Land, Food, and Bioenergy in Response to the Great Challenges of our Time

Lee Rybeck Lynd
Thayer School of Engineering, Dartmouth College
Global Sustainable Bioenergy Project
Bioenergy Science Center
Enchi Corp.

MacQuarie University
February 24, 2015

Thayer School of Engineering, Dartmouth

Global Sustainable Bioenergy

BESC
BioEnergy Science Center

Ethical Behavior

Doing the right thing when no one else is watching – even when doing the wrong thing is legal. Aldo Leopold, leading conservation thinker in the first half of 20th century.

Doing the right thing is a higher standard than not doing the wrong thing.

Service Professions

Work for the public sector (http://education-portal.com/). A career in public service means you pick your profession and go to work for a government or non-profit entity.

Work for the public good (non-monetized objectives). Health, social work, education.

Typically does not include. Business, law, science, and engineering – which generally have monetizable benefits and are the most highly rewarded by society.

But…

All socially-motivated initiatives must pay their bills. Alignment of profitability and social good is a powerful ways to get things done and is thus logical to seek.

Almost all of our biggest challenges either originate because of technology, or require technology to solve, and quite often both.

Science and engineering as a service profession?

If engineering is the application of science for human benefit, then the engineer must be a student of not only the application of science, but of human benefit as well.
John Prausnitz, Emeritus Professor of Chemical Engineering, Berkeley.

So what benefits is humanity most in need of?

When people a few hundred years from now look back on those alive today, what will then think we should have been paying attention to?

My picks

Smoothly navigating the sustainable resource revolution. Arguably the greatest physical imperative, also has moral dimensions

Global poverty. Arguably the greatest moral imperative, also has physical dimensions

Global Poverty Indicators (http://www.globalissues.org/article/26/poverty-facts-and-stats; some info dated)

1 billion people (1 in 7) live on less than $1.25/day

Almost half of the world's population live on < $2.50/day

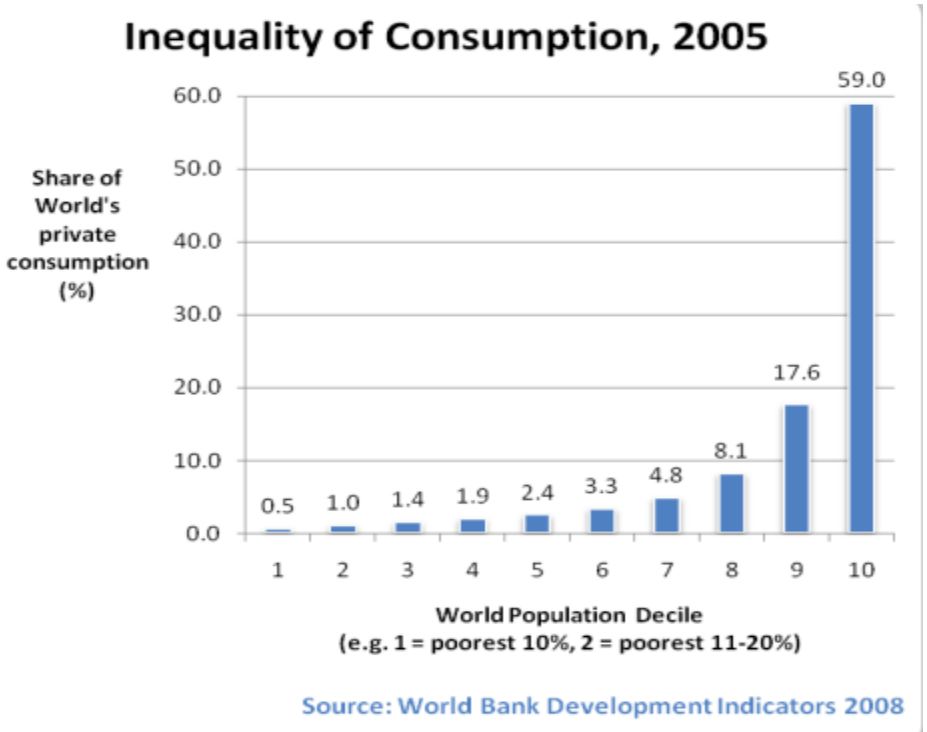
80% of the world's population live on < $10/day

One out of every two children live in poverty

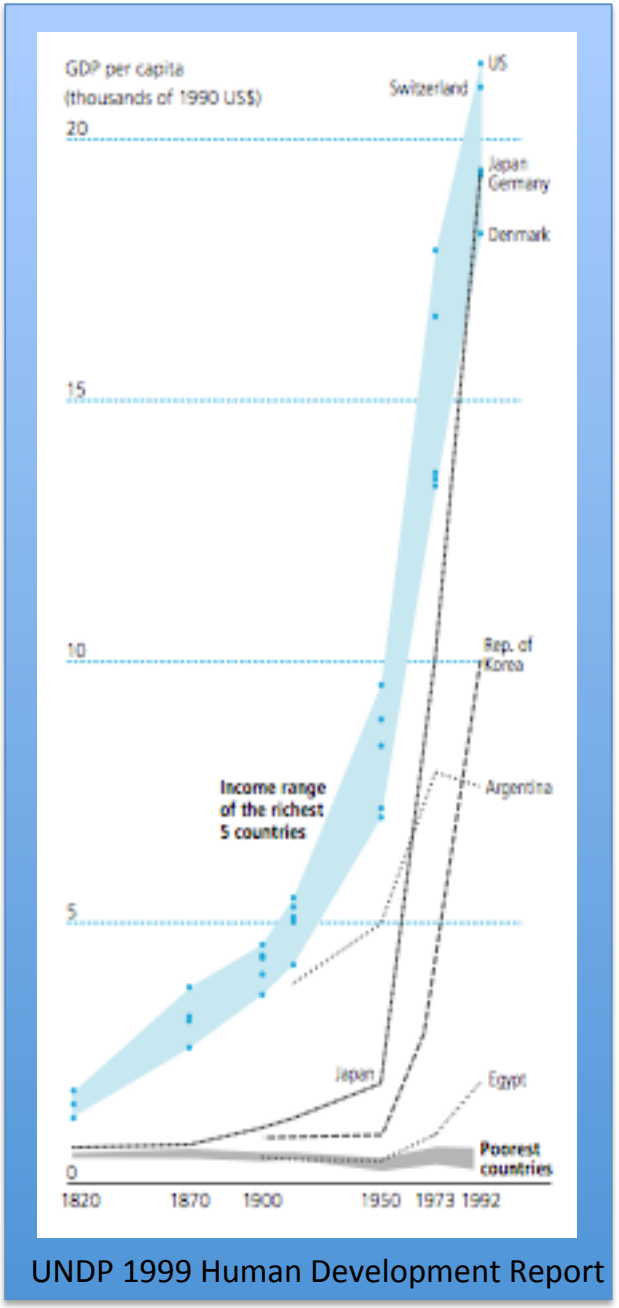
Rural areas account for 75% of poor people

Yet one in three city dwellers worldwide live in slums

Wealth inequality – a problem distinctive to our time



Source: World Bank Development Indicators 2008



UNDP 1999 Human Development Report

Progression of the Human Enterprise

	Hunting & Gathering →	Preindustrial Agricultural →	Presustainable Industrial
Energy	Human	Animal	Fossil
Food	Hunting & Gathering	Preindustrial farming	D: Industrial agriculture LD: Mixed agriculture
Equity of resource access	Substantial	Few very rich, many poor	Few very rich Many moderately rich ~ 20% very poor
Occupation	Food	Food	D: Manufacturing, finance, service LD Rural: Food LD Urban: "Informal economy"
Scale of societal integration	Small groups	Farms/ villages	Cities →countries→ Global

D: Developed
LD: Less Developed

Progression of the Human Enterprise

	Hunting & Gathering →	Preindustrial Agricultural →	Presustainable Industrial →	Sustainable Industrial
Energy	Human	Animal	Fossil	**Low-carbon, renewable**
Food	Hunting & Gathering	Preindustrial farming	D: Industrial agriculture LD: Mixed agriculture	**10 billion people** **Interesting, nutritious, environmentally graceful**
Equity of resource access	Substantial	Few very rich, many poor	Growing inequity	**Greater than today** **Eradicate extreme poverty**

Transitions

	Neolithic Revolution	**Industrial Revolution**	**Sustainability Revolution**
Initiation	~ 10,000 BC	1750 AD	**Now**
Duration	Millenia	Several centuries	**< a century**
Population	50 million	750 million	**7 billion**

Progression of the Human Enterprise

	Hunting & Gathering	→ Preindustrial Agricultural	→ Presustainable Industrial	→ Sustainable Industrial
Energy	Human	Animal	Fossil	**Low-carbon, renewable**
Food	Hunting & Gathering	Preindustrial farming	D: Industrial ulture LD: Mixed a ture	**10 billion people Interesting, nutritious, environmentally graceful**
Equity of resource access	Substantial	Few very rich, many poor	Few ve Many ly rich ~ 20	**Greater than today Eradicate extreme poverty**

Transitions

Sustainability Revolution

Critical challenge: From resource capital to resource income

Navigating this smoothly requires, for all sectors

Doing things differently than we do them now. It is unreasonable to expect an extrapolated future to be different from the present.

