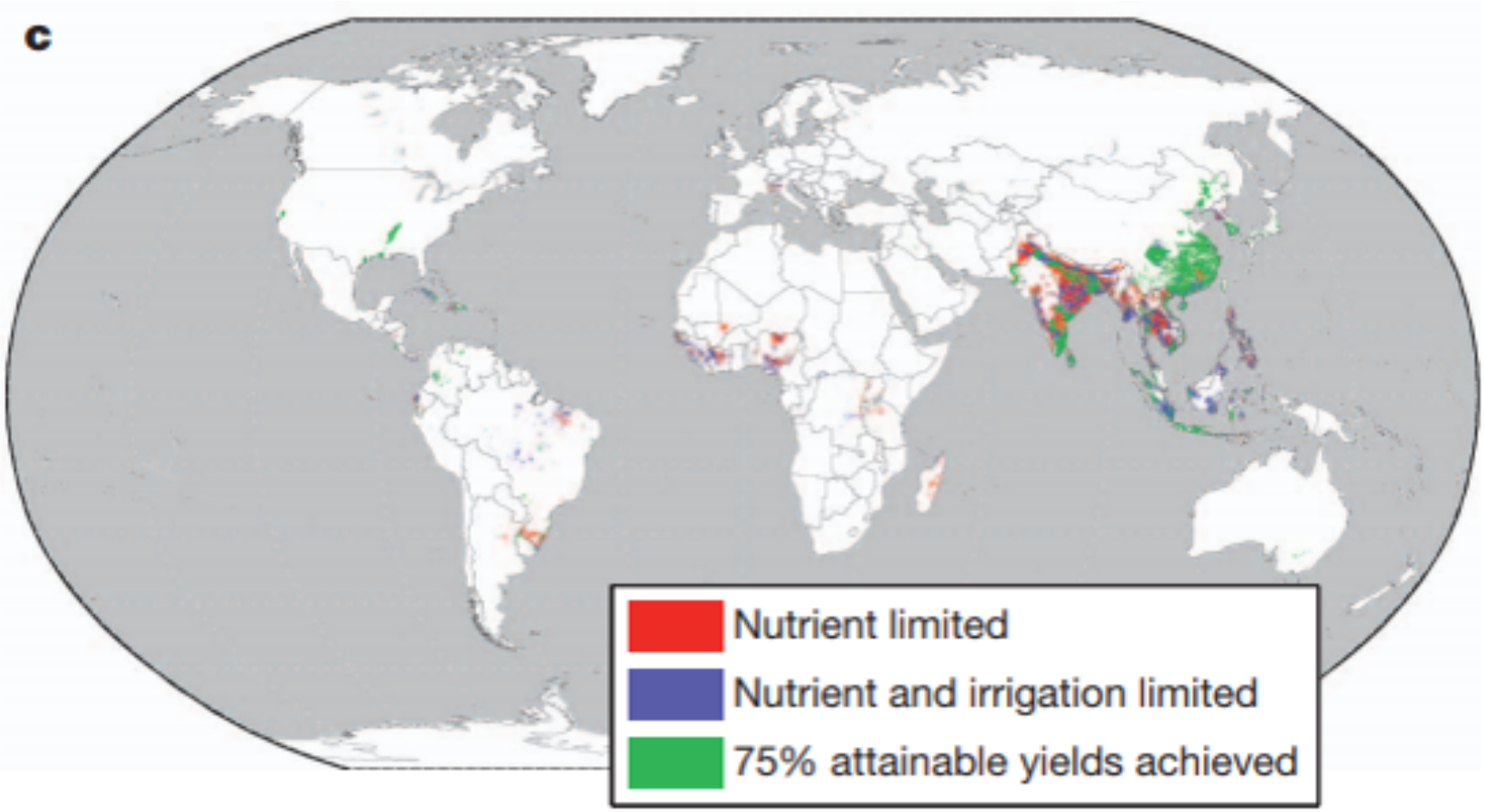

Rice

Source: Mueller, *et al* (2012), *Nature*.

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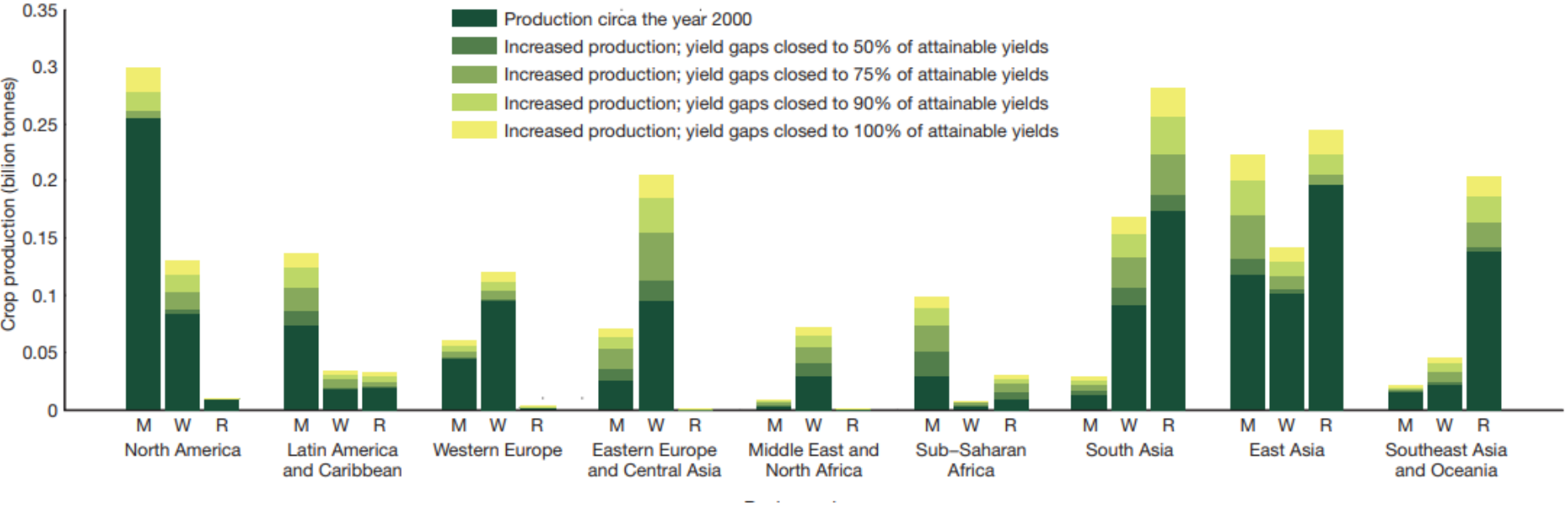
Closing These Gaps Would Provide a Substantial Boost to Production



Source: Mueller, *et al* (2012), *Nature*.

