Water, food & fuel: when does land matter?

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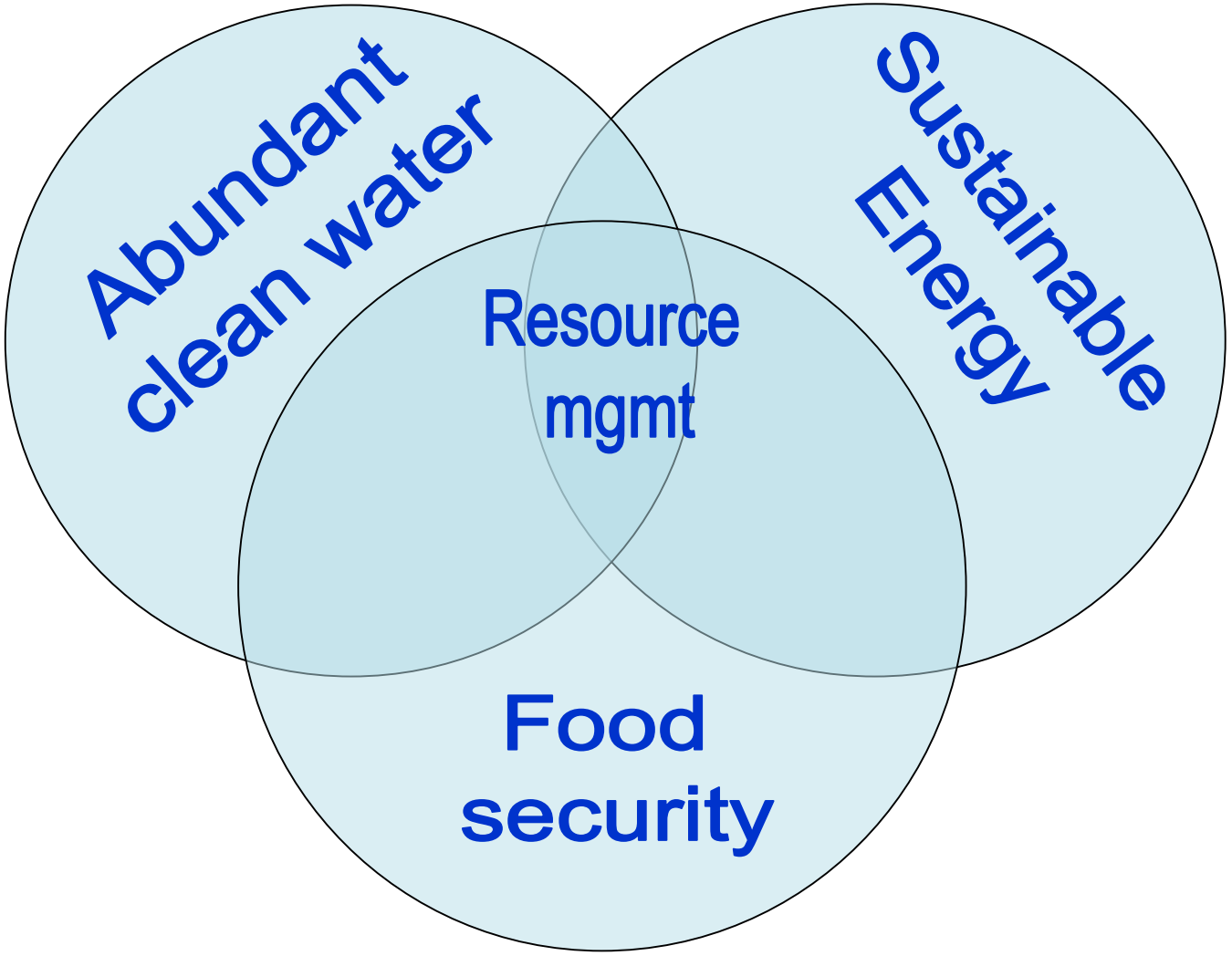
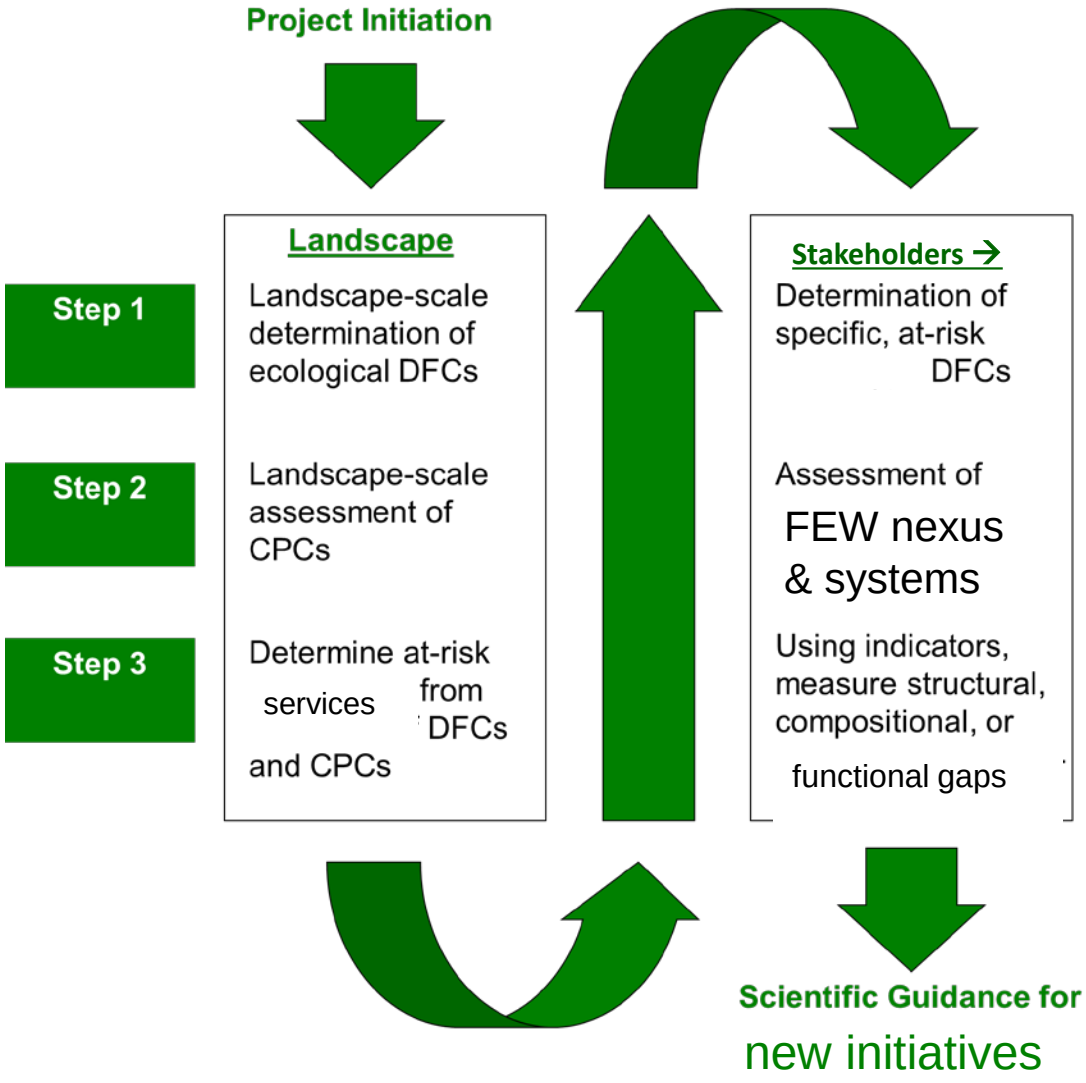
*The views in this presentation are those of the presenter who is responsible for any errors or omissions.

The nexus between "sustainable" energy, food security & water centers on human interventions on land & resulting interactions with ecosystem services such as clean water & productive soils



(adapted from Kline et al. 2017 – Reconciling Food Security…)

Grand challenge: (1) identify desired future conditions (DFC), (2) agree on current prevailing conditions (CPC) and (3) their causes, to understand "*How we got here*" and focus efforts on real solutions



Proposal: FEWS project to help address stakeholder engagement challenges:

Demonstrate and document methods & "better practices" to

- effectively engages stakeholders
- facilitate agreement on common understandings of
  - current status
  - past trends and
  - desired future conditions

How to best ensure stakeholder buy-in (?) to:

- Reach ***consensus*** on a "desired future" for food-energy-water
- Identify highly *undesired* but possible BAU future conditions
- Understand past trends and current status with attribution of drivers for "How we got here"
- Apply multi-disciplinary expertise for science-based analyses that
  - Compare realistic options for pathways
  - How to move from current state → desired future conditions

When, where, how & why does land matter?
Perceptions are important

Reconciling food security and bioenergy: priorities for action (see Kline et al., 2017)

- Land management and land qualities matter
- "LUC" from simple land classifications and assumption-driven models is often misleading
- What we need to know can't be learned from available global data sets (trade, commodity prices, "food" price indices, product footprints)
- For example, the same data are used to support distinct and mutually incompatible hypotheses (see Table 3 in Kline et al. 2017)
  - No hypotheses can be supported or refuted by global modeling – need local analyses
  - Context-specific data are required
  - Analyses of empirical data: common assumptions about price-food security relationships are questionable

Review of empirical data -

- Land area & commodity output do not limit global food or bioenergy production[1,2,3,4,5]
- The land *required* to feed the world in 2050 is a fraction (<1/10th) of the area currently classified as agricultural land[1]
- Land scams, tenure issues, poverty, & market distortions cause land clearing (see CBES & 1,4)
- Ag system responses to demand are quick and rely on existing production systems (e.g., intensification) rather than new land clearing[1]
- "Growing more" is not the solution when 40% of production is wasted & commodity stocks are at historic highs (FAO & others, see following slides)

We need policies to stimulate investments in new markets & clean, renewable production to displace non-renewable inputs

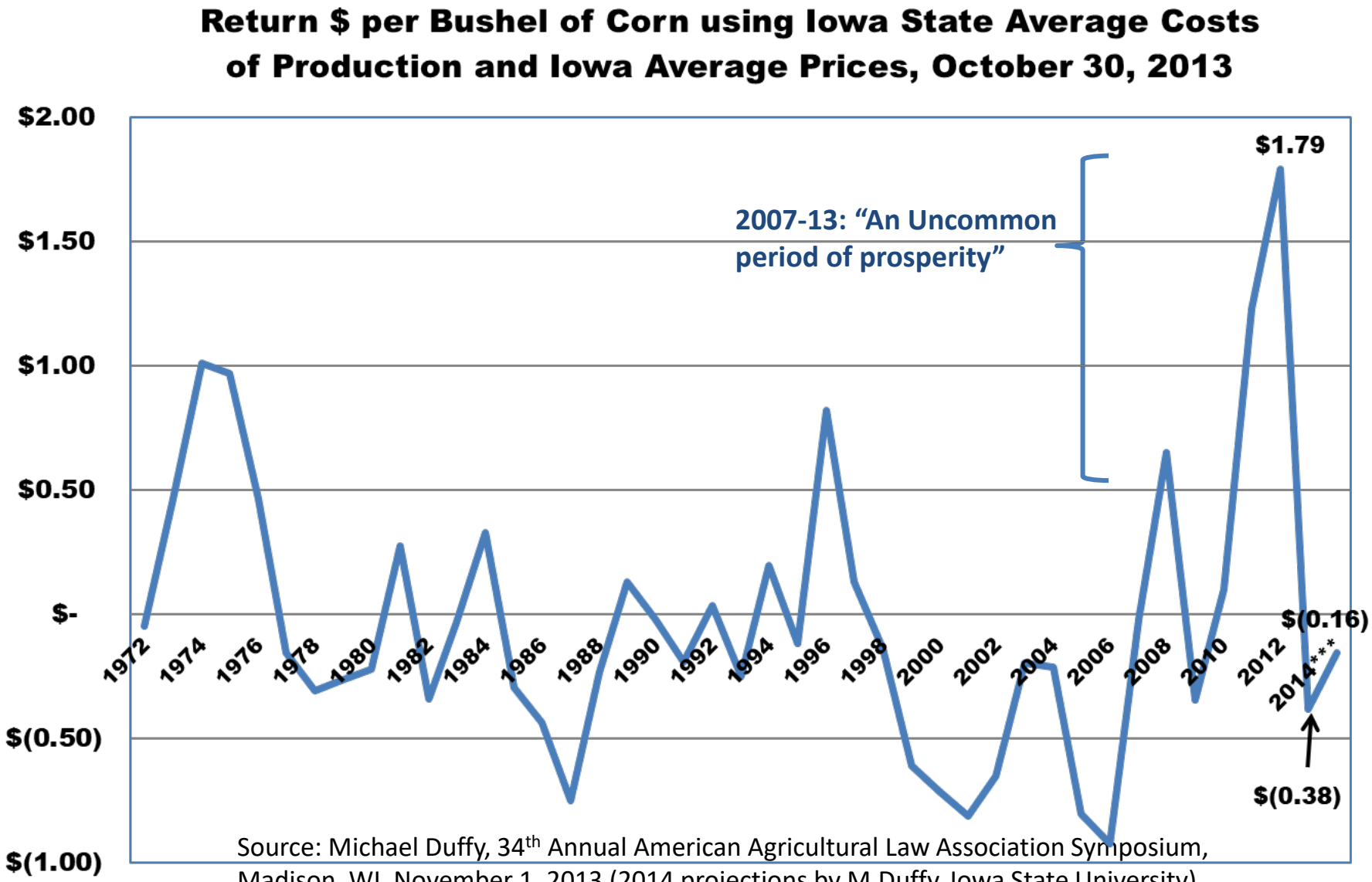
BEFS Bioenergy and Food Security Projects

Hunger, famine and food insecurity are context-specific, often politically driven, and not due to a shortage of food at global scale[5].