Systemic approach. Multiple, mutually-reinforcing approaches to achieve multiple, complementary objectives.

Increased efficiency. All supply chain steps.

Energy and Food

Enable and largely define human development and well-being

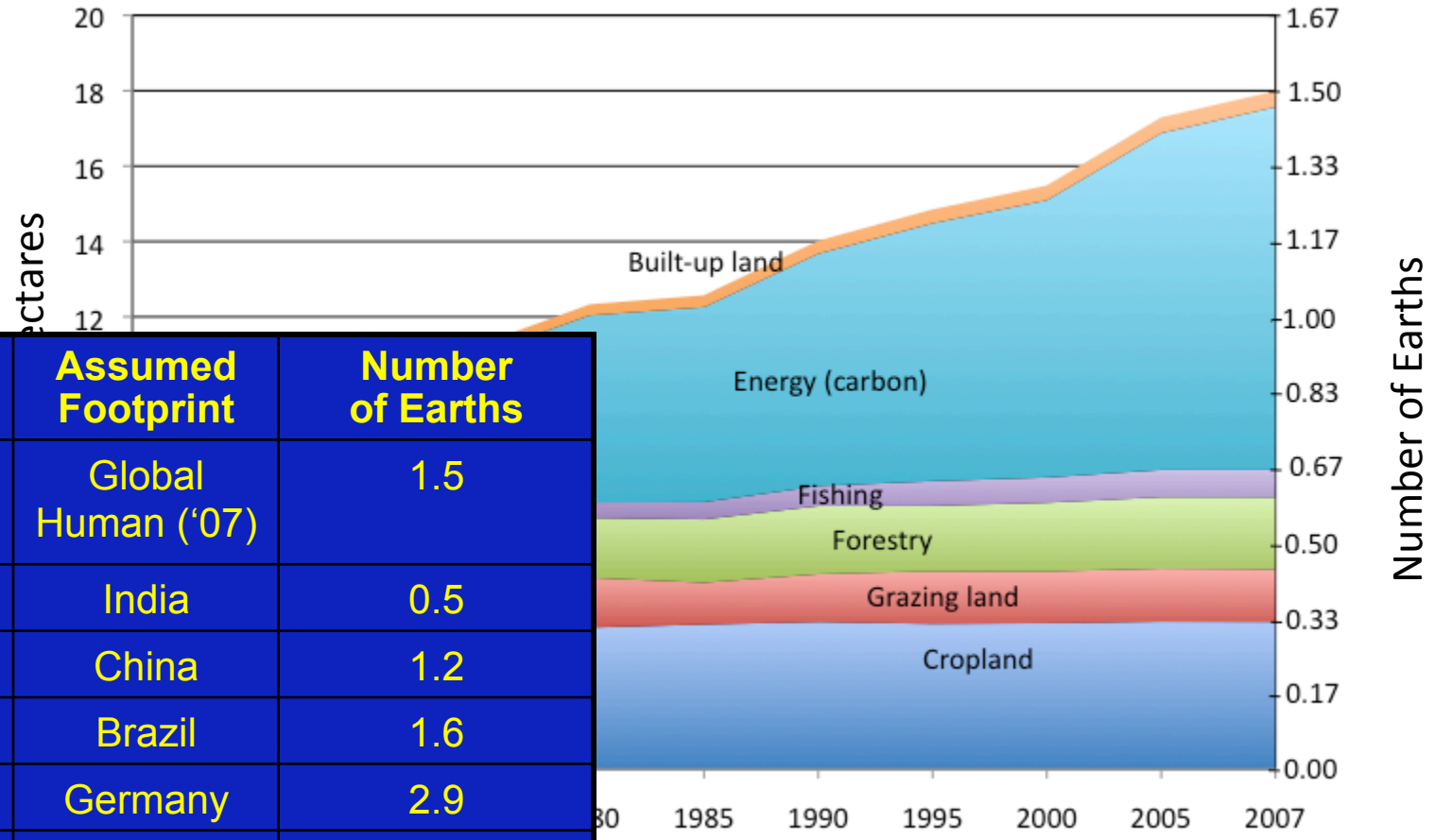
Dominate environmental impact

Environmental Impacts per Household (US)

	Global Warming	*Air Pollution*		*Water Pollution*		*Habitat Alteration*	
Activity Area	Greenhouse Gases	Common	Toxic	Common	Toxic	Water use	Land use
Personal Transportation	32%	28%	51%	7%	23%	2%	15%
Food	12%	17%	9%	38%	22%	73%	45%
Household Operations	35%	32%	20%	21%	14%	11%	4%
Sum	**80%**	**77%**	**80%**	**67%**	**59%**	**86%**	**64%**

Brower, M., and W. Leon. The consumer's guide to effective environmental choices. (1999).

Environmental "footprint": *Land area required to provide for resource consumption & waste assimilation on a sustainable basis*



Population	Assumed Footprint	Number of Earths
6.7 billion (2007)	Global Human ('07)	1.5
6.7 billion	India	0.5
6.7 billion	China	1.2
6.7 billion	Brazil	1.6
6.7 billion	Germany	2.9
6.7 billion	USA	4.5
10 billion	Germany	4.3

Higher utilization efficiency also required

Energy & Agriculture: 80% of footprint

Updated from Wackernagel et al., PNAS, 2002
Global Footprint Network, *Living Planet Report, 2010*

Environmental "footprint": *Land area required to provide for resource consumption & waste assimilation on a sustainable basis*

Population	Assumed Footprint	Number of Earths
6.7 billion (2007)	Global Human ('07)	1.5
6.7 billion	India	0.5
6.7 billion	China	1.2
6.7 billion	Brazil	1.6
6.7 billion	Germany	2.9
6.7 billion	USA	4.5
10 billion	Germany	4.3

Updated from Wackernagel et al., PNAS, 2002
Global Footprint Network, *Living Planet Report, 2010*

Future increases in consumption are a more important footprint driver than future increases in population

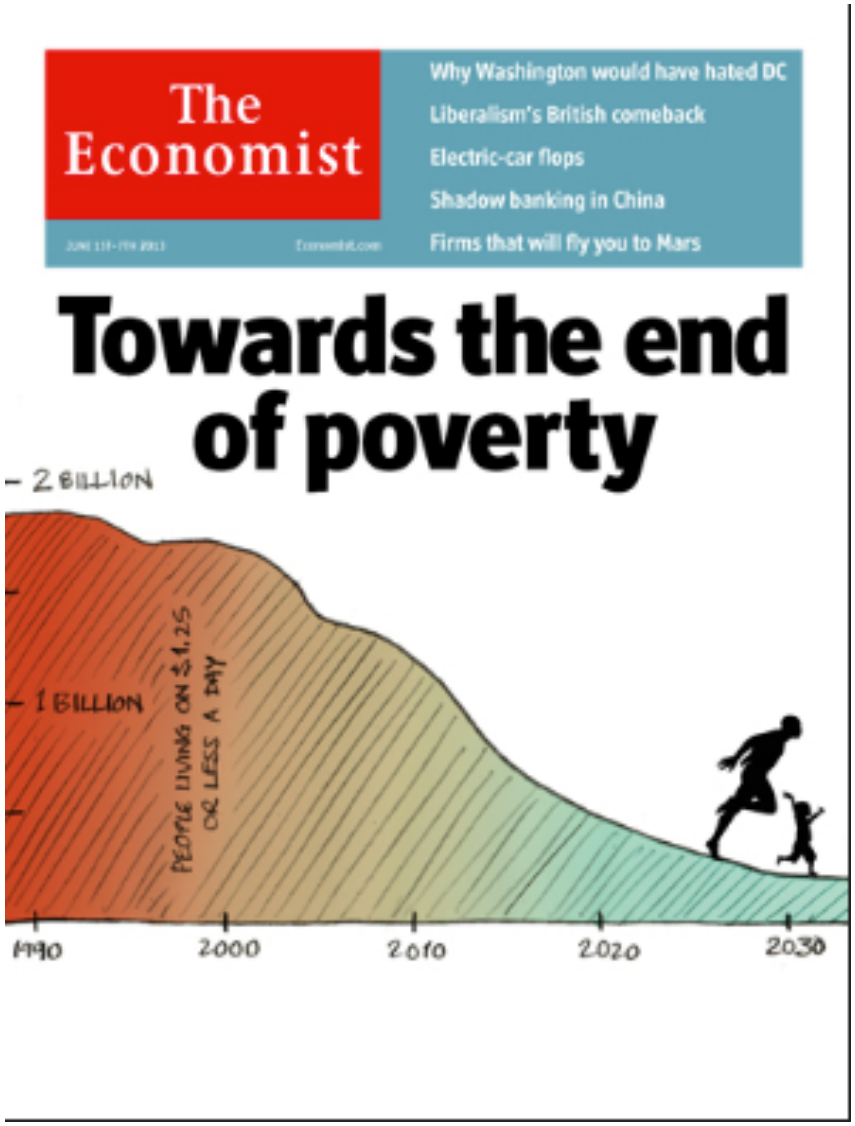
Anticipated global population increase: ~ 50%