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Ultimately, Yield Gaps Are Driven by Economic Factors

Robert Herdt's conclusion from an in-depth IRRI study of rice yield gaps:

- *"What is technically possible is more modest than most observers admit; <u>the economics of substantially higher yields is not attractive</u>."*

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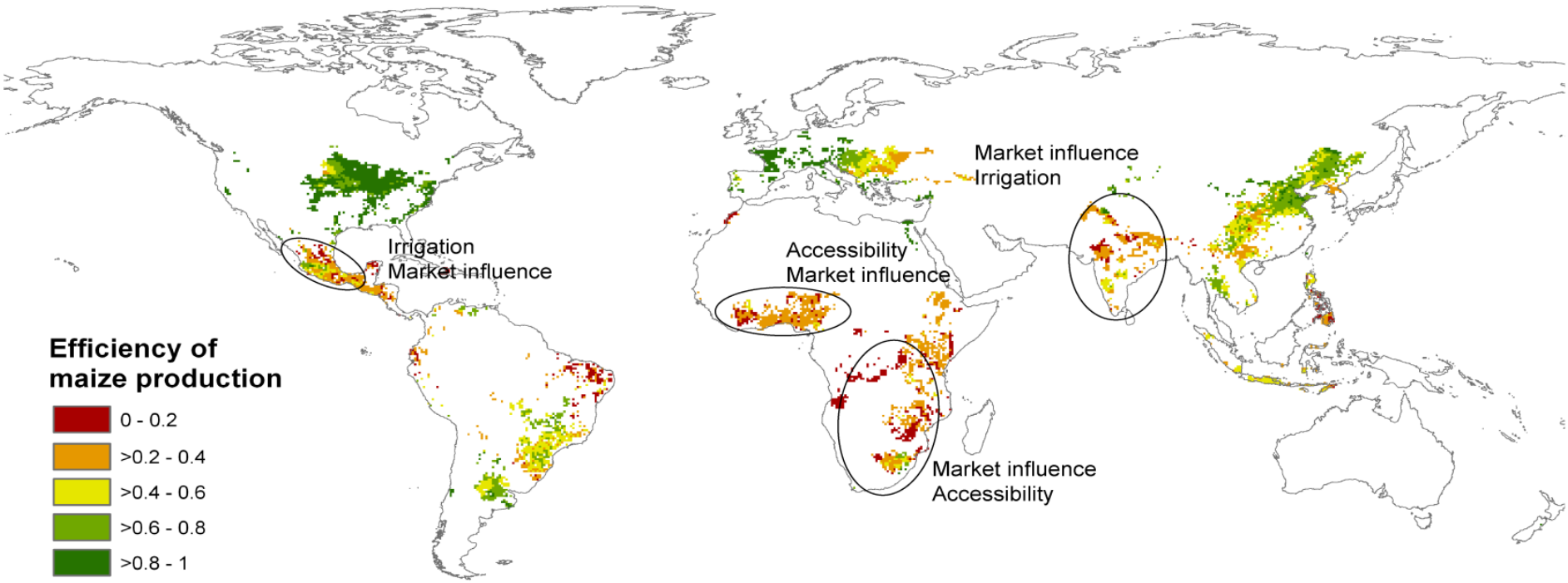
Economic Factors Influence Production Efficiency in Low-Yield Regions



Darkened green areas are more efficient – serve to "set the frontier".
Circled areas are inefficient, and the primary source of the yield gap is identified

Source: Neumann *et al* (2010), frontier production function estimated based on the Monfreda *et al* (2008) data set.