Sources

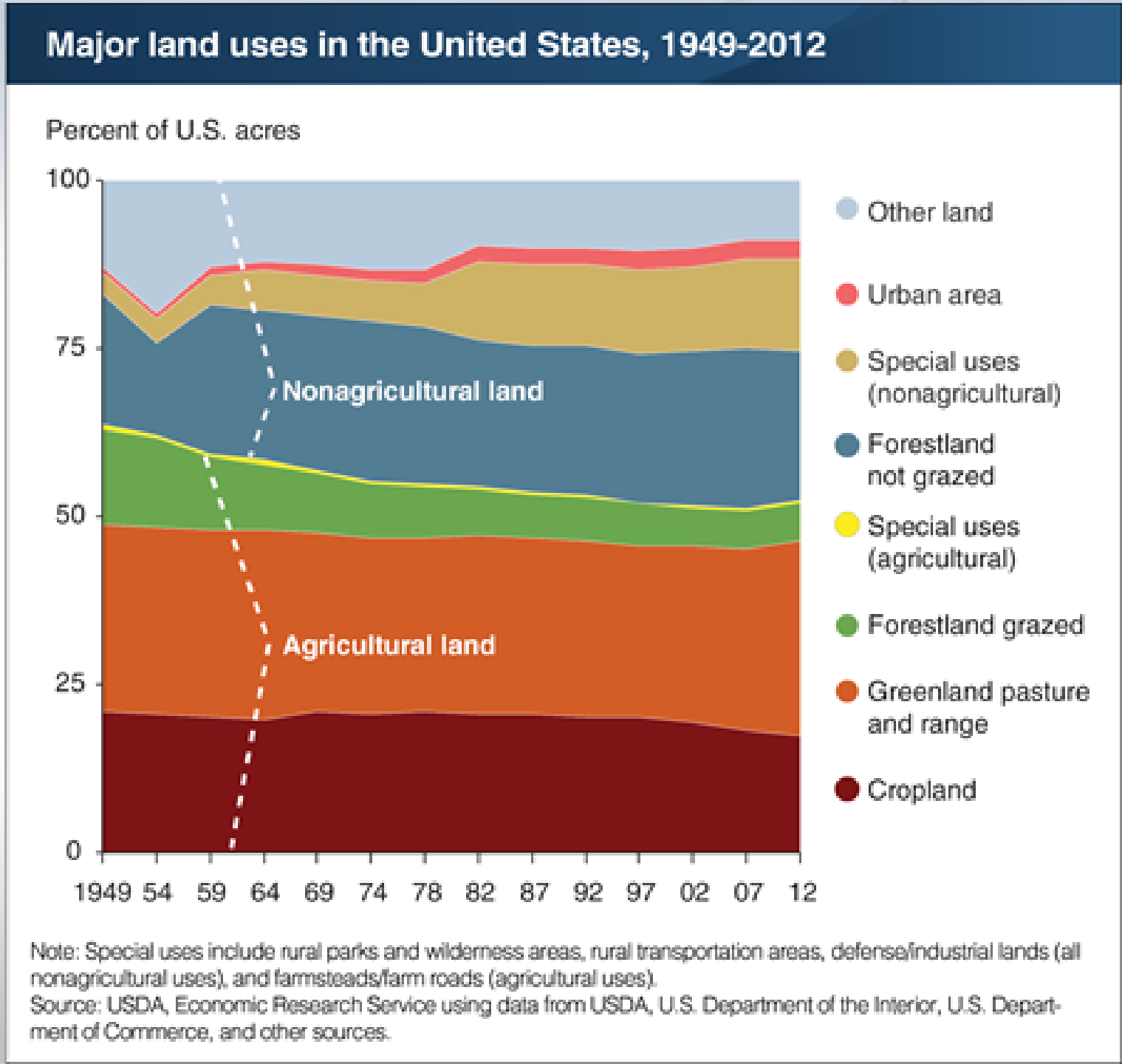
1. Kline et al. 2009, 2011, 2017
2. Thornhill et al. 2016
3. Leonardo et al. 2015
4. SCOPE 72 (Souza et al. eds.) 2015.
5. Thurow and Kilman 2009. *Enough: Why the World's Poor Starve in an Age of Plenty*

Farmers respond quickly to market signals while using less land

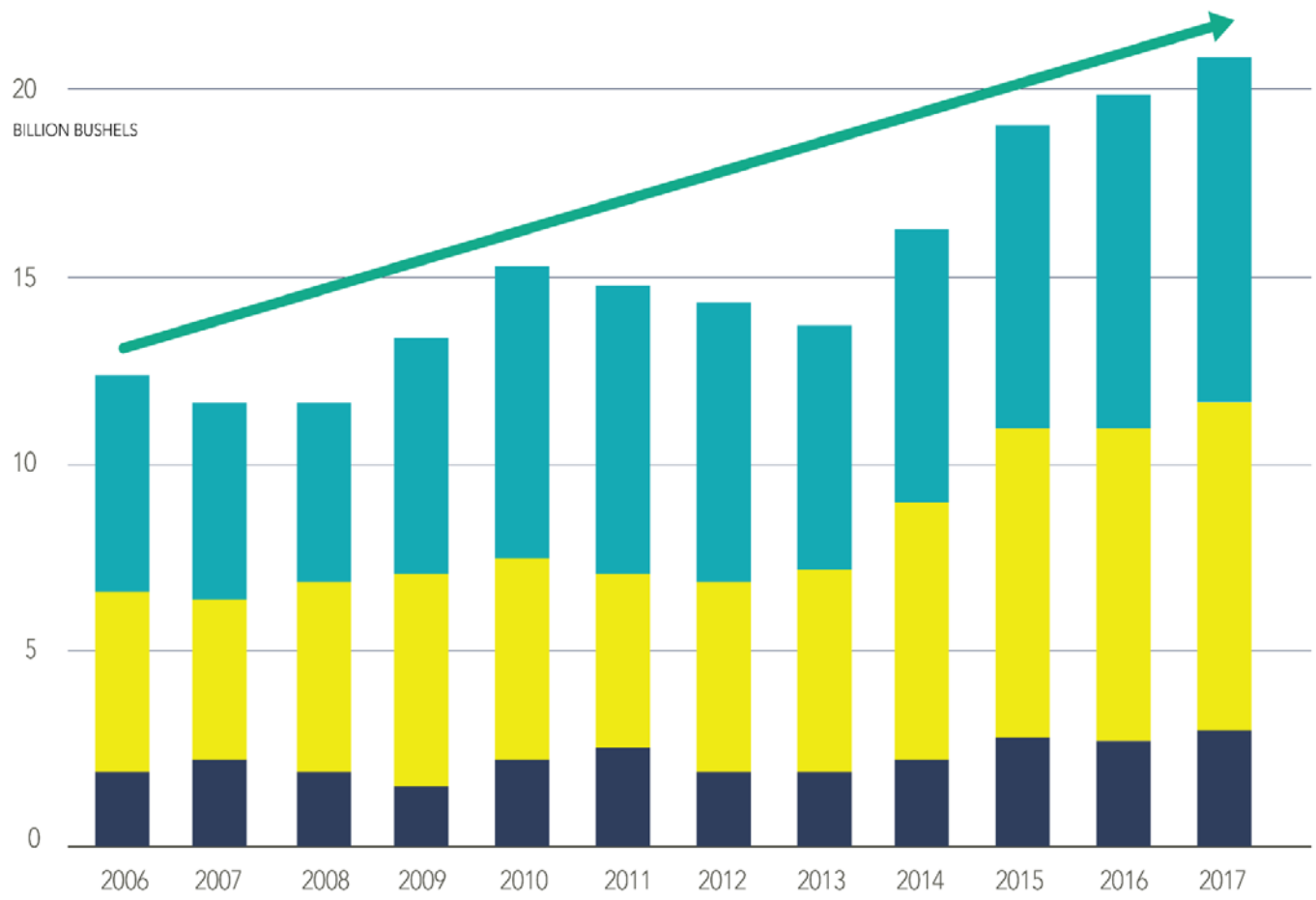


Source: Michael Duffy, 34th Annual American Agricultural Law Association Symposium, Madison, WI, November 1, 2013 (2014 projections by M.Duffy, Iowa State University)

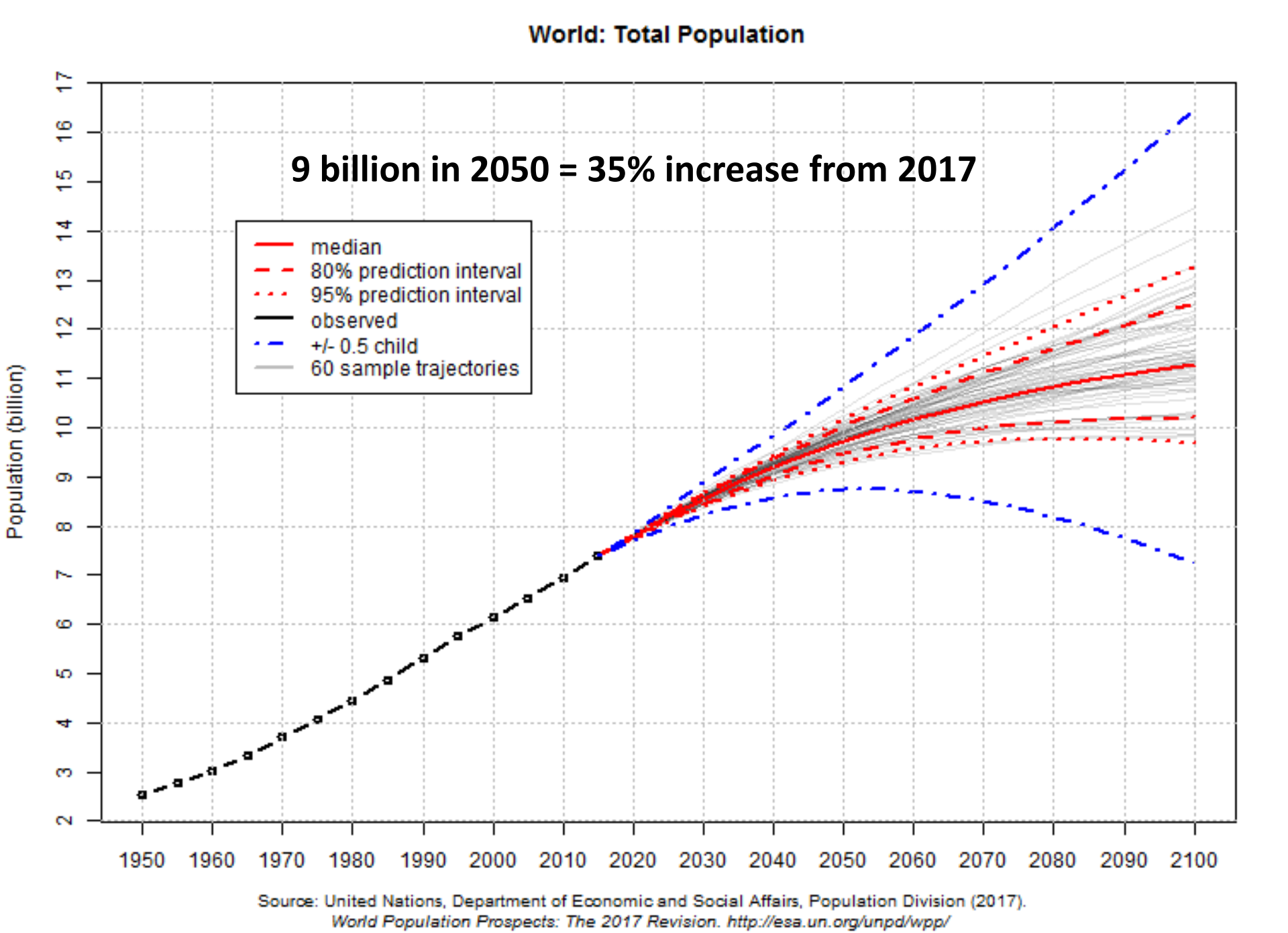
Increasing output 0.5% per year (avg) while decreasing land use 0.7% per year (avg).



Global stocks are rising.