Δ Footprint of rich, poor: ~ 1000%

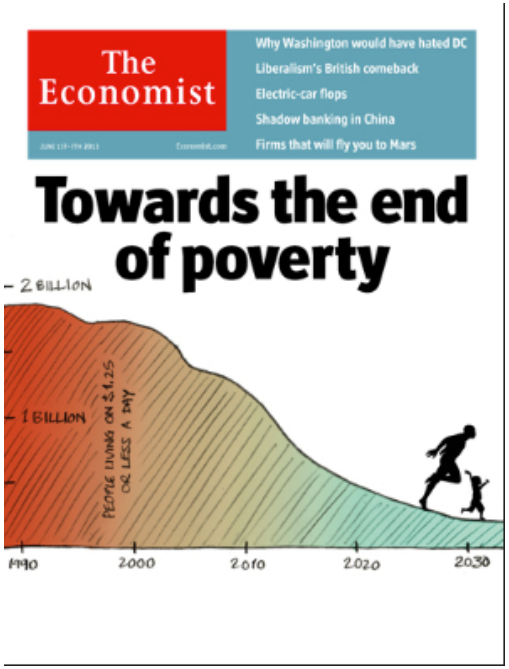
Higher utilization efficiency also required

Energy & Agriculture: 80% of footprint

The "century of biology" needs to be the century of the sustainable resource revolution, and could also be the century of the end of poverty



The "century of biology" needs to be the century of the sustainable resource revolution, and could also be the century of the end of poverty



Food (agricultural biotechnology)**, energy** (energy biotechnology)**…**

By far the most important causes of human planetary impact

Critical to get right in a sustainable world

Food access the highest priority for the world's poor

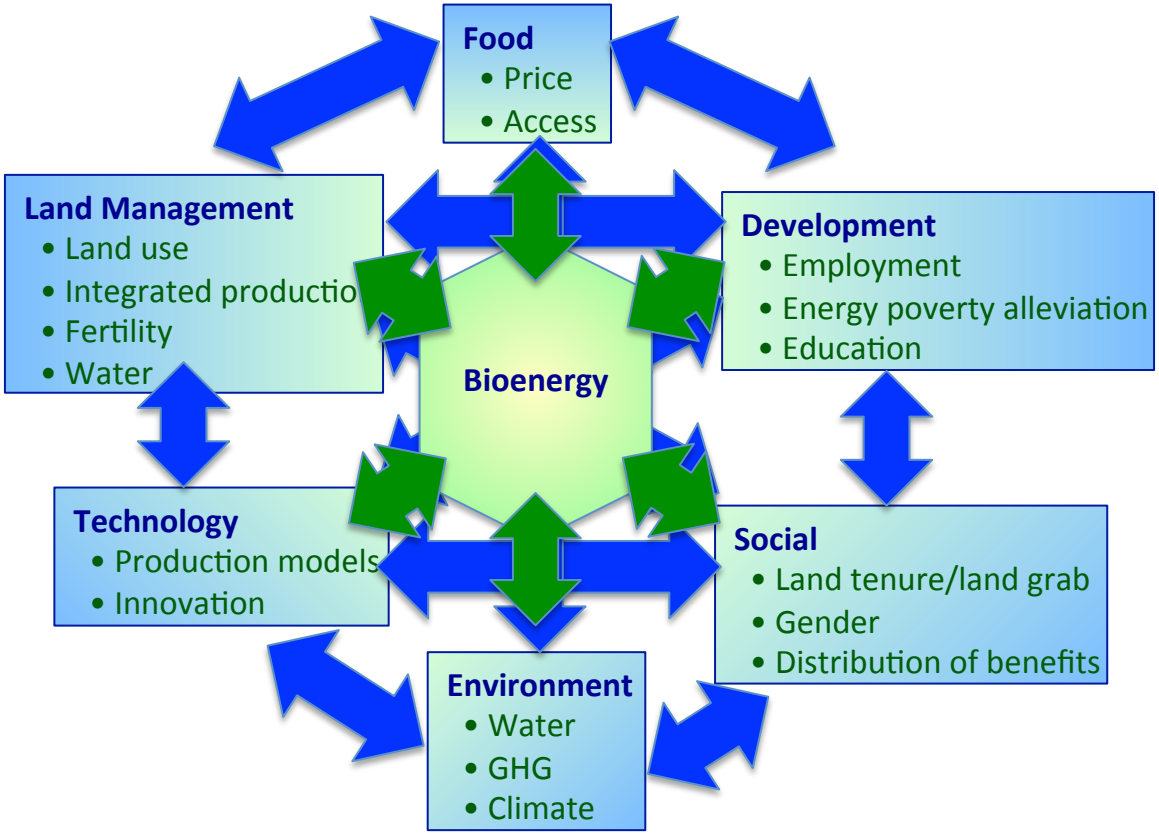
Hunger kills more people than AIDS, malaria, and TB combined, & stunts growth, blunts human initiative, causes suffering for many more

Energy access recognized as a key enabler & constraint for economic development

"None of the Millennium Development Goals can be met without major improvement in the quality and quantity of energy services in developing countries" (UNDP).

Bioenergy *(fuel, electricity & heat from plant biomass)****: At the intersection of food & energy***

An already complex set of interactions



…can result in positive or negative outcomes when bioenergy is added.

Bioenergy production requires land, and is thus inextricably linked with social development, agriculture and environmental quality. These linkages increase the complexity of analysis and deployment of bioenergy, and can result in undesirable consequences if managed poorly. If managed well, they also have potential to greatly multiply the benefits beyond energy provision per se.
Lynd et al., Bioenergy and African Transformation, in press