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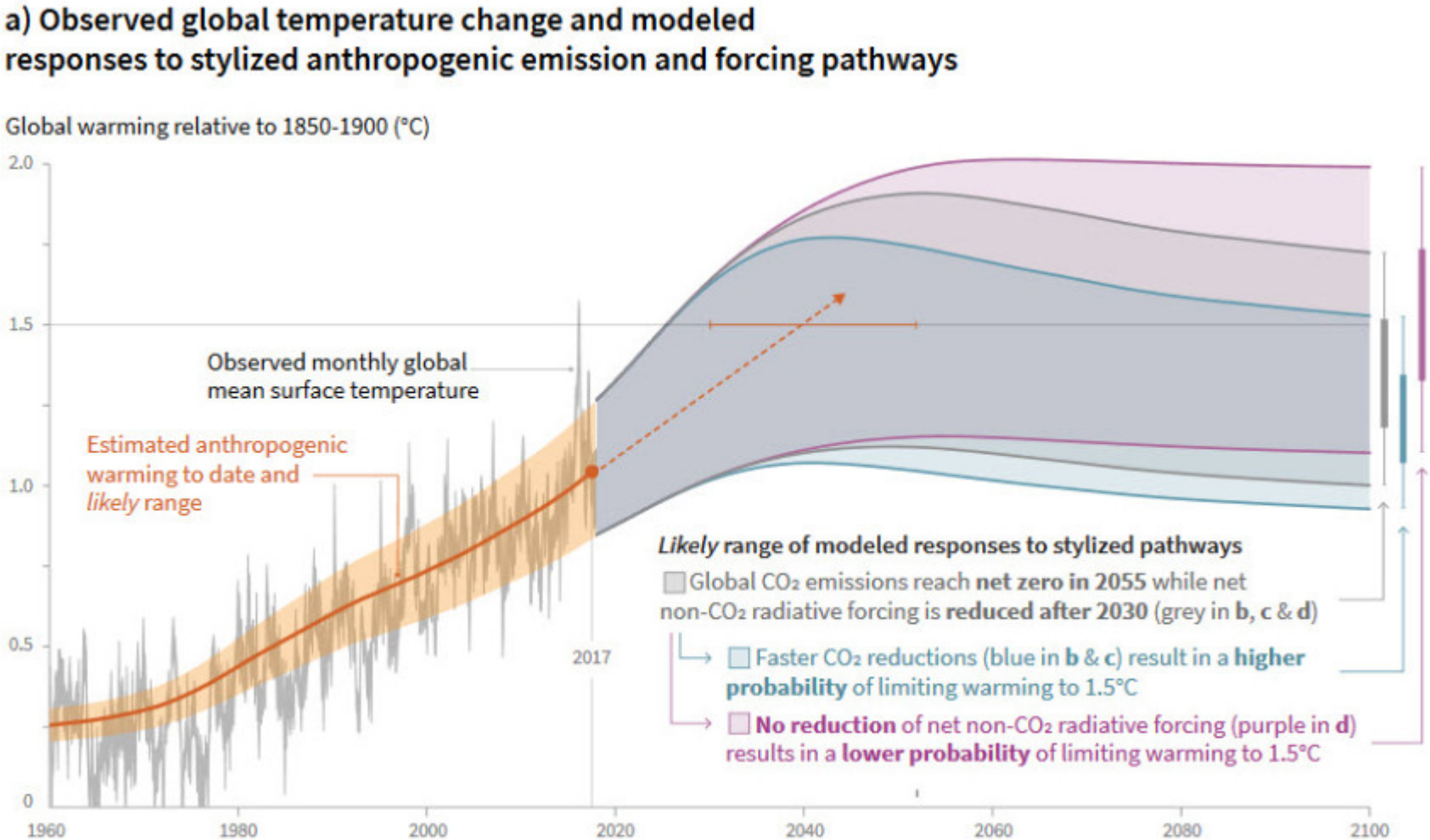
Factors Shaping Supply: Climate Change



Source: IPCC. 2018. Special Report: Global Warming of 1.5° C. Summary for Policymakers.

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Climate Change Will Make Further Growth in Productivity Challenging

"… negative impacts on average yields become likely in the 2030s"

"… median yield impacts from 0 to -2% per decade over the rest of the century"

"… negative impacts of more than 5% are more likely than not after 2050"

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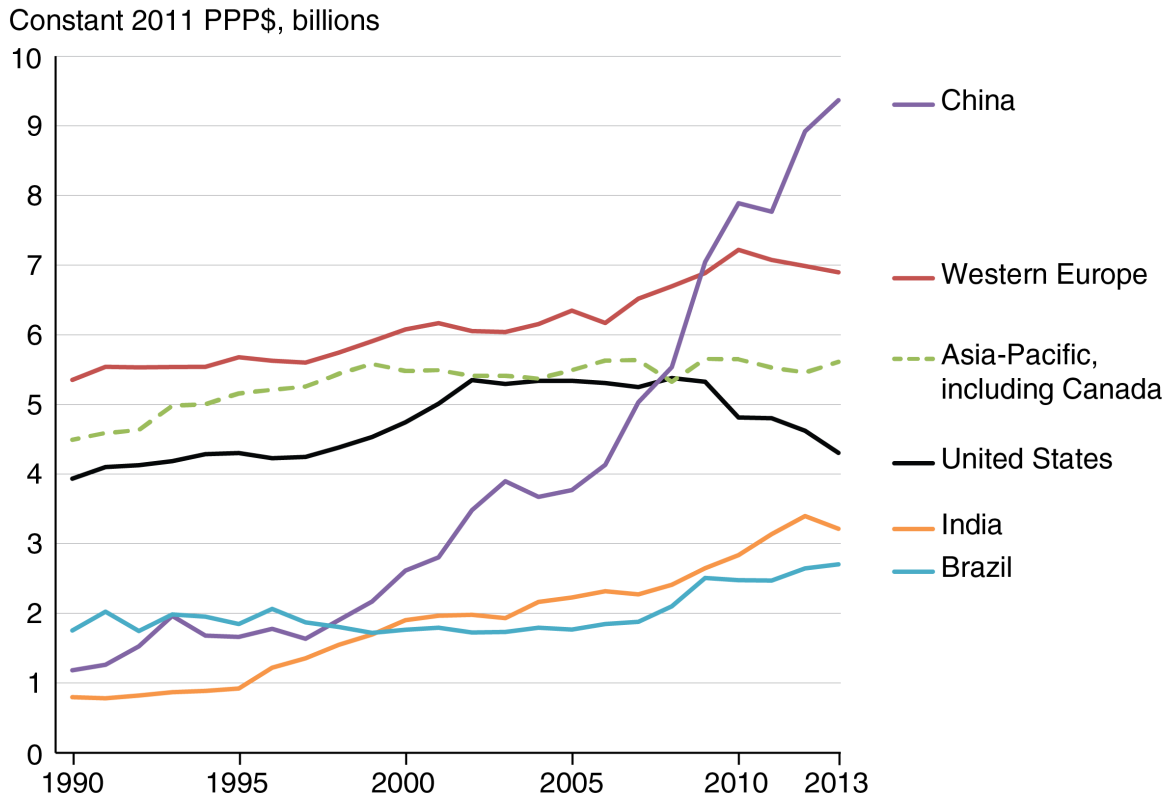
Source: Rosenzweig *et al* (2013), *PNAS*.

Factors Shaping Supply: Investments in Agriculture R&D

- Public spending in developing countries has responded strongly to increases in food prices during the 2000s
- Private R&D is also up strongly (26%) from 2000-2008



PPP = purchasing power parity.
Source: USDA, Economic Research Service and Agricultural Science and Technology Indicators (ASTI), Organisation for Economic Cooperation and Development.