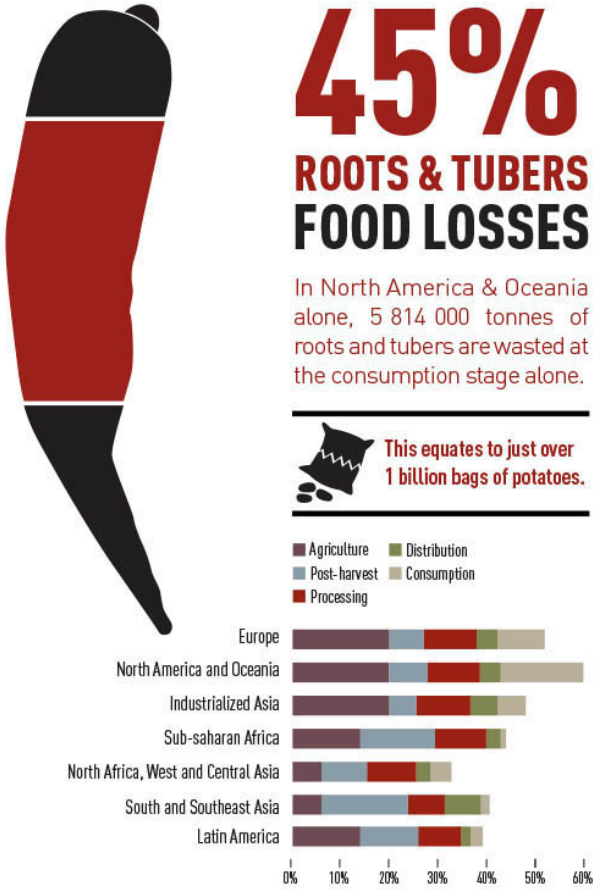


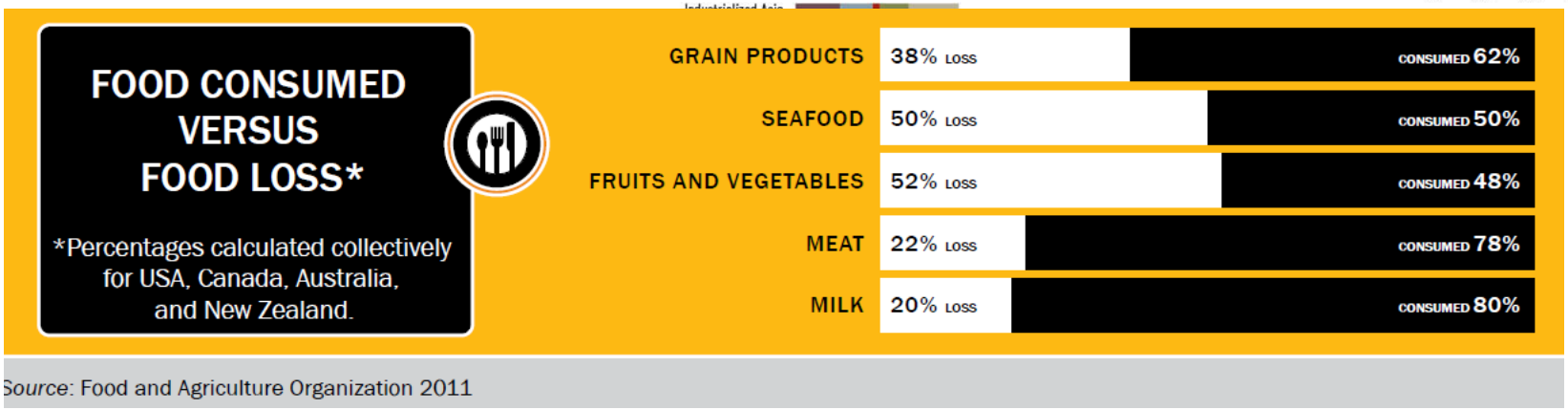
USDA data.
Slide credit to
D.Berven, POET


World: Total Population
9 billion in 2050 = 35% increase from 2017
median
80% prediction interval
95% prediction interval
observed
+/- 0.5 child
60 sample trajectories
Population (billion)
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Source: United Nations, Department of Economic and Social Affairs, Population Division (2017).
World Population Prospects: The 2017 Revision. http://esa.un.org/unpd/wpp/

Today, we waste about 40% of food

"Spoiler Alert" (2016): If wasted food was a country, it would be 3rd largest producer of greenhouse gases (GHGs) in the world, after China and the United States. And food wastes represent ***>1.6 trillion gallons water wasted***





Source: FAO http://www.fao.org/save-food/resources/keyfindings/en/

1.4 billion hectares, 28% of world's agricultural area, is used annually to produce food that is lost or wasted

http://www.fao.org/news/story/en/item/196402/icode/


“Waste” results when production exceeds demand

Do we need degraded and fallow land to supply future needs for food, feed, fiber, energy…?

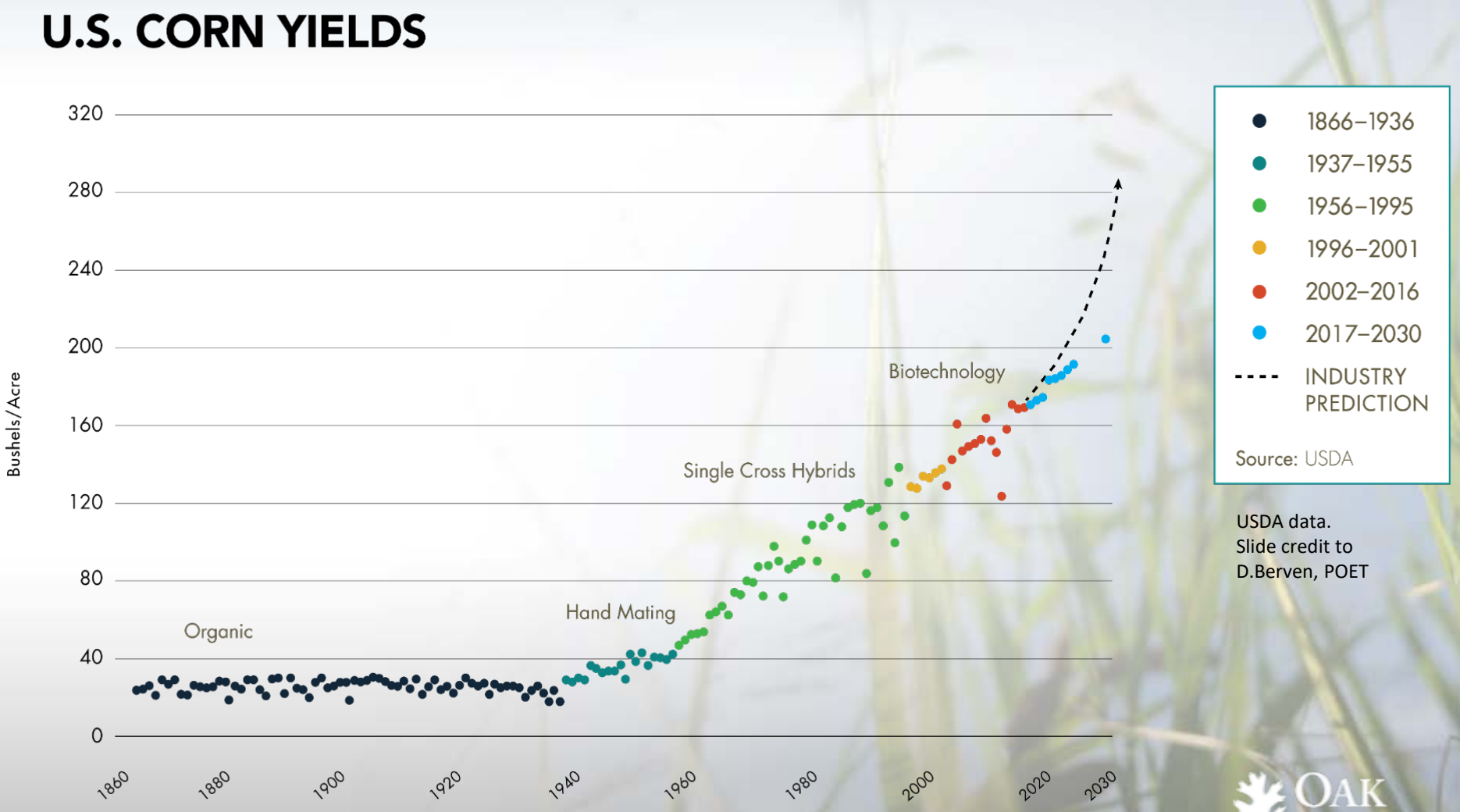
- Why not invest more in
  - Productive lands?
  - Urban FEWS?
- Tenure matters
- Understand & address local causes of poverty & malnutrition
  - Identify populations at high-risk
  - Design targeted interventions
    - Diversify sources of income
    - Build ownership in the process, the monitoring, & the science

USAID photo - Feed the Future annual report 2015

Rather than targeting a subjective land class, work with local leaders, government and civil society to:

- develop strategies and policies
- measure progress
- apply adaptive management (continual improvement)
- achieve common goals

Current yields avg. 165 bushel/acre. Potential yields >300 bushel/acre. Where will we put all that maize?



USDA data.
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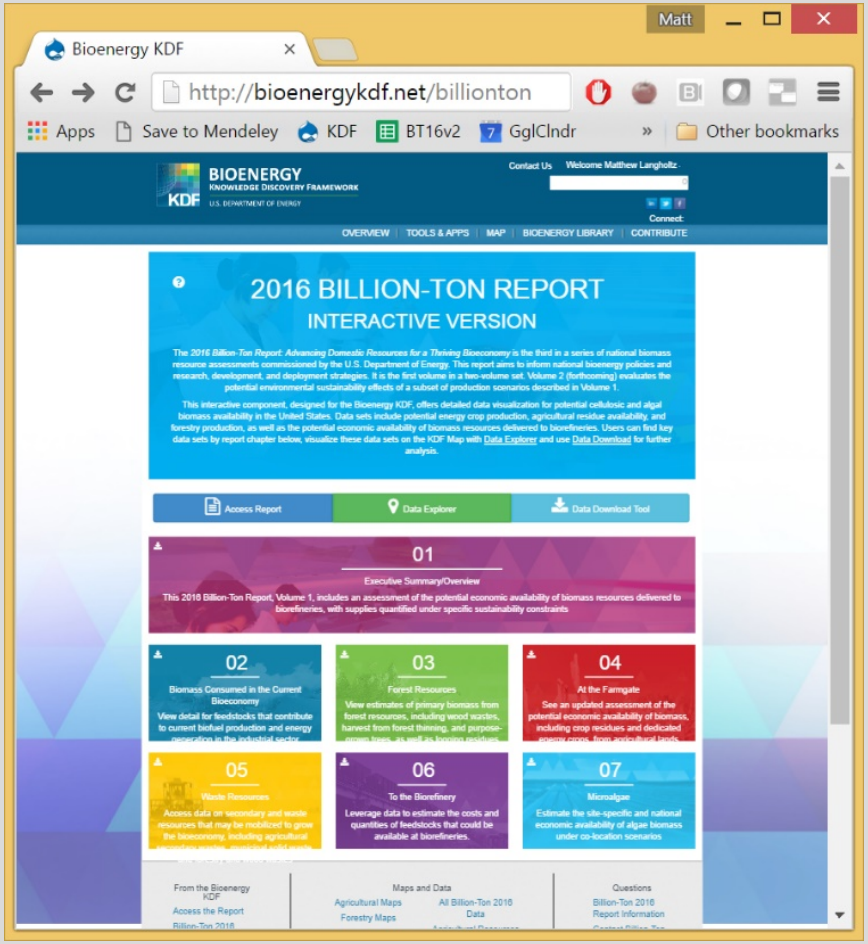
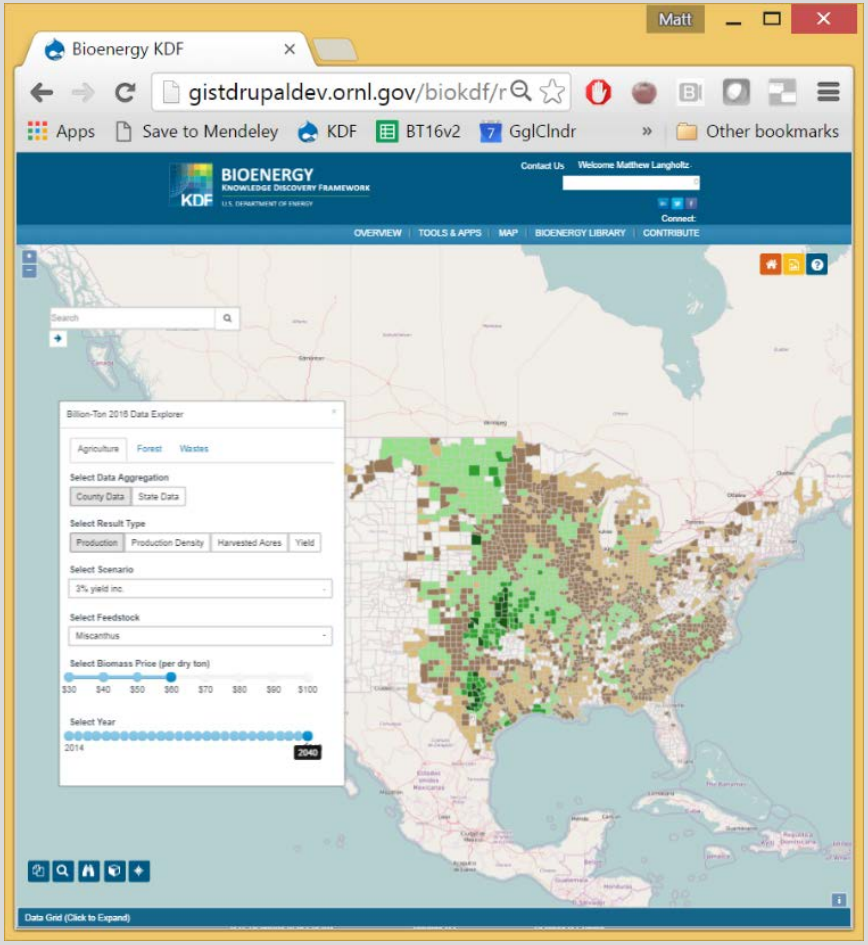
Resources available from currently managed lands:

U.S. example--US Billion-ton 2016 Resource Assessment

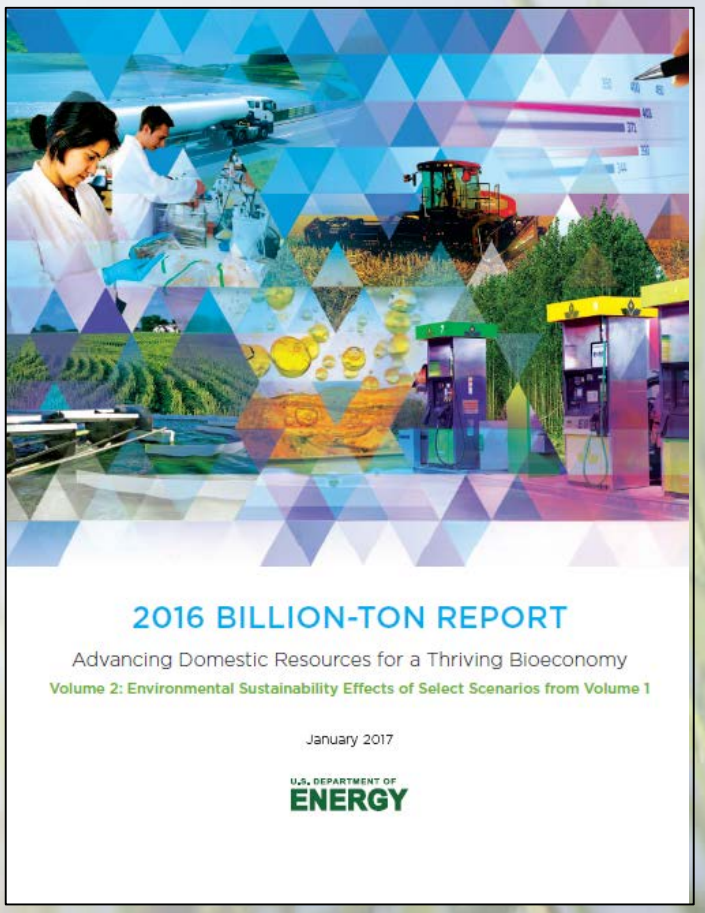
Interactive resources http://bioenergykdf.net/billionton (volume 1) and NEW sustainability volume 2 https://www.bioenergykdf.net/billionton2016vol2





Quantifying potential for 'sustainable' US supplies: BT16 Volume 2

- Previous Billion-Ton studies focus on quantifying potential biomass supplies.
- Volume 2 is first to assess environmental implications of BT scenarios and identify data gaps.
- *Online resources* enable additional analyses and inform future R&D. http://bioenergykdf.net/billionton (volume 1) & https://www.bioenergykdf.net/billionton2016vol2
- ***BT16 scenarios and simulations are designed to avoid induced (market-mediated) effects on food and land (LUC)***



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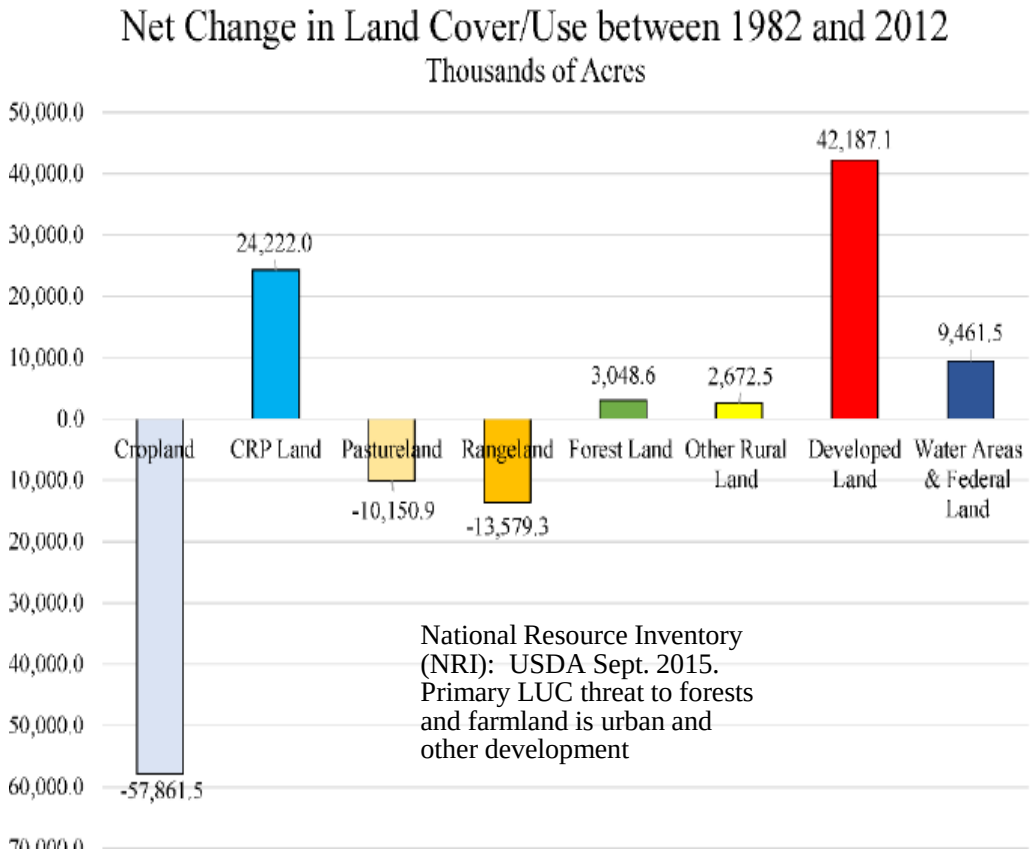
LUC summary findings (BT16 Chapter 3, Kline et al.)

Significant biomass available @ no/low-risk of LUC & ILUC

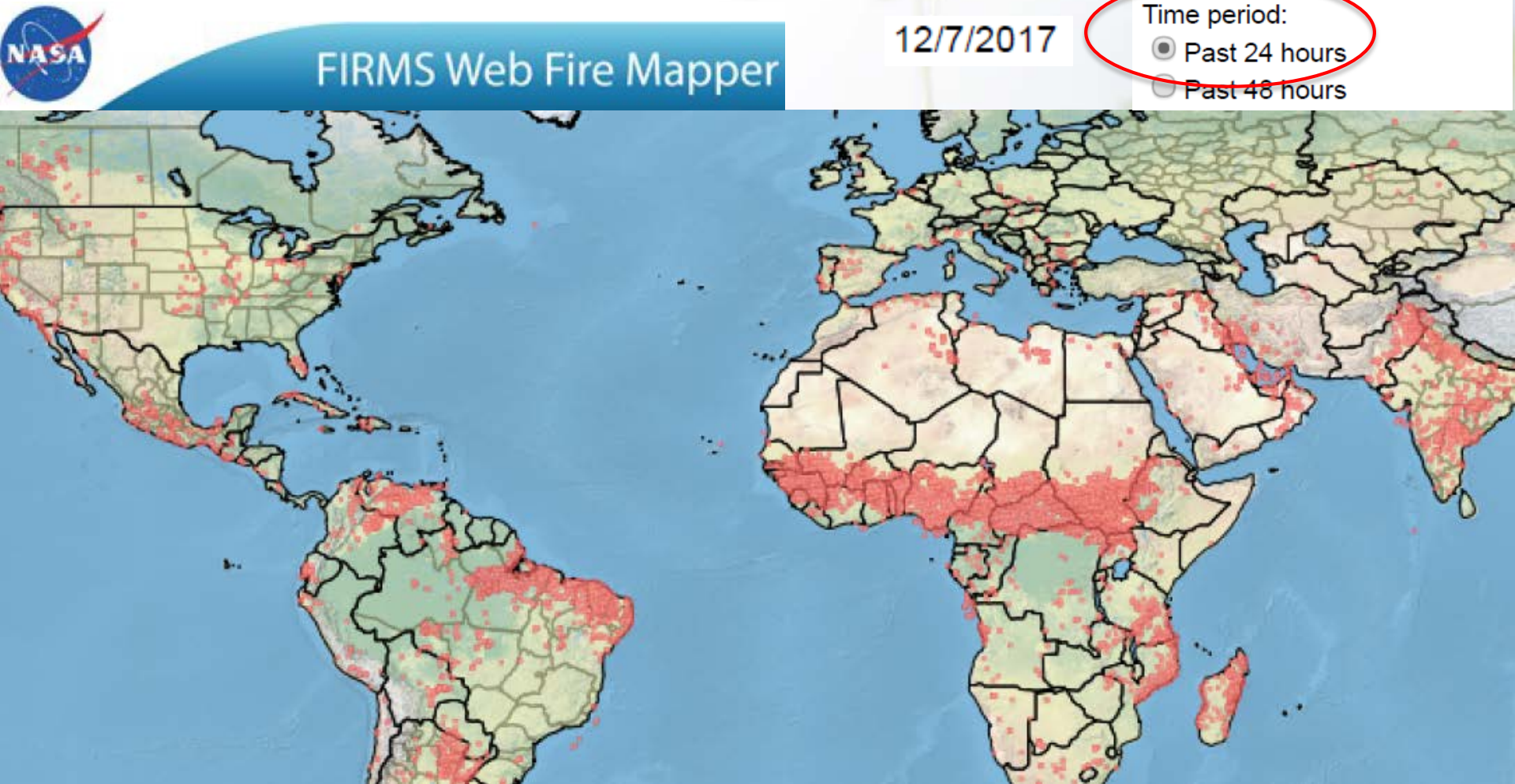
- LUC estimates depend on model specifications and assumptions.
- All estimates of change depend on a selected reference scenario
- BT16 land allocation for energy crops in 2040 is consistent with historic agriculture land trends (see USDA NRI Figure) →
- Science-based approaches and causal analysis are essential to understand relationships among drivers of LUC
- ***It's not "LUC" that matters but how matter changes that matters.***



We've got biomass to BURN! 400-550 million hectares of global land burns every year *(Randerson et. al., 2012; Giglio et al. 2010; Doerr and Santin 2016).*

Managed lands burn less often, less intensely *(Andela et al. 2017, Science).*

US Billion-ton sustained biomass supply involves residues +18 million hectares of cropland managed for perennials.