Potential Bioenergy Benefits

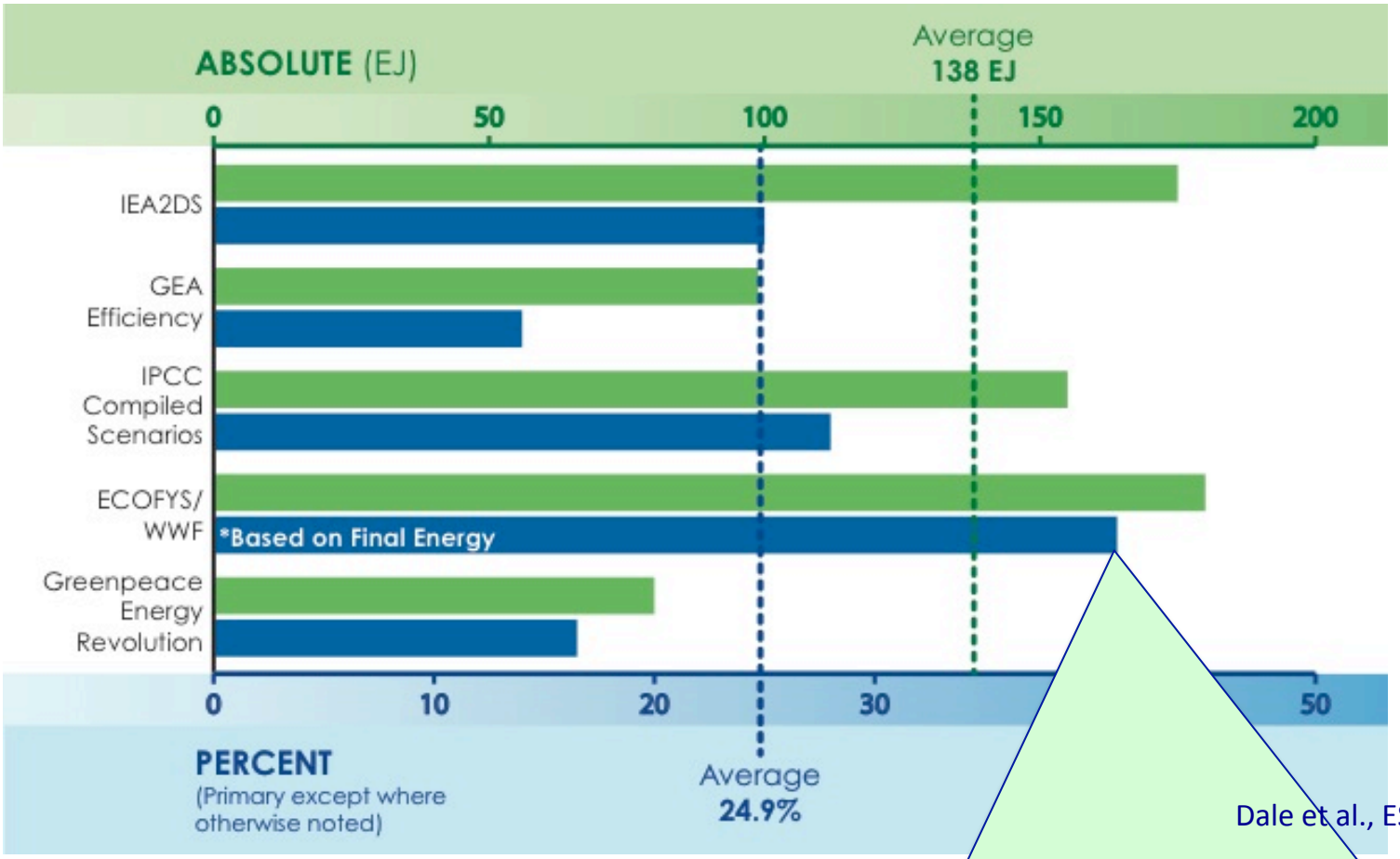
Greenhouse gas mitigation

Environmental quality & improved sustainability of agriculture

Economic benefits and food security for the rural poor

Potential Bioenergy Benefits: Climate Change Mitigation

Bioenergy Contribution in 2050: Five Low-Carbon Energy Scenarios

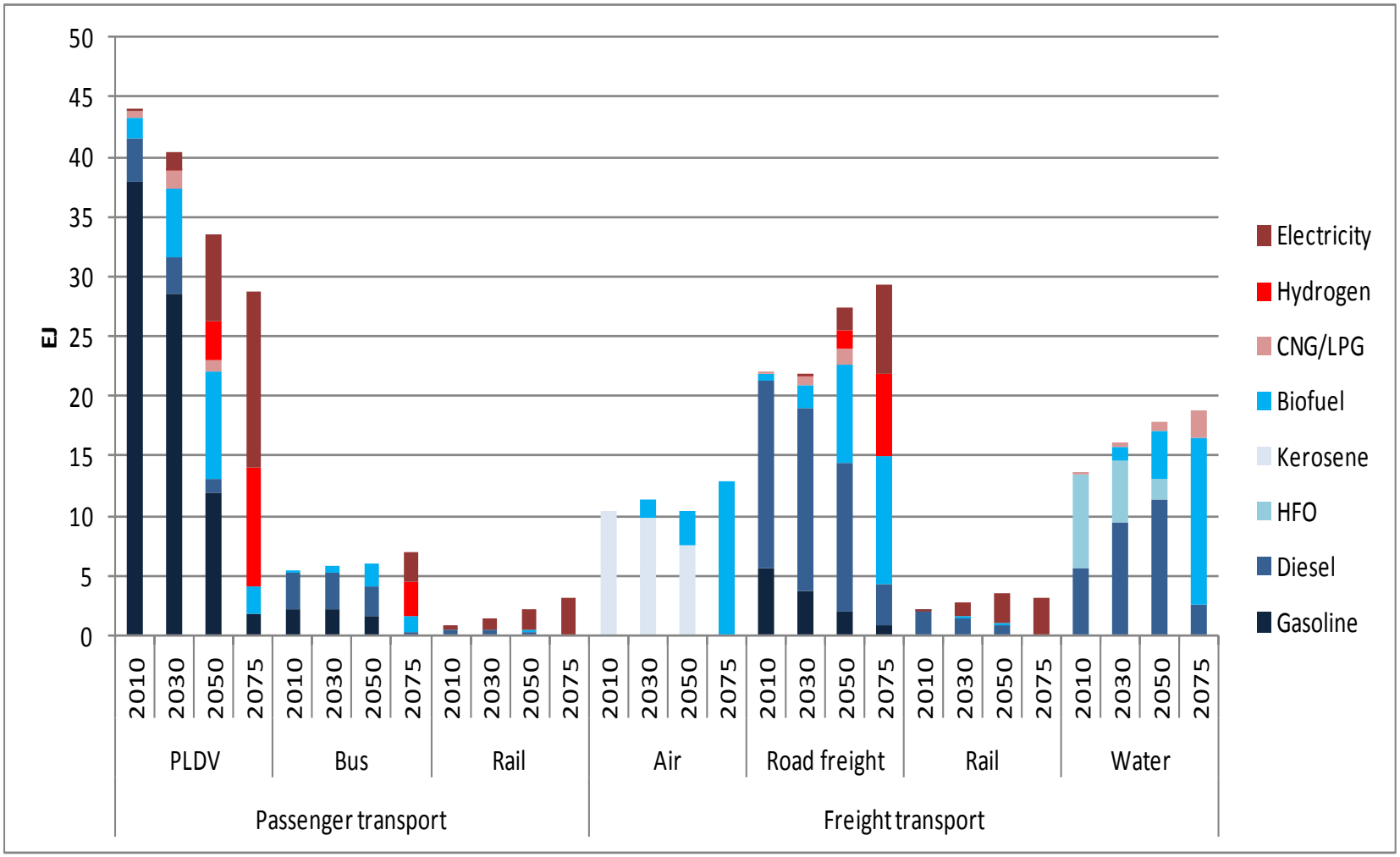


Dale et al., ES&T, 2014

***Other renewables first**:* "To achieve … high renewable energy shares, finding a renewable fuel and heat supply is the biggest challenge. The scenario's bioenergy is therefore … used mainly to provide transport fuel and industrial fuel and heat – i.e. to meet energy demands that cannot be met through renewable electricity or other renewable heat applications." ECOFYS/WWF 100% Renewable Energy by 2050 Report.

Potential Bioenergy Benefits: Low-Carbon Transport Fuels

Transport energy use by mode, vehicle type and fuel type, 2DS (Fulton et al., in review)