Source: Clancy, M, Fuglie, K & Heisey, P. 2016. U.S. Agricultural R&D in an Era of Falling Public Funding. *Amber Waves*.

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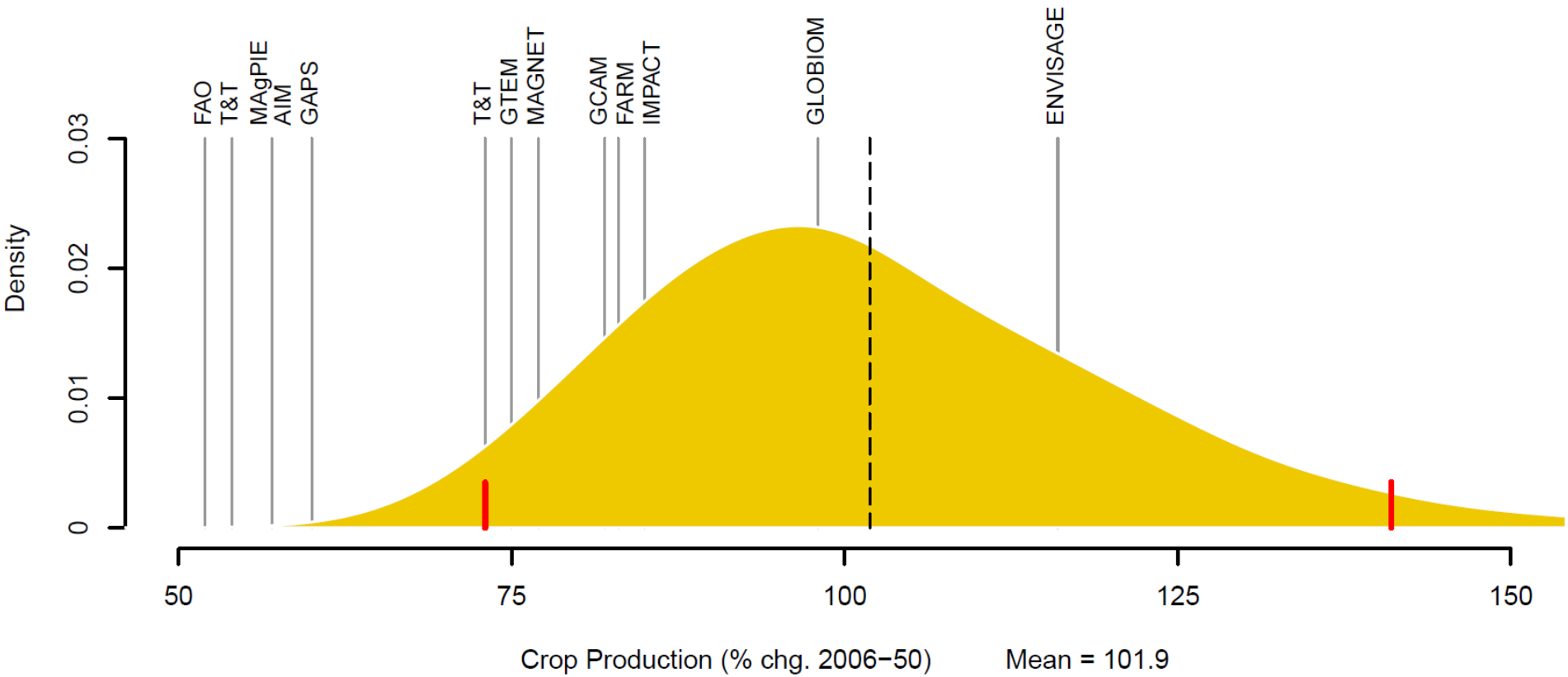
Projections from SIMPLE Fall in the Same Range as Other Models

Change in production outcome, 2006-2050



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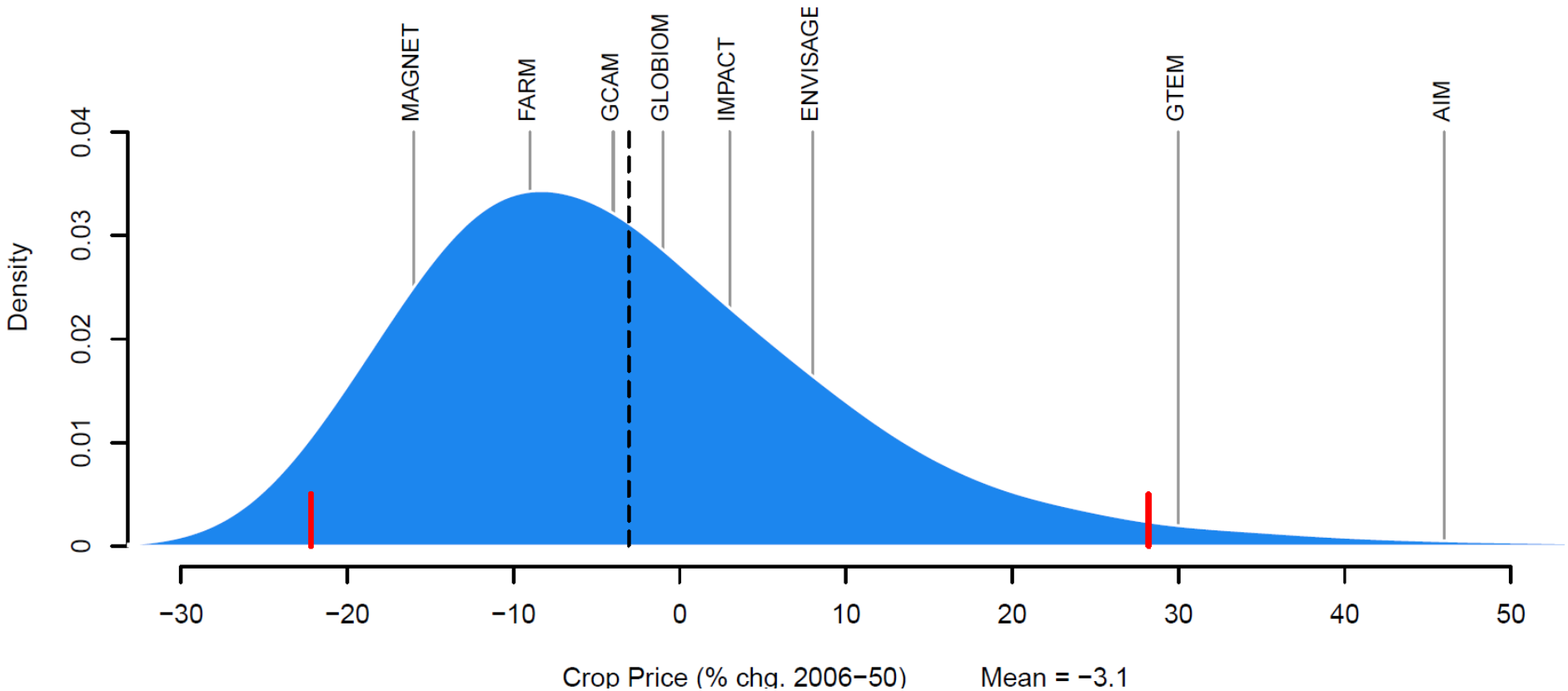