Science-based analysis to guide decisions

Science: systematic methodology based on evidence and observation

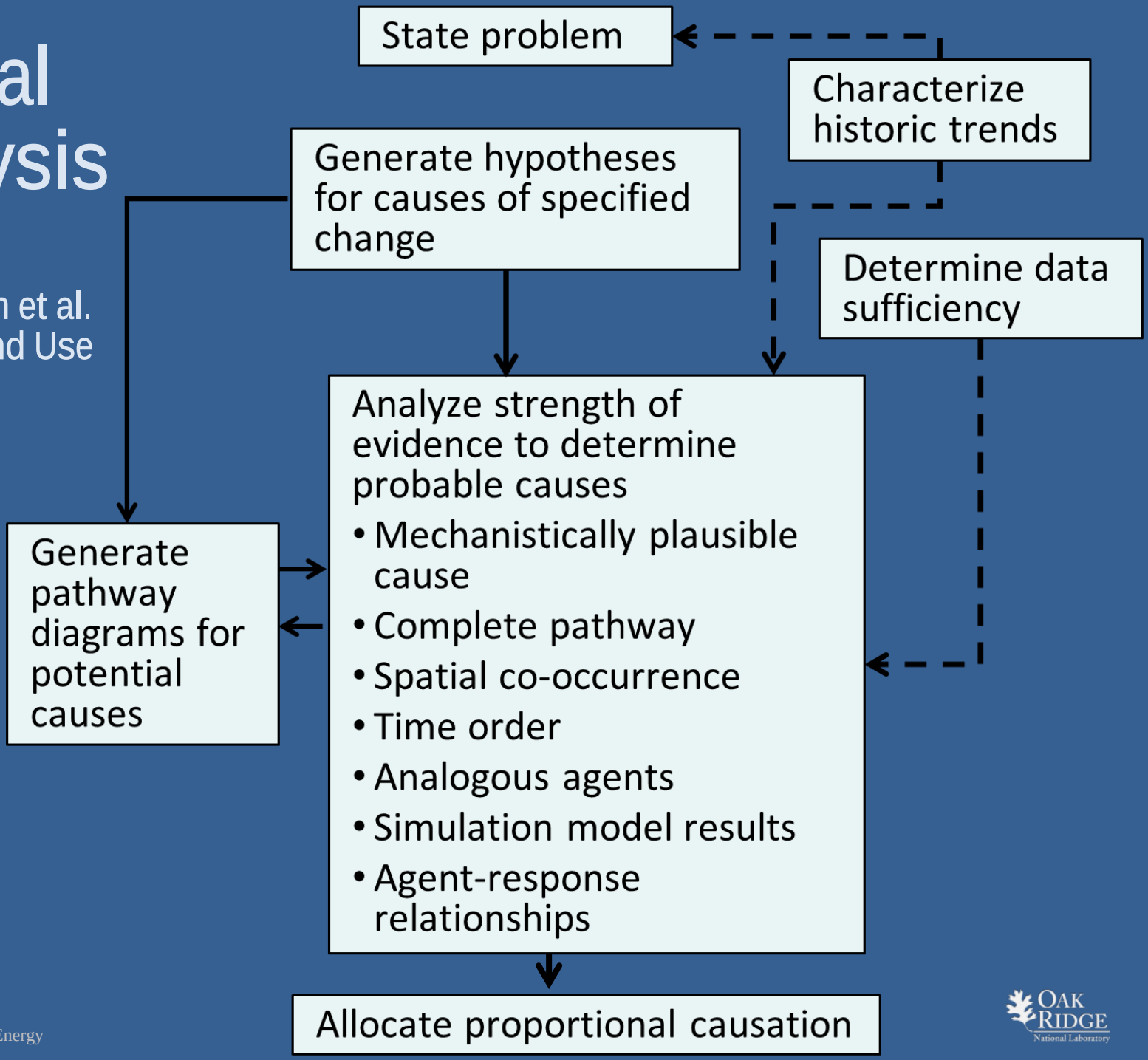
- ✓ Start with clear definition of problem
- ✓ Ask the right questions
- ✓ Test hypotheses
- ✓ Conduct critical analysis
- ✓ Determine cause and effect
- ✓ Document verifiable, replicable results
- ✓ Peer review and exchange
- ✓ Build on experience
- ✓ **Knowledge evolves as new data and understanding become available**

Challenges

- **Confounding data and terminology**
  - ✓ Land cover versus land uses (multiple) and land management
  - ✓ Crop price and trade versus total production and actual uses, losses
  - ✓ Correlation versus causation
  - ✓ Models over-simplify land classes
- **Limited data but new field work is tedious and costly to complete**
- **REALITY is always a *special case***

Causal Analysis

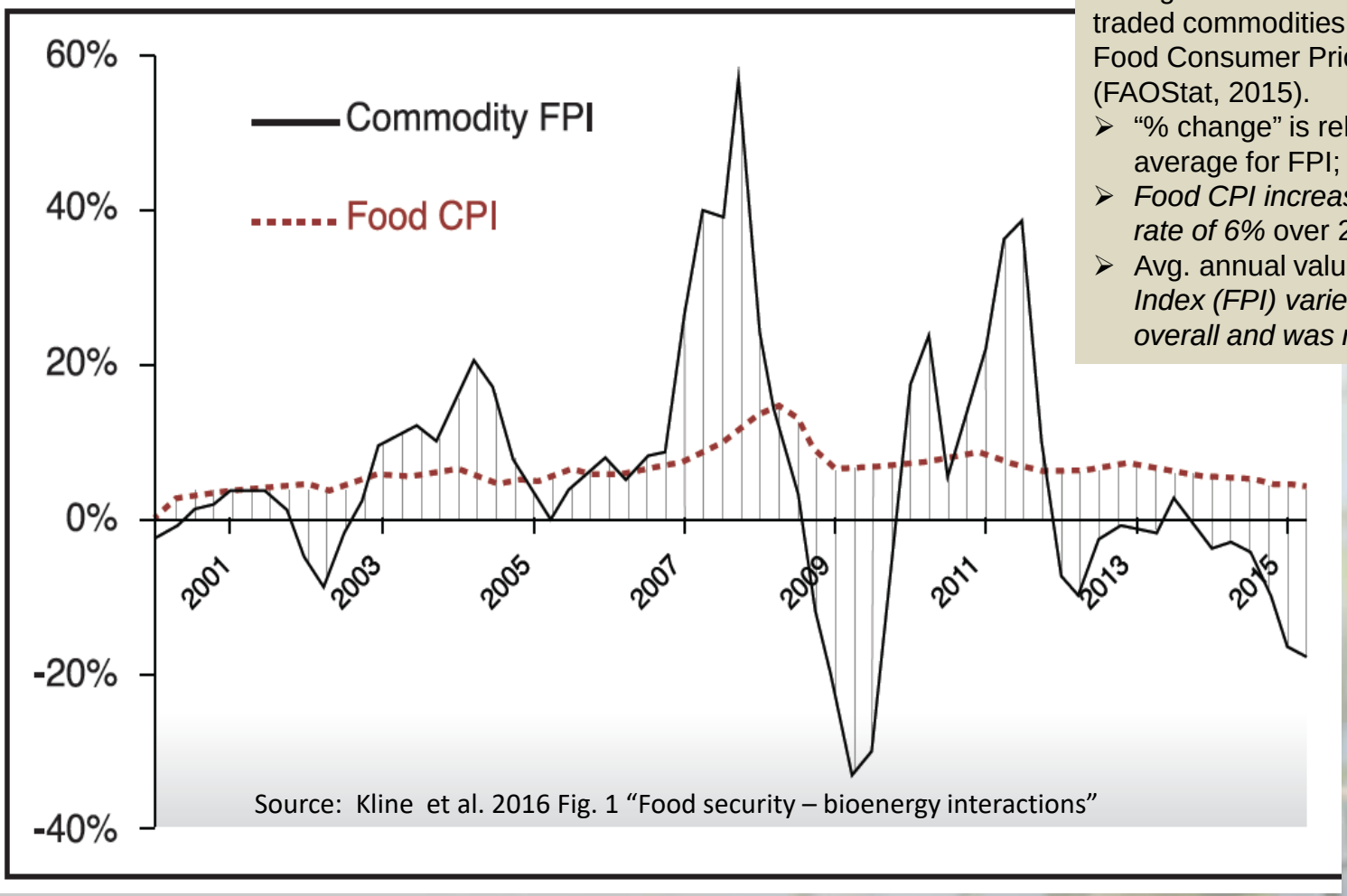
(Efroymson et al. 2016 in Land Use Policy)



Discussion:

Which ‘food prices’ matter for food security?

Is it better if the prices are falling or increasing?



Source: Kline et al. 2016 Fig. 1 “Food security – bioenergy interactions”

FAO global Food Price Index (FPI) based on traded commodities versus the FAO global Food Consumer Price Index (CPI) 2000-2015 (FAOStat, 2015).

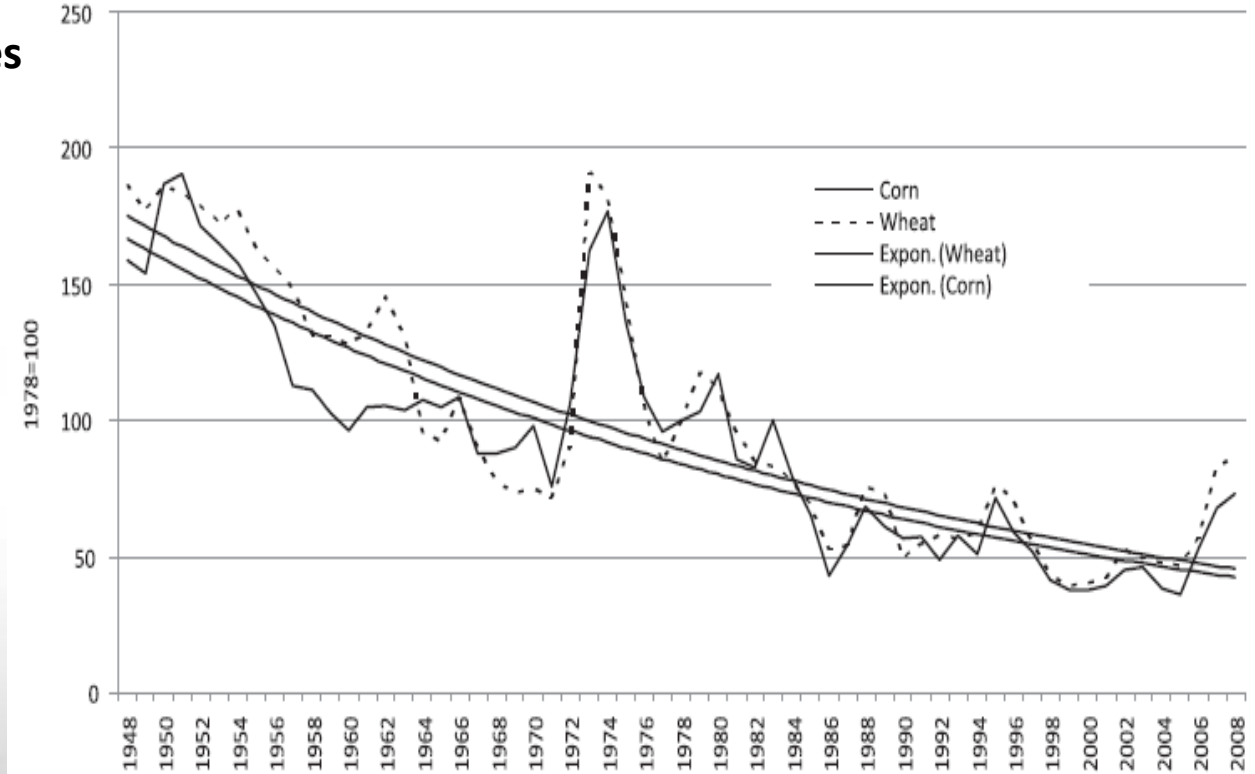
- “% change” is relative to the 2002-2004 average for FPI; and to year 2000 for CPI.
- *Food CPI increased at an average annual rate of 6%* over 2000-2015.
- Avg. annual values for global *Food Price Index (FPI) varied sharply: fell slightly overall and was negative in 7 of 15 years*.

Food security concerns stem in part from the lack of common understanding about key terms and concepts

- Definitions: "Food" security / insecurity, induced effects (LUC and ILUC)
- Facts, linkages, correlation versus causation, and RELEVANCE

Historical Price Trends for Globally Traded Commodities
(Sumner 2009)

- USDA NASS data (1948-2008)
- 1978 reference year (1978 =100).
- ***Indices, even if based on identical source data, can appear to tell different stories***
- Some argue that "food" prices are declining while others argue that food prices are increasing.
- Source: Notes on discussions in EUBCE Workshop on LUC (Kline, June 2016).