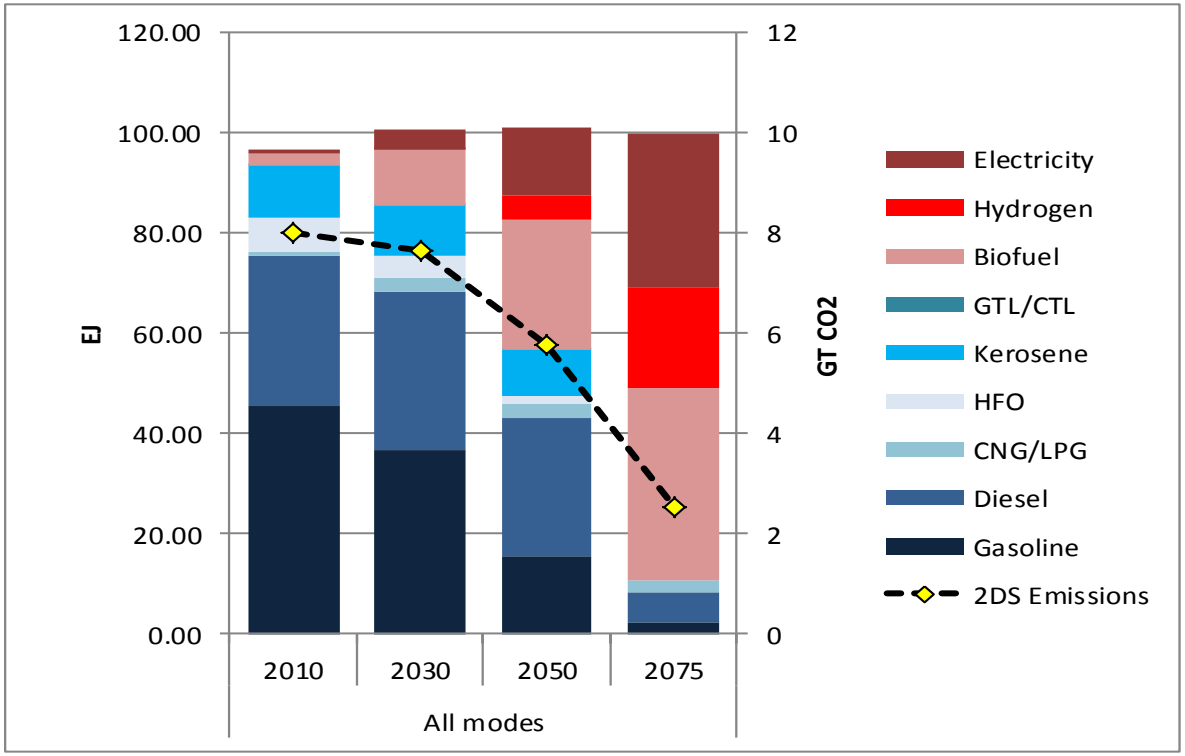


H_2 + electricity, 2075: > 80% > 70% 100% 0% ~ 50% 100% 0%

Other renewables first. Biofuels only used where other renewables likely infeasible.

Potential Bioenergy Benefits: Low-Carbon Transport Fuels

Aggregated transport energy use, 2DS (Fulton et al., in review)



Lots of time for non-biofuel renewables to overcome kinetic barriers by 2075. Further penetration faces steep technical hurdles.

The greater the distance between refueling, the greater the advantages of liquid biofuels as compared to other low carbon alternatives

Potential Bioenergy Benefits: Improved Sustainability of Agriculture

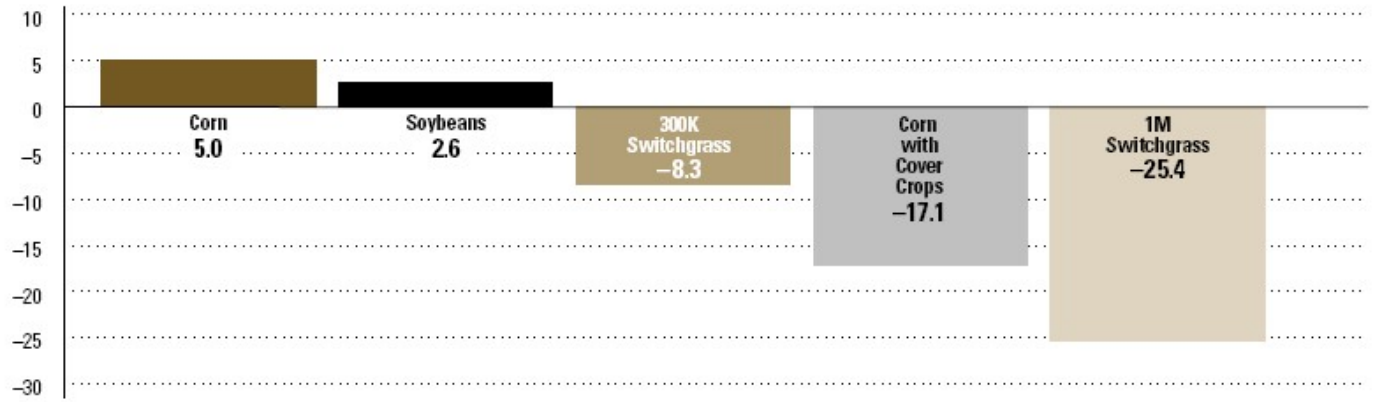
Widely recognized potential benefits to integrating perennial bioenergy crops into agricultural landscapes

- Soil carbon accumulation, erosion prevention, and improved fertility
- Enhanced habitat/biodiversity
- Nutrient retention/improved water quality

FIGURE 5

Maximum Nitrogen Load Changes for Biofuels

Millions of pounds per year of nitrogen delivered from the Chesapeake Bay watershed to the Bay under five modeling scenarios.

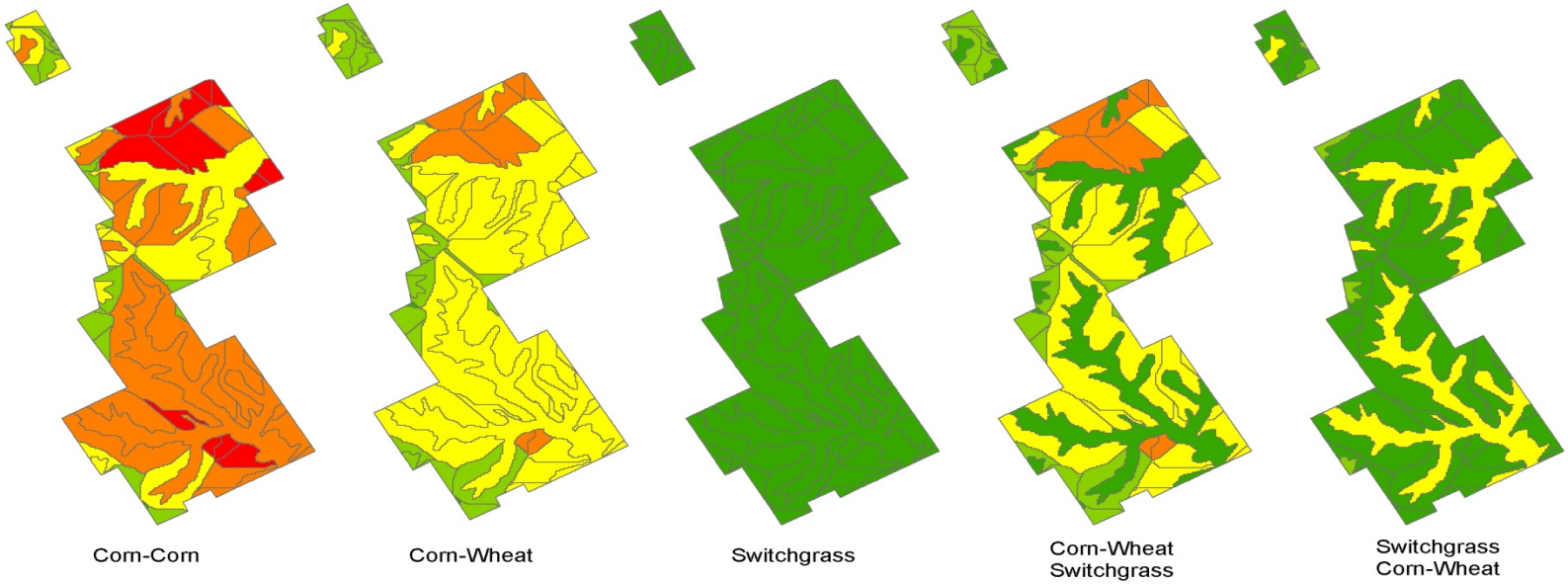


Assumptions for Alternative Scenarios:

- **Corn:** 300,000 additional acres of corn with typical levels of management practices
- **Soybeans:** 300,000 additional acres of soybeans with typical levels of management practices
- **300K Switchgrass:** 300,000 acres of switchgrass, converted primarily from hay and pastureland, with no fertilization
- **Corn with Cover Crops:** Cover crops on all existing and new (additional 300,000) corn acres and one quarter of all other row crops, watershed-wide.
- **1M Switchgrass:** 1 million acres of switchgrass, converted primarily from hay and pastureland, with no fertilization

SOURCE: U.S. EPA CHESAPEAKE BAY PROGRAM OFFICE

Potential Bioenergy Benefits: Improved Sustainability of Agriculture



Perennial bioenergy crops
→ Large erosion benefits

(Kemanian 2009 in Tom Richard GSB Presentation, 26th Oct 2012, Campinas)