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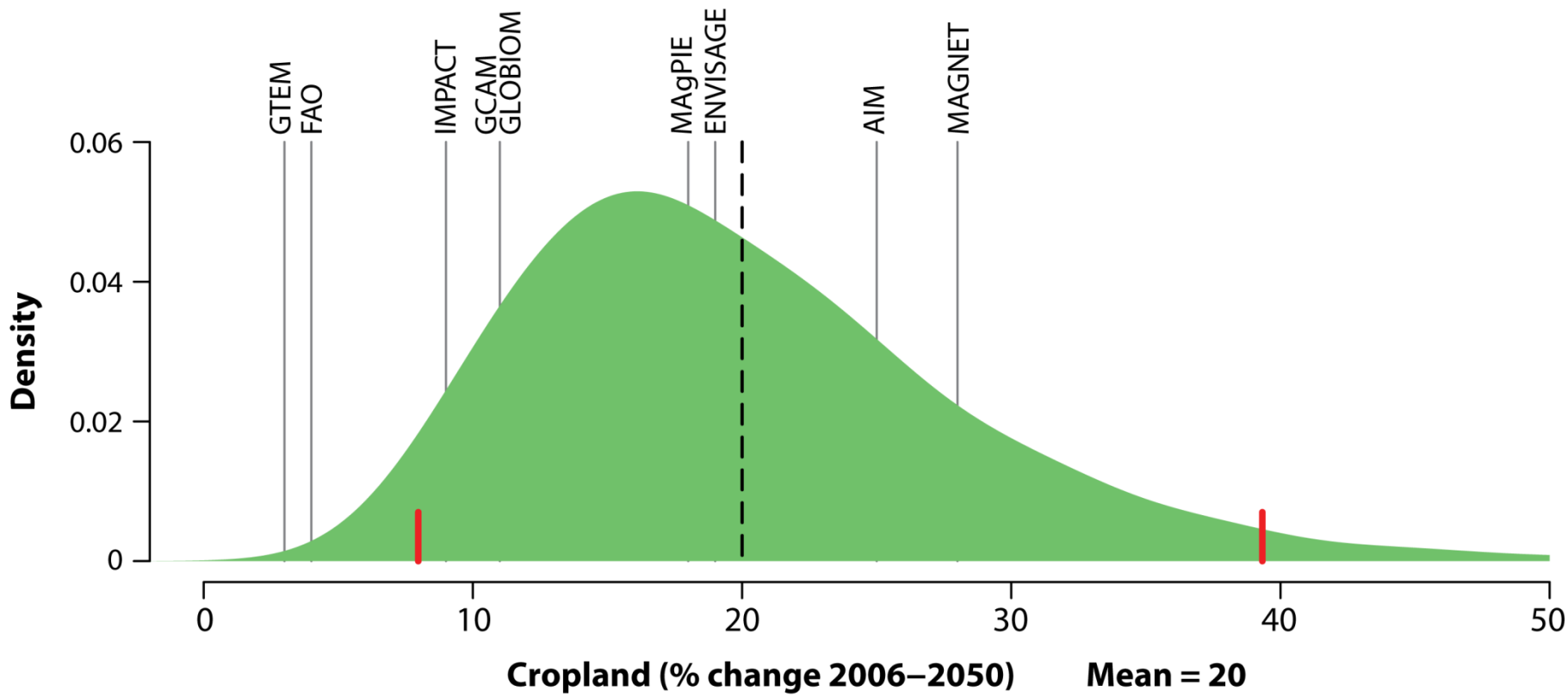