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SUSTAINABLE DEVELOPMENT GOALS

17 GOALS TO TRANSFORM OUR WORLD >160 indicators

FEW nexus linked to most SDGs ✓

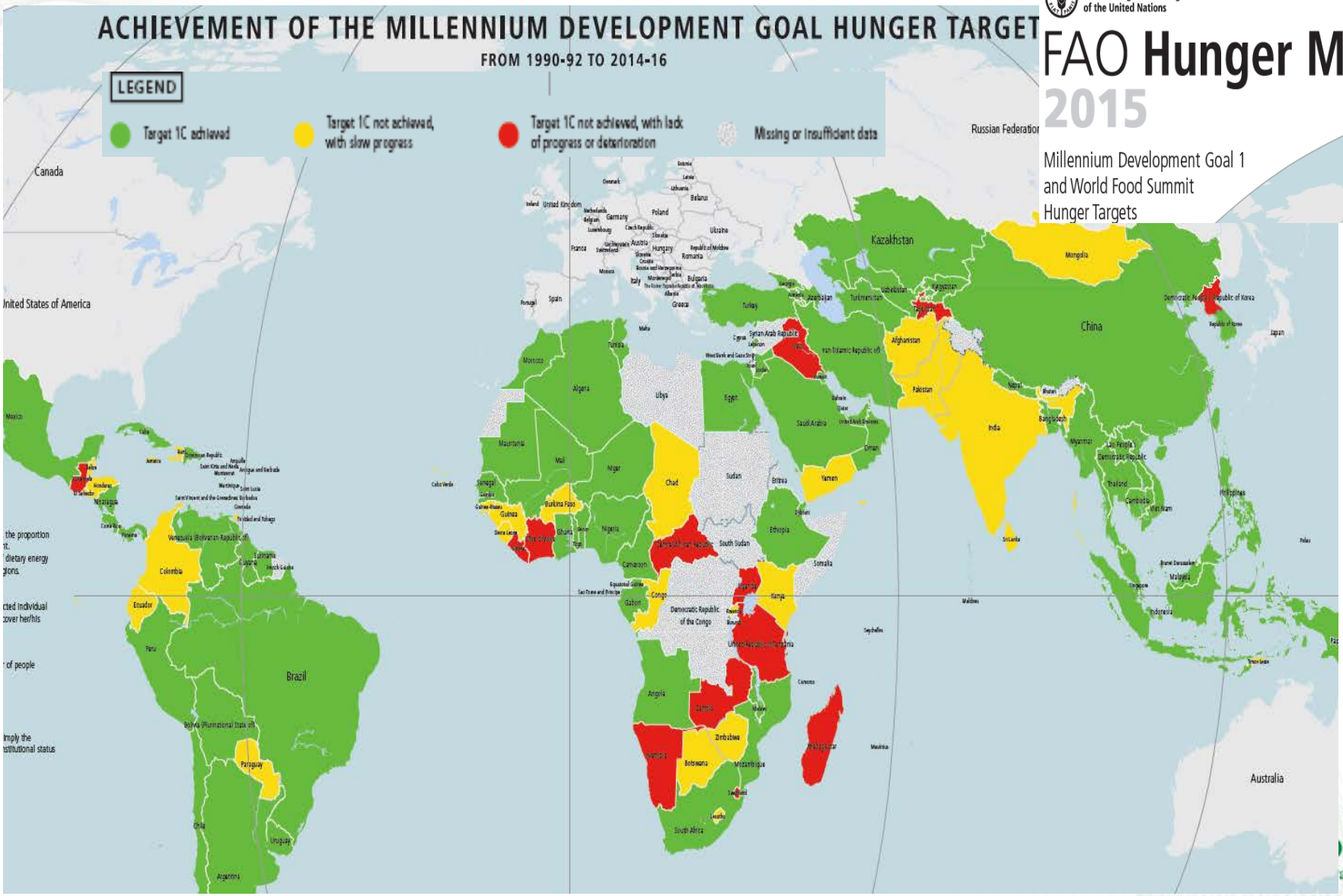
http://sd.iisd.org/news/iaeg-sdgs-sets-workplan-for-finalizing-indicators/

Food, energy water -- linked to SDGs addressing **poverty**, food security, **nutrition** and health, gender, water and sanitation, affordable and clean energy, **jobs**, innovation, sustainable consumption/production, climate change, oceans, seas and marine resources, terrestrial eco-systems, forests, **land degradation** and biodiversity, and **strengthened institutions**

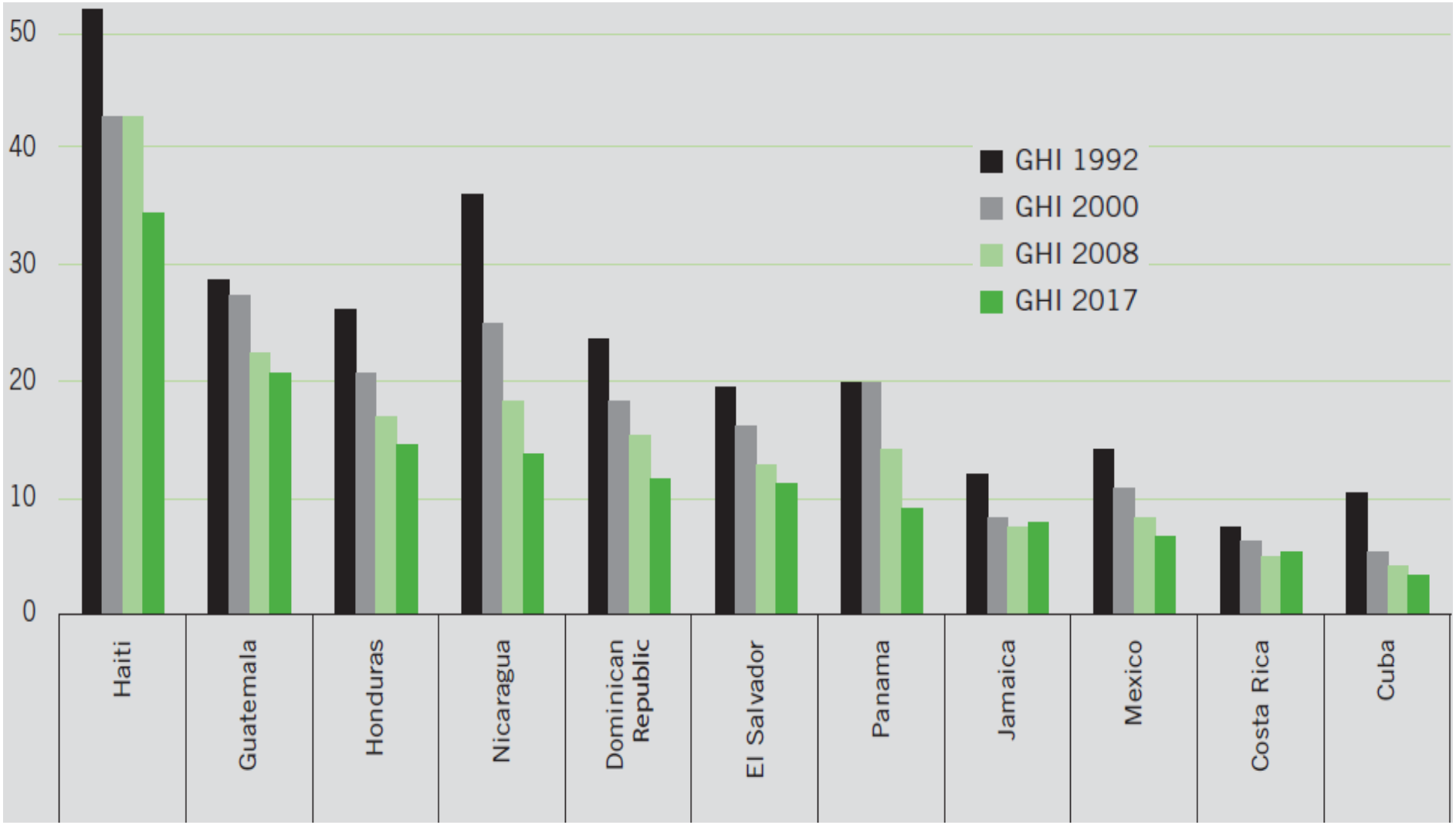
Hypothesis: providing additional options to add value to rural production and enterprise supports SDGs for food, energy, water & others simultaneously. Plenty of land but a lack of the 'right market incentives.'

A common request heard in rural areas:
"***I have land, labor, climate; what can I grow and make a profit***?"

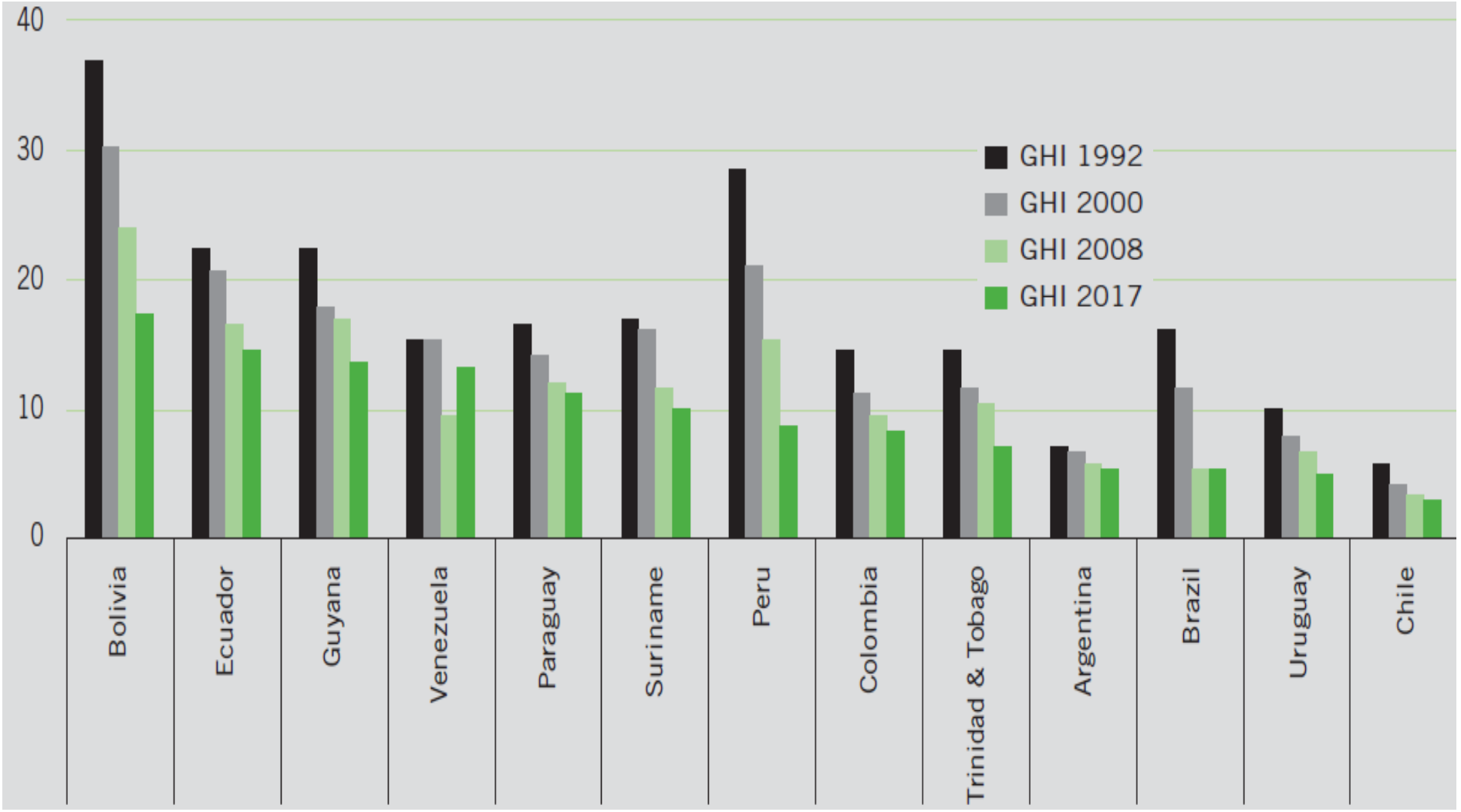
Food security is difficult to quantify. Goals focus on reducing indicators of chronic hunger



Global Hunger Index (GHI) 2017: Progress is being made across the Americas (International Food Policy Research Institute (IFPRI), Concern Worldwide, and Welthungerhilfe; Washington, DC / Dublin / Bonn. October 2017)



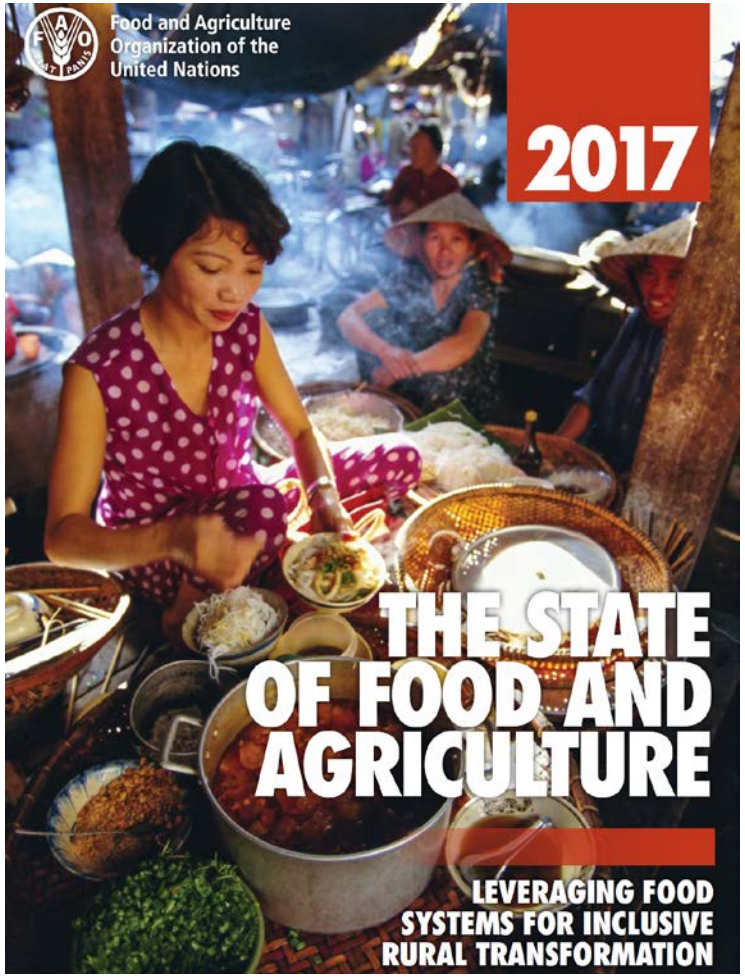
Global Hunger Index (GHI) 2017. GHI reflects rates of child mortality, stunting and wasting, and undernourishment in general population (IFPRI, et al., October 2017)



As long as hunger persists, food security will remain a concern

Despite major increases in global food stocks, more people hungry today than 2015.
815 million people chronically undernourished (FAO 2017), vs 793 million (2015).
Achieving SDG to reduce hunger "***depends crucially on progress in rural areas, which is where most of the poor and hungry live***." **Constructive actions: policies** supporting successful "rural transformation" are expected to improve food security:

- Facilitate access to inputs;
- Foster sustainable management practices;
- Better access to credit and markets;
- Mechanization;
- Effective extension systems;
- Strengthen land tenure rights;
- Equitable supply contracts; and
- Stronger links between rural areas and towns.