Potential Bioenergy Benefits: Improved Sustainability of Agriculture

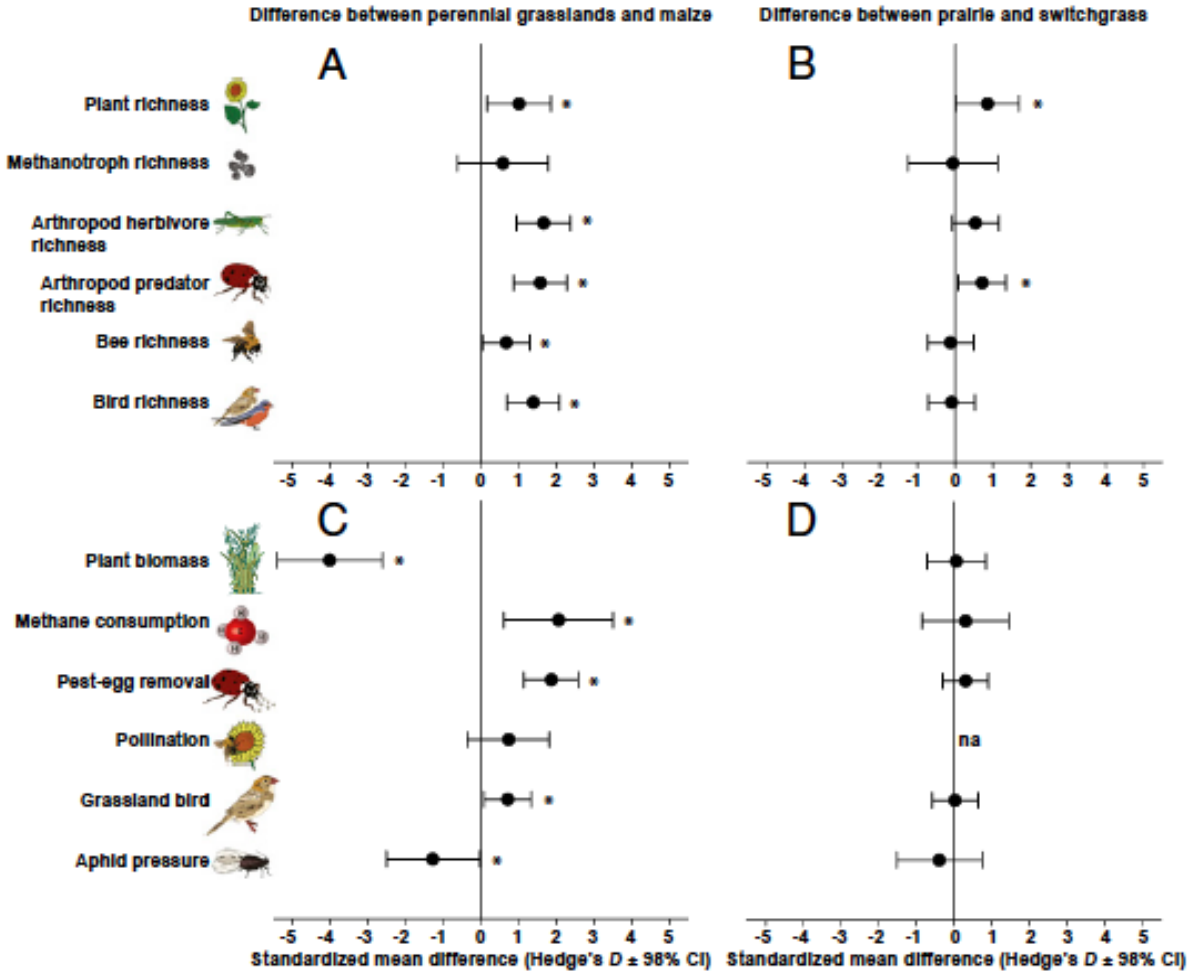


Fig. 3. Differences in richness and ecological processes were larger between the two perennial grasslands and maize than between prairie and switchgrass. Standardized effect sizes (Hedge's *D*) are shown for differences in richness and key ecological processes between grasslands and maize (*A* and *C*) (effect is difference between average of the two grasslands and maize) and prairie compared with switchgrass (*B* and *D*). Error bars show 98% confidence intervals. Asterisks indicate statistical significance at $\alpha = 0.02$.

Werling et al., PNAS, 2014.

Potential Bioenergy Benefits: Economic Development and Food Security for the Rural Poor

Wilson Conway, Can we Feed the World?

Agriculture typically accounts for over 80% of the work force and 50% of GDP in developing countries.

A 1% gain in GDP originating from agriculture generates a 6% increase in overall expenditure of the poorest 10% of the population.

A 1% gain in GDP originating from non-agricultural sectors creates zero growth in overall expenditure of the poorest 10% of the population.

A substantial literature points to disproportionately large benefits to the rural poor from agricultural development as compared to other kinds of development.

Christaensen L, Demery L. The evolving role of agriculture in poverty reduction: an empirical perspective. J Dev Econ. 2011;96:239–54.

Ligon E, Sadoulet E: Estimating the effects of aggregate agricultural growth on the distribution of expenditures. Background paper for the World Development Report 2008. 2007.

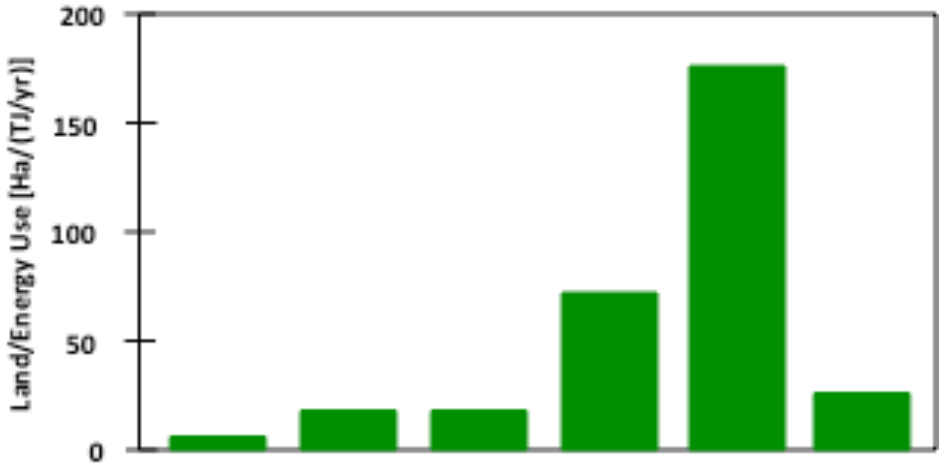
United Nations Development Project (UNDP): African human development report 2012: towards a food secure future. United Nations Publication, New York, USA; 2012.

In Brazil – the foremost example of bioenergy deployed in a developing country context – social development, agricultural development, food security, and bioenergy development have been synergistic rather than antagonistic. (Lynd et al., in review).

Potential Bioenergy Benefits: Economic Development and Food Security for the Rural Poor

Consideration of the impact of bioenergy on African food security has tended to focus on land competition and to overlook bioenergy's marked potential to promote rural development. However, potentially productive land is rather plentiful in much of Africa whereas lack of development is the most important underlying cause of hunger, with energy poverty also a significant contributor. (Lynd and Woods, 2011)

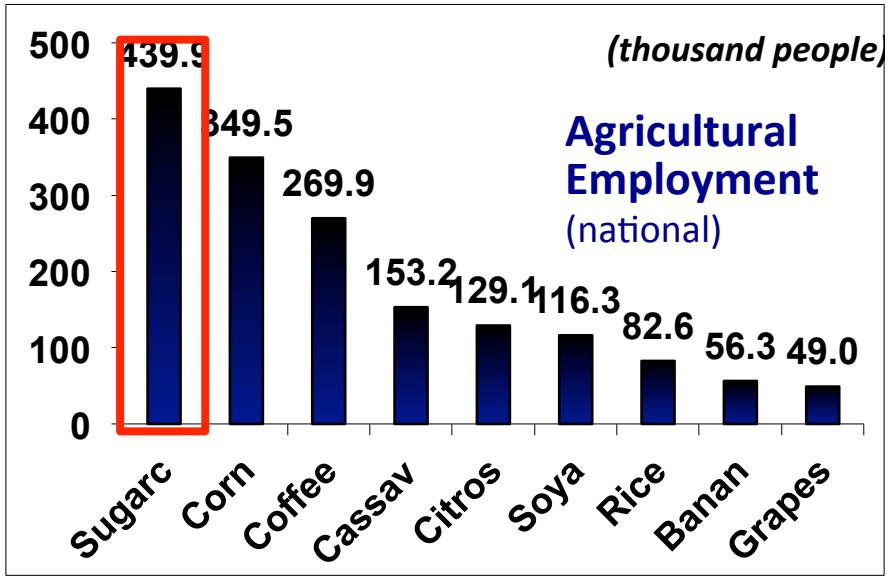
Continents	Europe	Asia	North America	South America	Africa	Global Ave.
Total Land (ha/capita)	1.3	1.1	7.1	4.6	3.0	2.2
Primary Energy Use (TJ/capita/yr)	0.172	0.055	0.364	0.062	0.017	0.079
Land/Energy Use [Ha/(TJ/yr)]	8	20	20	74	176	28