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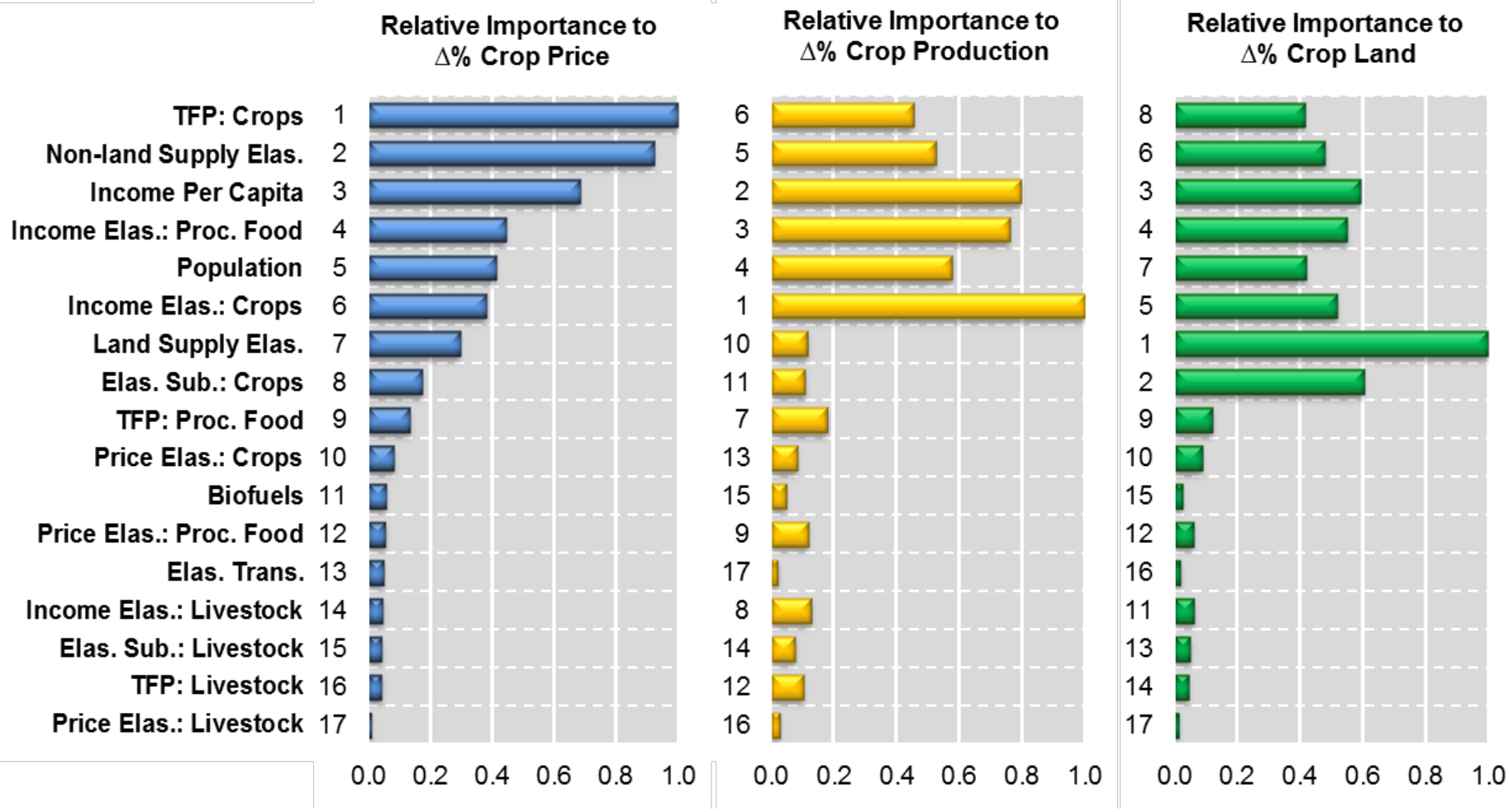
Variability in Model Outcomes Comes from a Small Set of Factors



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Recall That Half of the SDGs Relate to Agriculture and the Environment

We should expect to see tradeoffs when pursuing the SDGs

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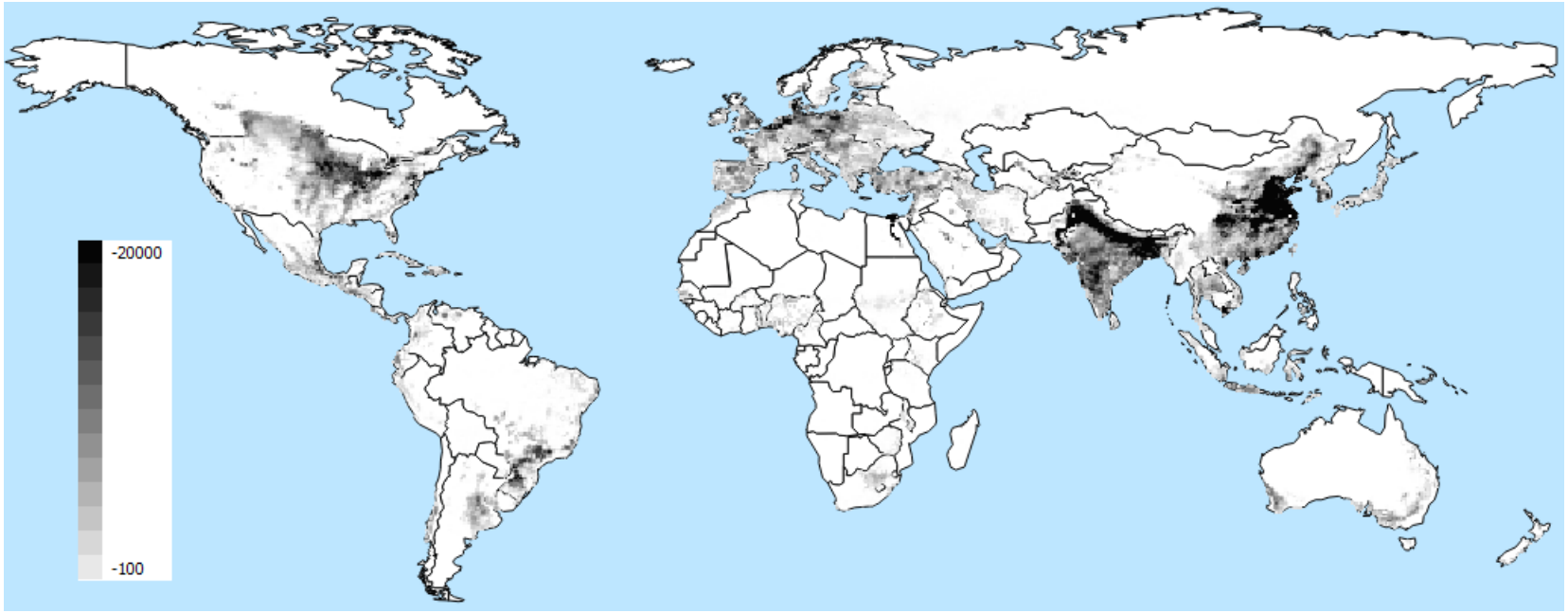
We Can Introduce Policy Interventions with SIMPLE and Observe Their Impact