A 2nd potential research topic

Applying FEWS expertise to accelerate improvements in maize and wheat production systems in China and the US (ORNL-UT, CIMMYT, China and CAS partners, others)

- Process to engage stakeholders and agree on priorities
  - Invest in better practices
  - Improve system efficiency
- Evidence-based analyses
- Indicators for quantitative analysis
  - Multi-sector
  - Multi-scale
  - Multi-institutional
- Ownership of process, data, results
- Manageable monitoring → new learning → better practices

==========

- FYI: Keith's current initiatives include
  - Protocol for reference scenario
  - Indirect effects and ILUC

Thank you!

Photo: ORNL

Epilogue for scientists: Do we have the right tools for the job?

"I used to think the top environmental problems were

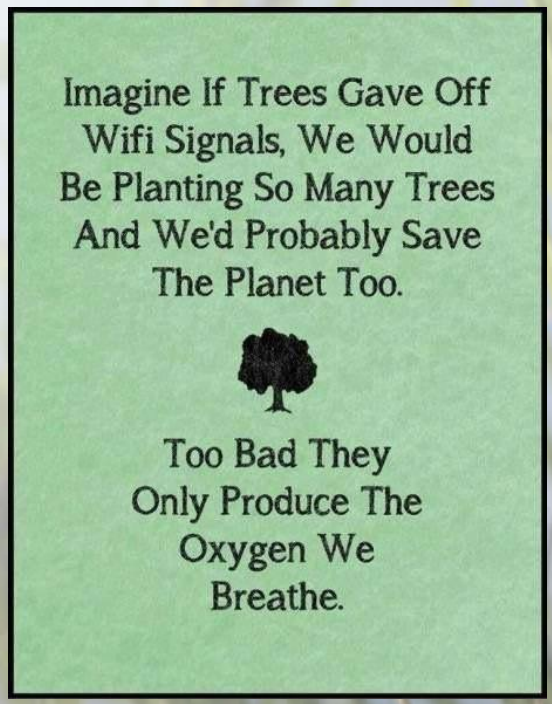
- *Biodiversity loss*
- *Ecosystem collapse*
- *Climate change*

And thought science could address these problems.

I was wrong.

The top environmental problems are greed and apathy, and to deal with those we need a cultural, spiritual transformation. Scientists don't know how to do that."

– attributed to Gus Speth



Thank you

Center for Bioenergy Sustainability
http://www.ornl.gov/sci/ees/cbes/

See CBES website for
- Reports
- Forums on current topics
- Recent publications

Reconciling food security and biofuels, http://onlinelibrary.wiley.com/doi/10.1111/gcbb.12366/full

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References and related reading

- Dale B et al. 2014. Take a closer look: biofuels can support environmental, economic and social goals. ES&T48(13):7200-7203
- Dale VH et al. 2013. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. Ecological Indicators 26: 87-102. http://dx.doi.org/10.1016/j.ecolind.2012.10.014
- Dale VH et al. 2016. Incorporating bioenergy into sustainable landscape designs. *Renewable & Sustainable Energy Reviews* 56:1158-1171. http://authors.elsevier.com/sd/article/S1364032115014215
- Dale VH et al.(Submitted 2016 for Biomass & Bioenergy Special Issue on Biofuels and Ecosystem Services) Selecting indicators of changes in ecosystem services due to cellulosic-based biofuels in the midwestern US.
- Efroymson RA et al. 2013. Environmental indicators of biofuel sustainability: What about context? Environmental Management 51(2): 291-306. http://web.ornl.gov/sci/ees/cbes/Publications/Efroymsonetal2012biofuelindicatorcontextEMfinal10%201007_s00267-012-9907-5.pdf
- FAO (2015a) Hunger Map 2015. FAO Statistics Division, Rome. Available: http://www.fao.org/hunger/en/
- FAO (2015b) Forty-second Session Report, Committee on World Food Security, Rome, Italy, 12-15 October 2015. Global Strategic Framework for Food Security & Nutrition (GSF) Available at: http://www.fao.org/3/a-mo187e.pdf Last Accessed 10/10/2015.
- FAO, IFAD, WFP (2013) The State of Food Insecurity (SOFI) in the World 2013 -The multiple dimensions of food security. And FAO, IFAD, WFP (2014) SOFI Strengthening the enabling environment for food security and nutrition. FAO Rome. And FAO, IFAD, WFP (2015) SOFI Meeting the 2015 international hunger targets: taking stock of uneven progress. FAO, Rome, Italy
- Kline KL, Dale VH (2008) Biofuels, causes of land-use change, and the role of fire in greenhouse gas emissions. Science, 321, 199.
- Kline KL, Dale VH, Lee R, Leiby P (2009) In Defense of Biofuels, Done Right. Issues in Science and Technology, 25(3), 75-84
- Kline KL, Oladosu GA, Dale VH, McBride AC (2011) Scientific analysis is essential to assess biofuel policy effects. Biomass and Bioenergy, 35, 4488-4491
- Kline KL (2014) Advanced School on Present and Future of BioEnergy, ESPCA–FAPESP–University of Campinas, 10-17 October, 2014. Campinas, SP Brazil.
- Kline KL et al. (2017) Reconciling biofuels and food security: priorities for action. GCB-Bioenergy. http://onlinelibrary.wiley.com/doi/10.1111/gcbb.12366/full
- McBride A et al. (2011) Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators* 11(5) 1277-1289.
- Parish ES et al. (2012) Multimetric spatial optimization of switchgrass plantings across a watershed. *BioFPR*. 6(1):58-72
- Parish ES, Kline KL, Dale VH, Efroymson RA, et al., (2013) Comparing Scales of Environmental Effects from Gasoline and Ethanol Production. Environmental Management 51(2):307-338
- REN 21 Renewables (2016) and (2014) Global Status Report Paris, REN21 Secretariat. http://www.ren21.net/status-of-renewables/global-status-report/
- IRENA (Jeff Skeer) (2016) Boosting Biofuels: Sustainable paths to greater energy security. www.irena.org
- Rainforest Alliance (2008) Impact of FSC Certification on Deforestation and the Incidence of Wildfires in the Maya Biosphere Reserve. http://www.rainforest-alliance.org/forestry/documents/peten_study.pdf
- Roser M (2015) Our World in Data. www.OurWorldinData.org
- Souza GM, Victoria RL, Joly CA and Verdade M, editors 2015. Scientific Committee on Problems of the Environment (SCOPE), Bioenergy & Sustainability: bridging the gaps. SCOPE 72. Paris, France and Sao Paulo, Brazil. ISBN: 978-2-9545557-0-6. http://bioenfapesp.org/scopebioenergy/index.php
- Sumner DA (2009) Recent commodity price movements in historical perspective. American Journal of Agricultural Economics, 91(5) 1250-1256
- Thurow R, Kilman S (2009) Enough: Why the World's Poor Starve in an Age of Plenty. BBS Public Affairs, New York.
- UNEP (2016) Unlocking the Sustainable Potential of Land Resources: Evaluation Systems, Strategies and Tools. Working Group on Land and Soils, International Resource Panel (IRP UNEP). Herrick, JE, O Arnalds, B Bestelmeyer, S Bringezu, G Han, MV Johnson et al. , ISBN: 978-92-807-3578-9
- USDA Economic Research Service (2015) Definitions of Food Security: Ranges of Food Security and Food Insecurity. U.S. Department of Agriculture
- Woodall et al. 2015. Monitoring Network Confirms Land-Use Change is a Substantial Component of the Forest Carbon Sink in eastern United States

References and related reading

- Arezki et al. 2014. Understanding international commodity price fluctuations. Journal of International Money and Finance 42 (2014) 1–8
- Babcock, B. A. (2011 June). The impact of US biofuel policies on agricultural price levels and volatility. International Centre for Trade and Sustainable Development (35)
- *BT 2016 Billion-Ton Report. Volume 2: Advancing Domestic Resources for a Thriving Bioeconomy. Volume 2. Environmental Sustainability Effects of Select Scenarios:* https://energy.gov/eere/bioenergy/downloads/2016-billion-ton-report-volume-2-environmental-sustainability-effects
- Charles, C. (2012 April). Should we be concerned about competition between food and fuel? International Institute for Sustainable Development.
- de Gorter, H., & Just, D. R. (2010). The social costs and benefits of biofuels: The intersection of environmental, energy and agricultural policy. Applied Economic Perspectives and Policy.
- Economic Research Service, Amber Waves, 10(2 (June)), 2012.
- Durham, C., Davies, G., & Bhattacharyya, T. (2012, June). Can biofuels policy work for food security? Department for Environment Food and Rural Affairs.
- FAO, IFAD, IMF, OECD, UNCTAD, WFP, the World Bank, the WTO, IFPRI, and the UN HLTF. (2011, June 2). Price volatility in food and agricultural markets: Policy responses. Policy Report for the G-20 .
- King R (Oxfam), Kelbert A (IDS), Chisholm N (University College Cork), Hossain N (IDS). 2014. Help Yourself - Food Rights and Responsibilities: Year 2 findings from Life in a Time of Food Price Volatility. Joint Agency Research Report. www.ids.ac.uk and www.oxfam.org
- Leonardo WJ, Florin MJ, van de Ven GWJ, Udo H, Giller KE Leonardo et al., 2015. Which smallholder farmers benefit most from biomass production for food and biofuel? The case of Gondola district, central Mozambique Biomass and Bioenergy 83:257-268
- Locke, A., Wiggins, S., Henley, G., & Keats, S. (2013 April). Diverting grain from animal feed and biofuels. London : Overseas Development Institute.
- McPhail, Lihong Lu, & Du, X. (2012). Ethanol Strengthens the Link Between Agriculture and Energy Markets.
- ORNL BT16 Resource Assessment for US biomass supplies volume 1: https://energy.gov/eere/bioenergy/2016-billion-ton-report
- Peterka, A. (2012 31-July). Livestock groups urge EPA to waive ethanol mandate. Governors' Biofuels Coalition.
- Schafer, E. (2012 8-March). Proposed RFS changes spark food vs. fuel debate. Feed & Grain.
- Sepp S. 2014. Multiple-household fuel use; a balanced choice between firewood, charcoal and LPG. Published by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (www.giz.de/hera), Eschborn, Germany, on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ). http://www.eco-consult.com/fileadmin/user_upload/pdf/Multiple-Household_Fuel_Use.pdf
- Thornhill S, Vargyas E, Fitzgerald T, Chisholm N (2016) Household food security and biofuel feedstock production in rural Mozambique and Tanzania. Food Security 8:953-972.
- Tyner, W. E., Taheripour, F., & Hurt, C. (2012 16-August). Potential impacts of a partial waiver of the ethanol blending rules. Farm Foundation and Purdue University.
- Wright, B. (2011, February). Biofuels and food security: Time to consider safety valves? . IPC Policy Focus, International Food and Agricultural Trade Policy Council.

References and related reading

- Dale VH, KL Kline, LL Wright, RD Perlack, M Downing, RL Graham. 2011. Interactions among bioenergy feedstock choices, landscape dynamics and land use. *Ecological Applications* 21(4):1039-1054.
- Dale, VH, RA Efroymson, KL Kline, MH Langholtz, PN Leiby, GA Oladosu, MR Davis, ME Downing, MR Hilliard. 2013. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. Ecological Indicators 26: 87-102.
- Oladosu D, KL Kline, P Leiby, R Martinez, M Davis, M Downing, L Eaton. 2012. Global economic effects of the US biofuel policy and the potential contribution from advanced biofuels. Biofuels 3(6):703-723. http://www.future-science.com/doi/pdfplus/10.4155/bfs.12.6
- USDOE 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. ORNL. http://www1.eere.energy.gov/bioenergy/pdfs/billion_ton_update.pdf
- USDoe State of Technology updates: http://www1.eere.energy.gov/bioenergy/key_publications.html
- Dornburg et al. 2010. Bioenergy revisited: Key factors in global potentials of bioenergy. Energy Environ. Sci., 2010,3, 258-267..
- Efroymson, R. A., V. H. Dale, K. L. Kline, A. C. McBride, J. M. Bielicki, R. L. Smith, E. S. Parish, P. E. Schweizer, D. M. Shaw. 2012. Environmental indicators of biofuel sustainability: What about context? Environmental Management DOI 10.1007/s00267-012-9907-5
- Giglio L., J. T. Randerson, G. R. van derWerf, P. S. Kasibhatla, G. J. Collatz, D. C. Morton, and R. S. DeFries. Assessing variability and long-term trends in burned area by merging multiple satellite fire products. Biogeosciences, 7, 1171–1186, 2010.
- IPCC 2012 Special Report on Renewables and Climate Change Mitigation.
- Kline KL, Dale VH, Lee R, Leiby P. 2009. In Defense of Biofuels, Done Right. Issues in Science and Technology 25(3): 75-84. http://www.issues.org/25.3/kline.html
- Langholtz M, Eaton L and Turhollow A. (in press). 2013 Feedstock Supply and Price Projections and Sensitivity Analysis. (BioFPR 2014).
- McBride A, VH Dale, L Baskaran, M Downing, L Eaton, RA Efroymson, C Garten, KL Kline, H Jager, P Mulholland, E Parish, P Schweizer, and J Storey. 2011. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators* 11(5) 1277-1289.
- Parish ES, M Hilliard, LM Baskaran, VH Dale, NA Griffiths, PJ Mulholland, A Sorokine, NA Thomas, ME Downing, R Middleton. 2012. Multimetric spatial optimization of switchgrass plantings across a watershed. *Biofuels, Bioprod. Bioref*. 6(1):58-72.
- Strassburg BBN, Latwiec AE, et al., 2014. When enough should be enough. Improving the use of current agricultural lands could spare natural habitats in Brazil. Glob.Env.Change 28 84-97.