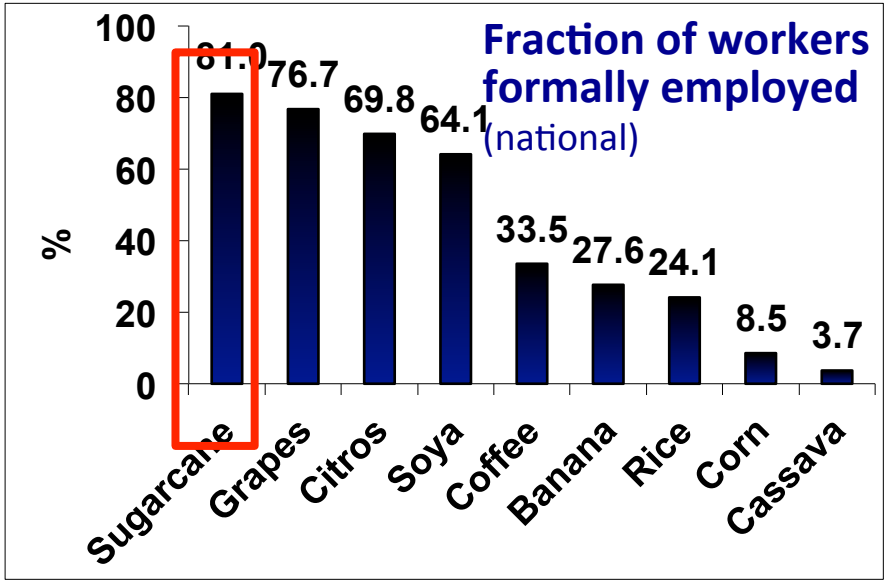


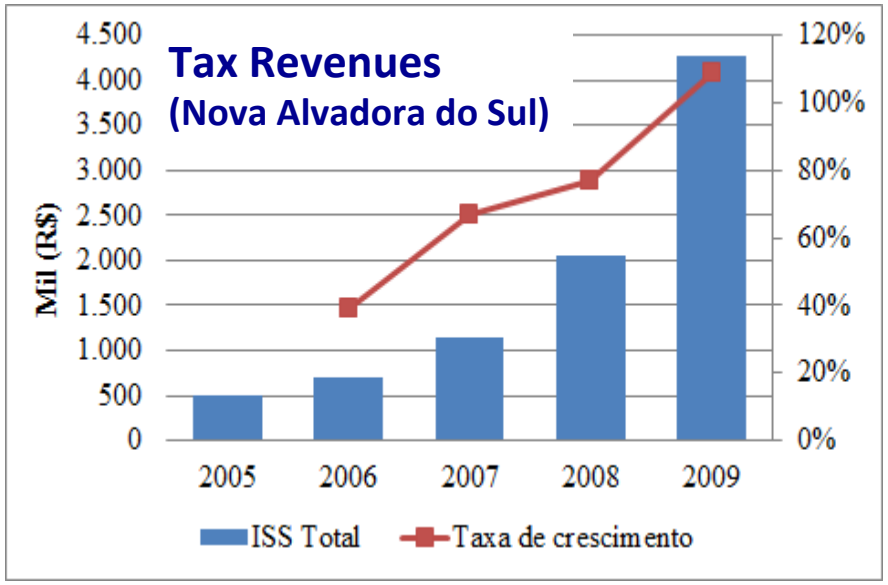
Africa has about 12 times the land area of India, similar land quality, and 30% fewer people – yet India produces enough food to feed itself and Africa does not. The green revolution bypassed Africa primarily due to serious organizational and institutional weaknesses, not geographically-limited capacity (A. Temu, World Agroforestry Centre)

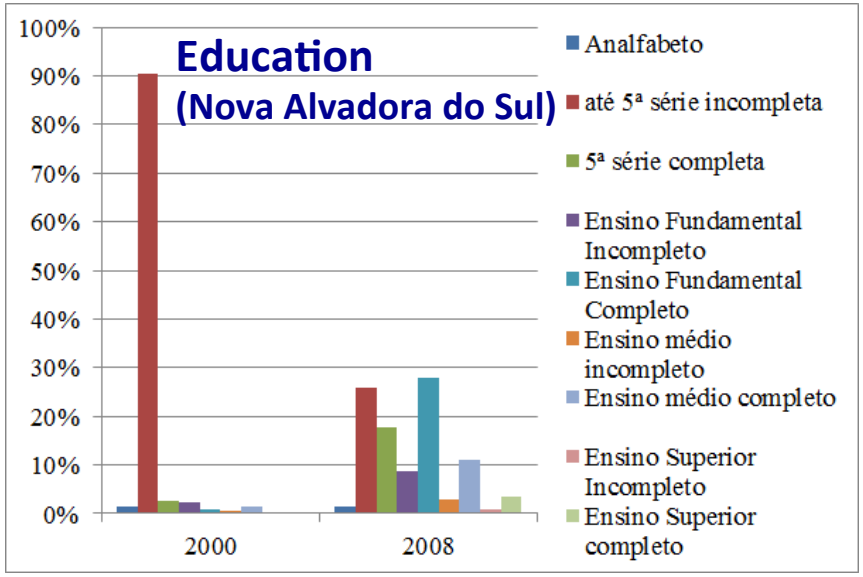
Retrospective studies document social benefits of bioethanol production in Brazil.

Marcia Azanha, USP ESALQ, Brazil.

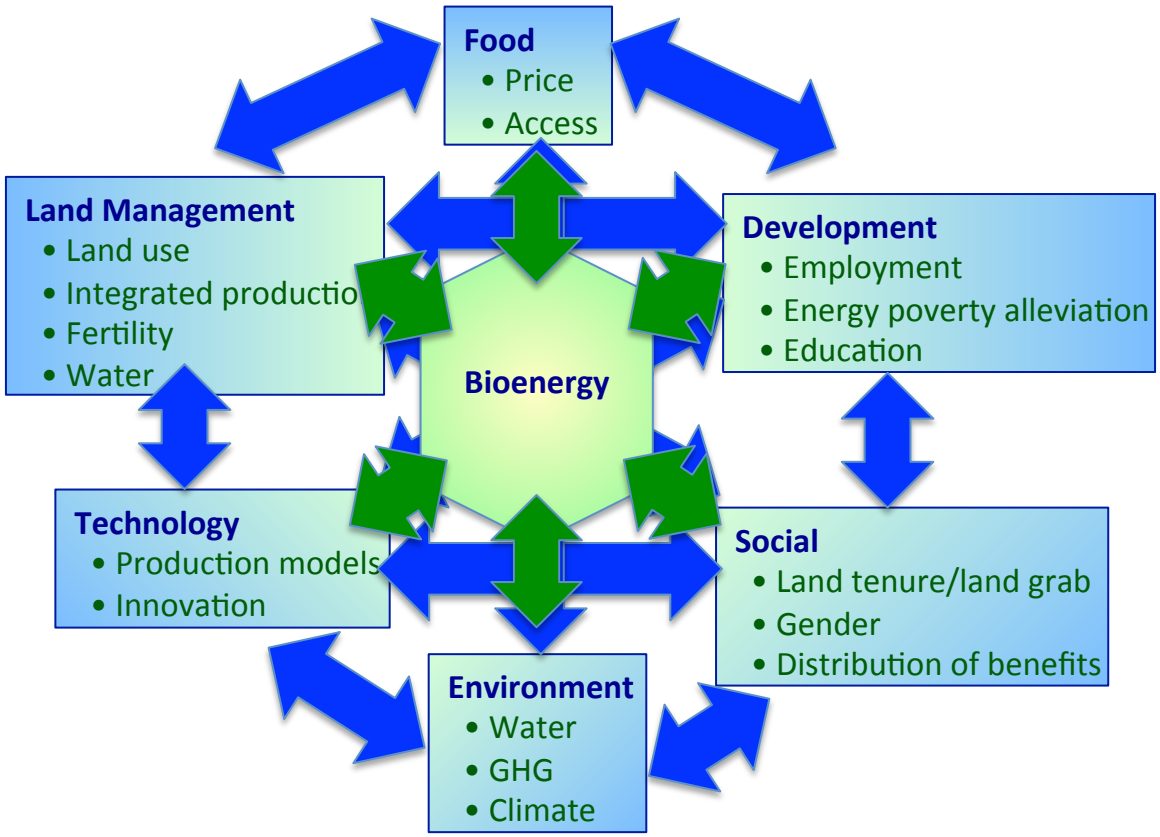








Bioenergy *(fuel, electricity & heat from plant biomass)****: At the intersection of food & energy***