Eliminate Excess Nitrogen
(reductions in MTs)



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We Can Introduce Policy Interventions with SIMPLE and Observe Their Impact

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Sustainable Water Use
(by reducing irrigated areas)

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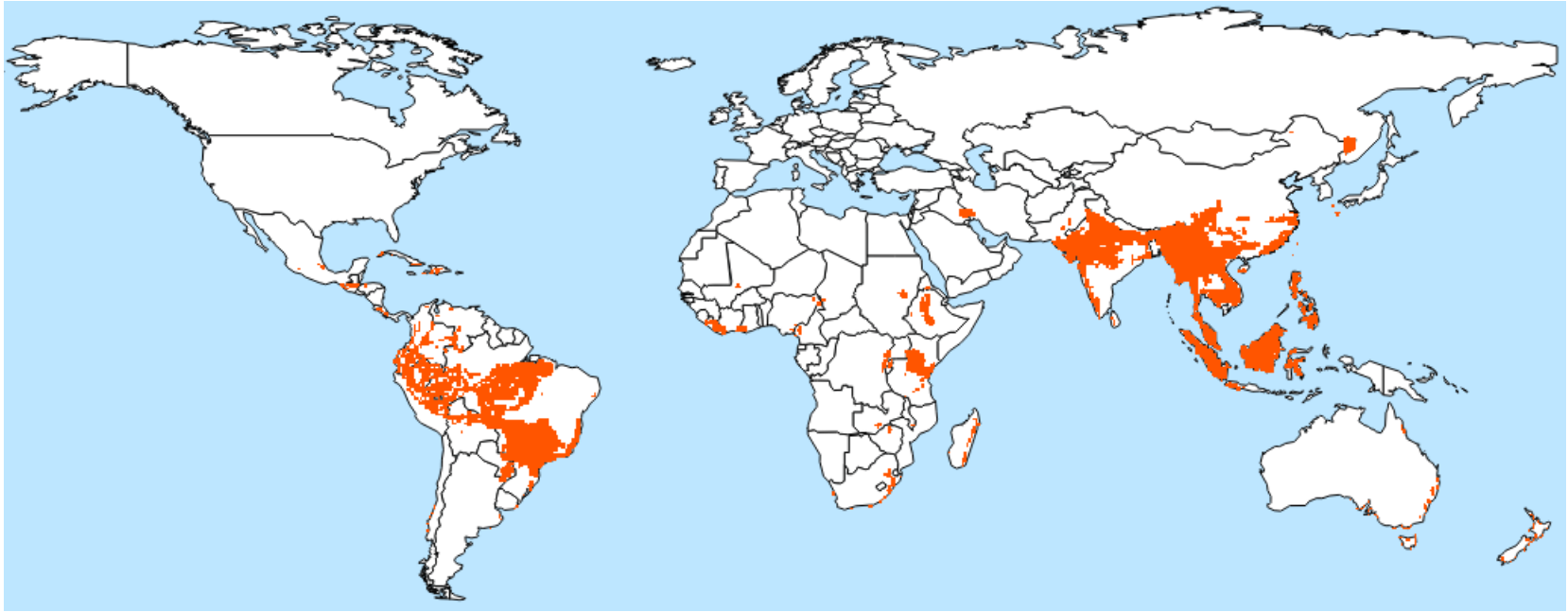
We Can Introduce Policy Interventions with SIMPLE and Observe Their Impact

Restore Biodiversity
(by reducing irrigated areas)



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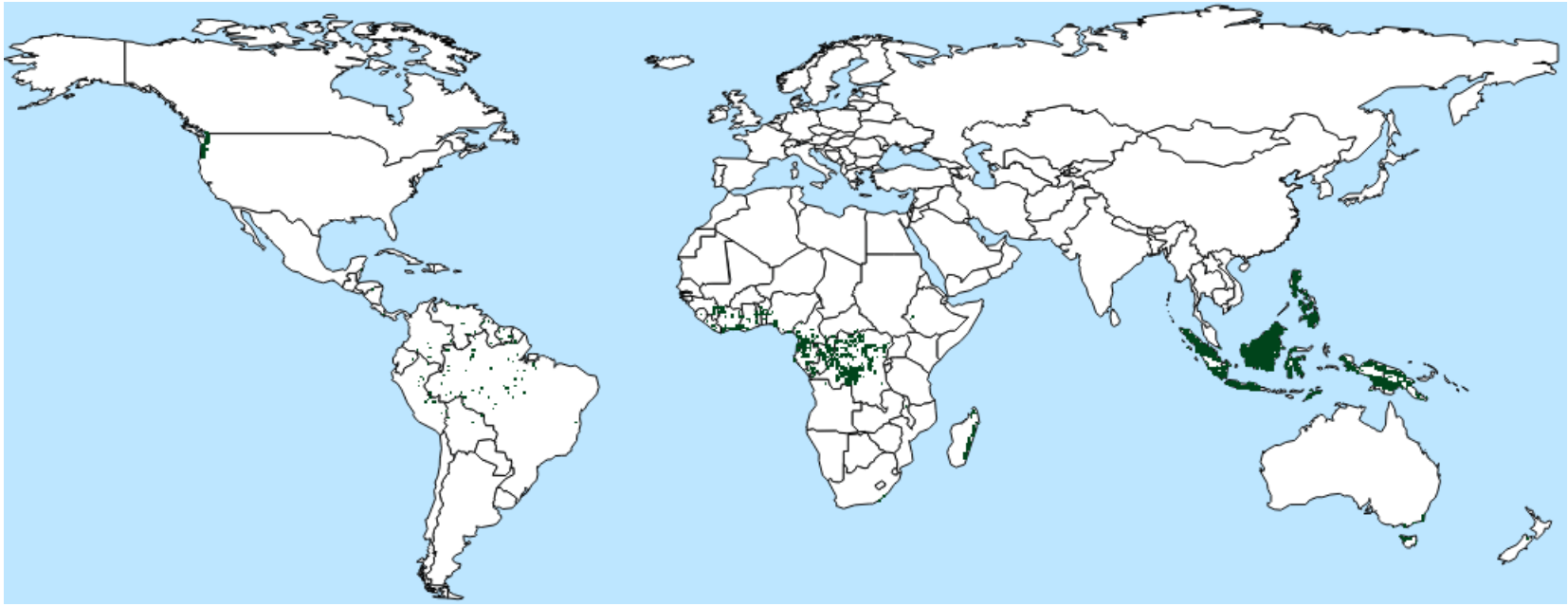
We Can Introduce Policy Interventions with SIMPLE and Observe Their Impact