A few background slides

Defining “sustainability”
&
DOE support for sustainable bioenergy

Terms
Define “sustainability” → An overused term

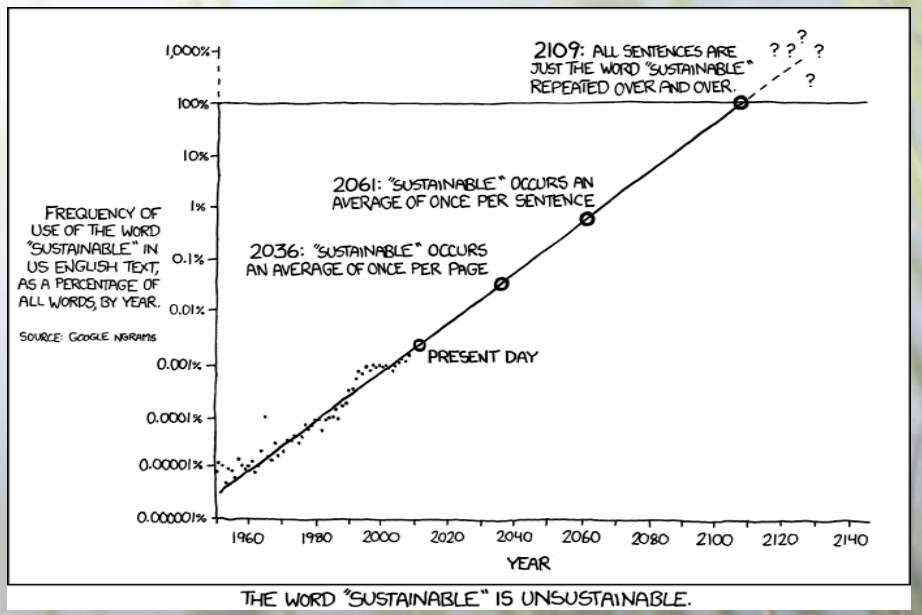
“The capacity of an activity to continue while maintaining options for future generations” (trans-generational equity)

- How to operationalize this?
- Standards and certification?
- Choices require trade-offs

- Cannot reach agreement about where to go without understanding *where we are, and how we got here*

Dale

Xkcd: if use of the word “sustainable” continues to increase at recent pace, it would become be the only English word used by 2109 (https://xkcd.com/1007/).



A proposed definition sustainability

A process of making informed choices for continual improvements where improvements are:

(a) 'best available' opportunities to achieve specified targets;

(b) identified using scientific analyses;

(c) relative to other options including status quo;

(d) based on criteria, indicators and targets prioritized by stakeholders while considering impacts on future generations;

(e) context-specific for a time, place and set of conditions; and

(f) supported by ongoing monitoring of observable conditions relevant to the indicators and targets.

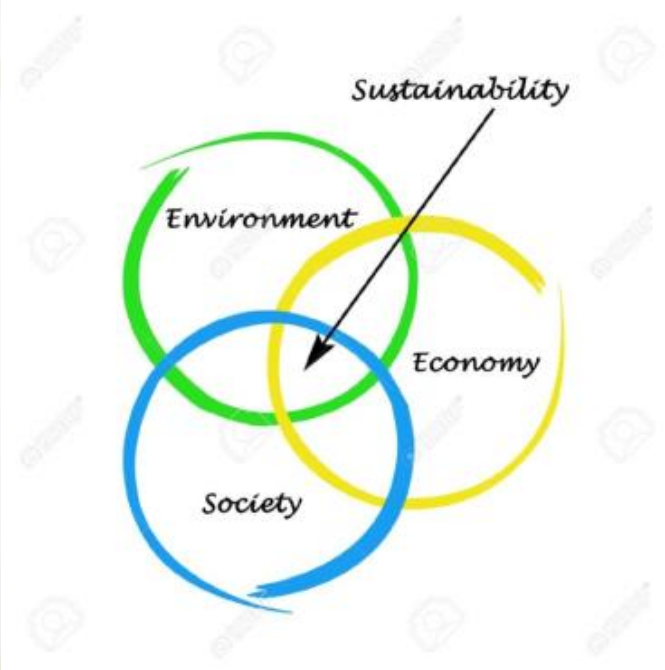
A process, not a state, sustainability is always relative.

No human endeavor is indefinitely sustainable but one option can be found to be more sustainable than another based on defined criteria in a particular place and time.

-Keith

Research on "sustainability" for the US Department of Energy (DOE BETO)

'Sustainability' is the capacity of an activity to continue while maintaining options for future generations



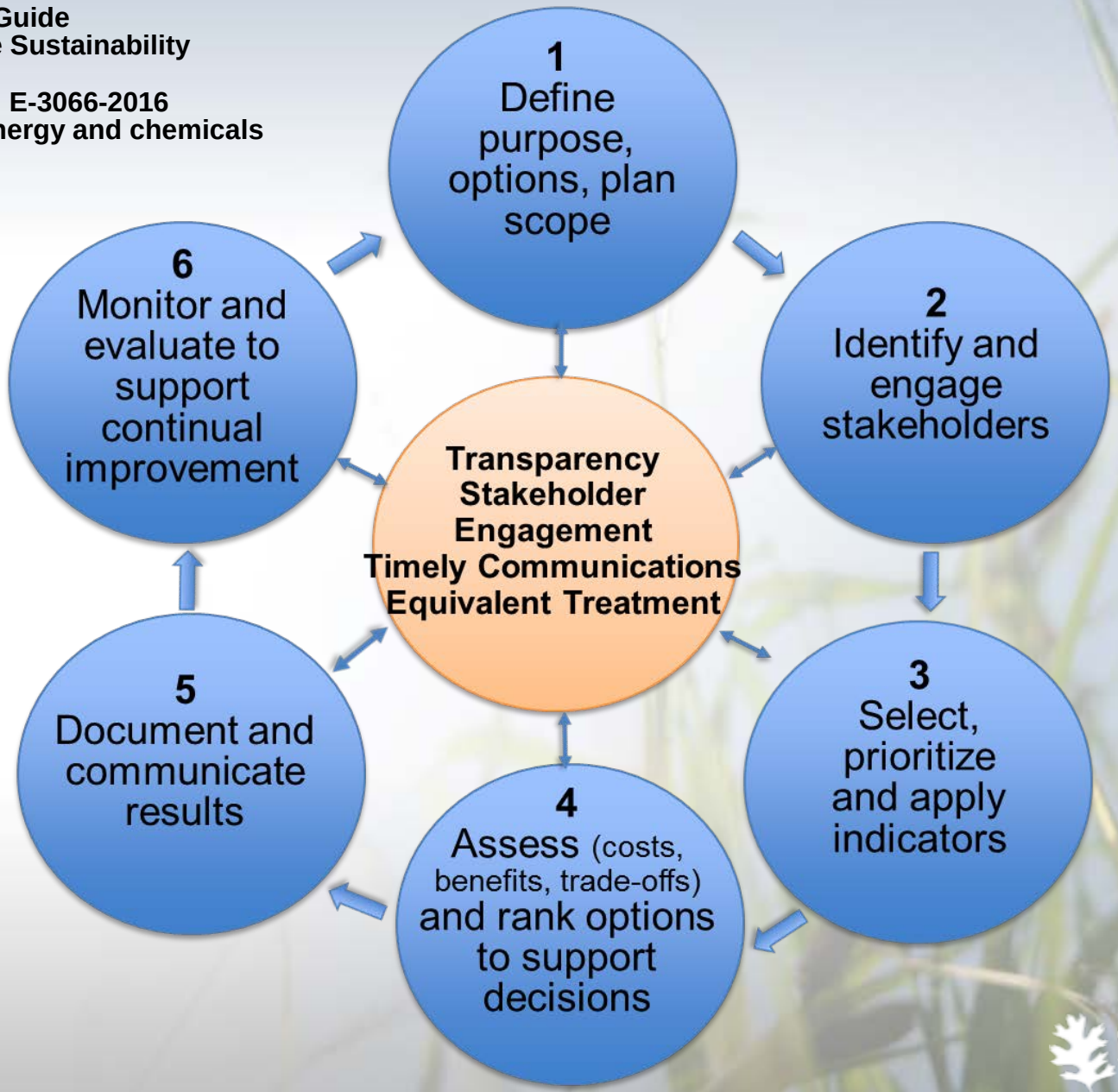
- **ORNL's research agenda includes**
  - Defining environmental & socioeconomic cost and benefits of bioenergy systems
  - Quantifying opportunities & risk associated with sustainable bioenergy and specific context.
  - Communicating the challenges & paths forward for sustainable bioenergy to a range of stakeholders
  - Deploying approach in case studies & thereby refining approach

- **Key challenges**
  - **Scientific consensus on operational definition of sustainability**
  - **Quantitative & consistent methods to**
    -implement indicators
    -monitor & evaluate progress &
    -ensure continual improvement

OAK RIDGE National Laboratory

Standard Practice Guide
Evaluating Relative Sustainability

ASTM International E-3066-2016
Committee E-48: energy and chemicals from biomass



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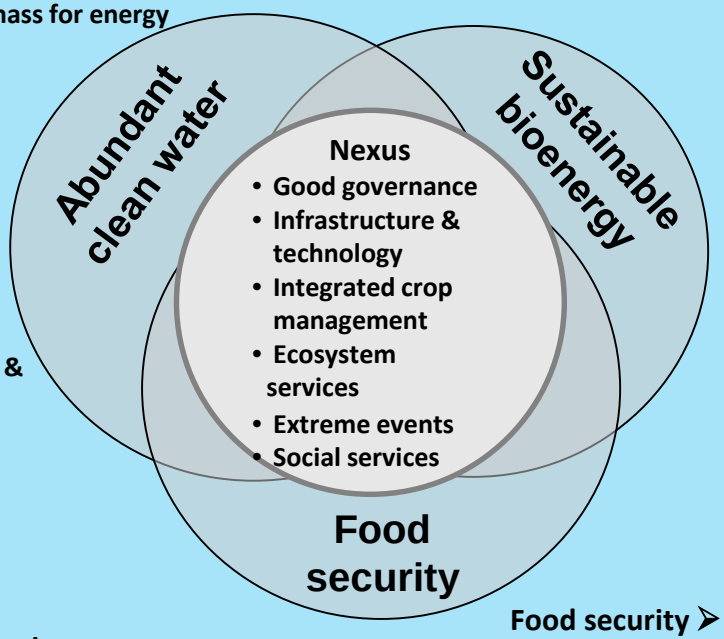
Details of Water – Bioenergy – Food Security NEXUS

Abundant clean water ➢ Sustainable energy
- Increased efficiency & productivity of bioenergy, hydropower, & nuclear energy
- Opportunities & constraints on locations for planting & harvesting biomass for energy

Sustainable energy ➢ Abundant clean water
- Reduced greenhouse gas emissions
- Attention to land-use planning & biodiversity
- Incentives for restoration



Abundant clean water ➢ Food security
- Water availability underpins food security
- Increased efficiency & productivity of food
- Place-based opportunities & constraints

Sustainable energy ➢ Food security
- Income enhancement & diversification
- Energy for food production, processing, & transportation
- Reduced volatility in market prices
- Enhanced sustainability of food crops

Food security ➢ Abundant clean water
- Secure, healthy diet is a prerequisite for water management
- Incentives for restoration
- Reduced pressure on marginal lands

Food security ➢ Sustainable energy
- Oversupply cushion required for food security
- Healthy workforce underpins energy markets

Source: Adapted from Kline et al. 2017 Bioenergy and Food Security (GSB-Bioenergy) for FEWSTERN Project http://fews.tennessee.edu/