Restore Terrestrial Carbon
(by eliminating cropland in critical regions)



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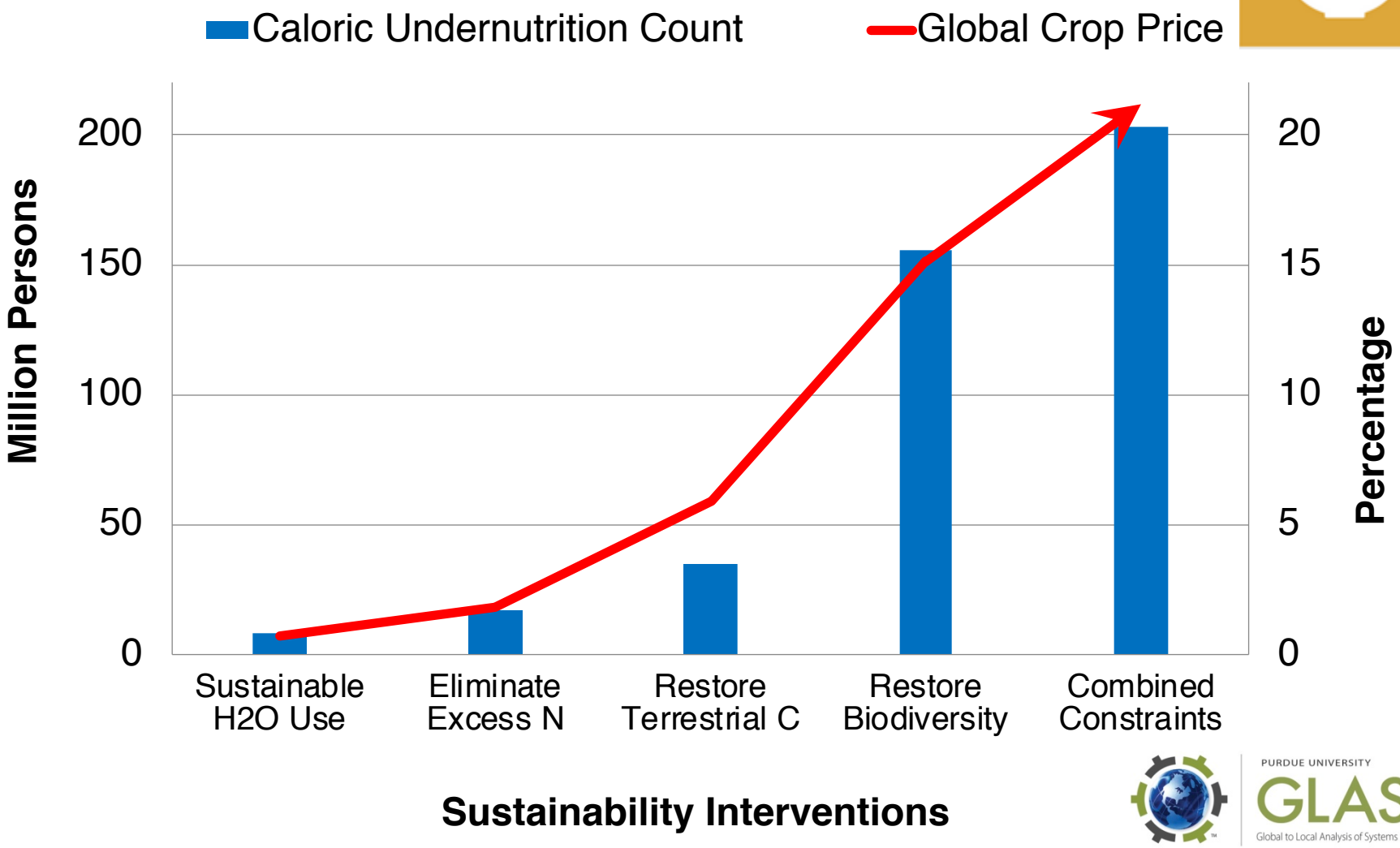
Some of These Policies Are Synergistic

- For example
  - Restoring terrestrial carbon also improves biodiversity
  - Targeting conservation of biodiversity would restore terrestrial carbon and also reduce irrigation
    - However, this would increase nitrogen use as compensation

However, These Strategies Would All Increase Malnutrition

Pursuing single SDGs can produce negative impacts



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Conclusions

- How much to produce in the future will still hinge on population and income
  - Population growth expected to slow down
  - Thus, income growth will play a large role in driving food demand
- Productivity growth is key for meeting food needs
  - Closing crop yield gaps can provide short-term gains in productivity
  - In the long run, technological improvements are critical: need to invest in agriculture R&D

Conclusions

- Global-to-local-to-global interconnections result in synergies and trade-offs among SDGs:
  - Restoring biodiversity brings large co-benefits for carbon and groundwater
  - However, area reductions increase intensity of cultivation on remaining croplands
  - Scenarios here highlight vulnerability of poor populations in South Asia, Southeast Asia and Sub-Saharan Africa

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THANK YOU!