Good governance is essential to maximize benefits

Does not always accompany bioenergy opportunities

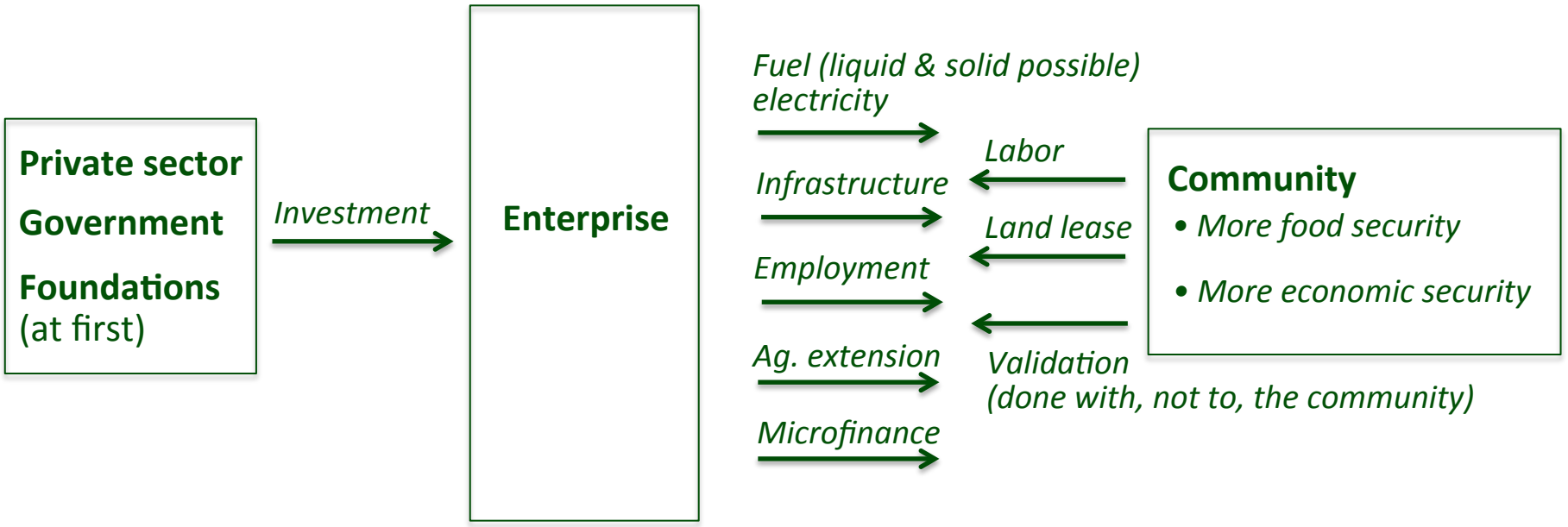
Multi-sector, multi-level governance structures more likely effective than single sector/level (which is the norm)

Innovative public-private partnerships and business models are promising for ensuring P^3 benefits

Maximizing Social Benefits of Bioenergy

How might an enterprise with the dual goals of producing bioenergy and enhancing local food security be configured?

Human and institutional perspective



Needed

Prospective analysis of social benefits of bioenergy

Project stakeholders for social benefits as well as profit.

Examples that realize the "triple bottom line".

Potential Bioenergy Benefits

Greenhouse gas mitigation

Environmental quality & improved sustainability of agriculture

Economic benefits and food security for the rural poor

Criticisms of Bioenergy

Cost effective cellulosic technology yet to appear.

There is not enough land

A key focus of mine and others, not considered further in this talk

Potential Bioenergy Benefits

Greenhouse gas mitigation

Environmental quality & improved sustainability of agriculture

Economic benefits and food security for the rural poor

Criticisms of Bioenergy

Cost effective cellulosic technology yet to appear.

There is not enough land

Land is used either for food or nature

Food production is operating at near capacity

Thus if bioenergy is produced on land that could produce food, nature suffers and people will go hungry

Global Land

Table 1: Estimates of land use (Mha) in 2000 and 2010 (FAOSTAT, 2014; Lambin and Meyfroidt, 2011)

	Land use in 2000			Land use in 2010	Change (2010-2000)
	(Lambin and Meyfroidt, 2011)		(FAOSTAT, 2014; FAO, 2006)	(FAOSTAT, 2014)	(FAOSTAT, 2014)
	Low estimate	High estimate	Alternative estimate		
Cropland[a,c]	1510	1611	1514	1541	27
Pastures[b]	2500	3410	3420	3353	- 67
Forests	3143	3871	4085	4033	- 52
Planted forests[d]	126	215	161	274	49
Urban, built-up[d,e]	66	351	40	65	25

} Net change in agricultural land: -40 million ha

Woods et al., in press

Large bodies of land could be used to grow bioenergy feedstocks: Cropland, forest, pasture.

Pasture has particular potential

- Small contributor to food supply
- Currently under utilized: ~40% does not have livestock on it (FAO), large intensification potential

Global Land

Table 1: Estimates of land use (Mha) in 2000 and 2010 (FAOSTAT, 2014; Lambin and Meyfroidt, 2011)

	Land use in 2000			Land use in 2010	Change (2010-2000)
	(Lambin and Meyfroidt, 2011)		(FAOSTAT, 2014; FAO, 2006)	(FAOSTAT, 2014)	(FAOSTAT, 2014)
	Low estimate	High estimate	Alternative estimate		
Cropland[a,c]	1510	1611	1514	1541	27
Pastures[b]	2500	3410	3420	3353	- 67
Forests	3143	3871	4085	4033	- 52
Planted forests[d]	126	215	161	274	49
Urban, built-up[d,e]		351	40	65	25

Woods et al., in press

} Net change in agricultural land: -40 million ha

Pasture

Calculated by subtraction:

Total land – (Forest + Cropland + Desert + Tundra + Urban +Protected)

Land Use for Food Production

What is the contribution of pasture to global food supply?

Dietary protein:

Animal Product	Fraction Total Protein	Fraction Production from Pasture	Overall Percent Dietary Protein from Pasture
Harvested from pasture			
Meat	0.178	0.084	1.5%
Milk	0.101	0.120	1.2%
Eggs	0.034	0.008	0.0%
Total	**0.313**		**2.7%**

Additional contribution from pastured fraction of meat from confined feed lots negligeable

$$\left(\frac{0.178\ \text{meat}}{\text{dietary protein}}\right)\left(\frac{0.25\ \text{beef + mutton}}{\text{meat}}\right)\left(\frac{0.094\ \text{industrial}}{\text{beef + mutton}}\right)\left(\frac{0.3\ \text{weight gain from pasture}}{\text{Total industrial weight gain}}\right)\times 100\% = 0.1\%\ \text{additional}$$

Dietary calories:

Overall percent dietary calories from pasture (similar calculation): **1.3%**

Woods et al. in press.

My view: Food security is a local problem, not a global problem, with poverty the most important driver.

Bioenergy in Relation to Metrics and Causes of Food Insecurity

When food insecurity is viewed in terms of ***metrics*** – availability, access, utilization, stability – the impact of bioenergy may appear obscure

Consider instead the **causes** of food insecurity*

Poverty

- Rural unemployment
- Lack of marketable skills
- Low currency value
- High food prices

Poverty and food insecurity: More one problem than two

- ***All wealthy people have access to food***
- ***All involuntarily hungry people are poor***

Poorly developed infrastructure
(Physical, market, knowhow)

Local production undermined by foreign subsidies

Degraded land

* Thurow, R, S. Kilman. Enough: Why the World's Poor Starve in an Age of Plenty. 2009.

Bioenergy in Relation to Metrics and Causes of Food Insecurity

When food insecurity is viewed in terms of ***metrics*** – availability, access, utilization, stability – bioenergy may appear to have indirect and perhaps negative impacts

Consider instead the **causes** of food insecurity*

Poverty

Rural unemployment
Lack of marketable skills
Low currency value
High food prices

Poorly developed infrastructure
(Physical, market, knowhow)

Local production undermined by foreign subsidies

Degraded land

Bioenergy done right has clear potential to positively impact all of these.

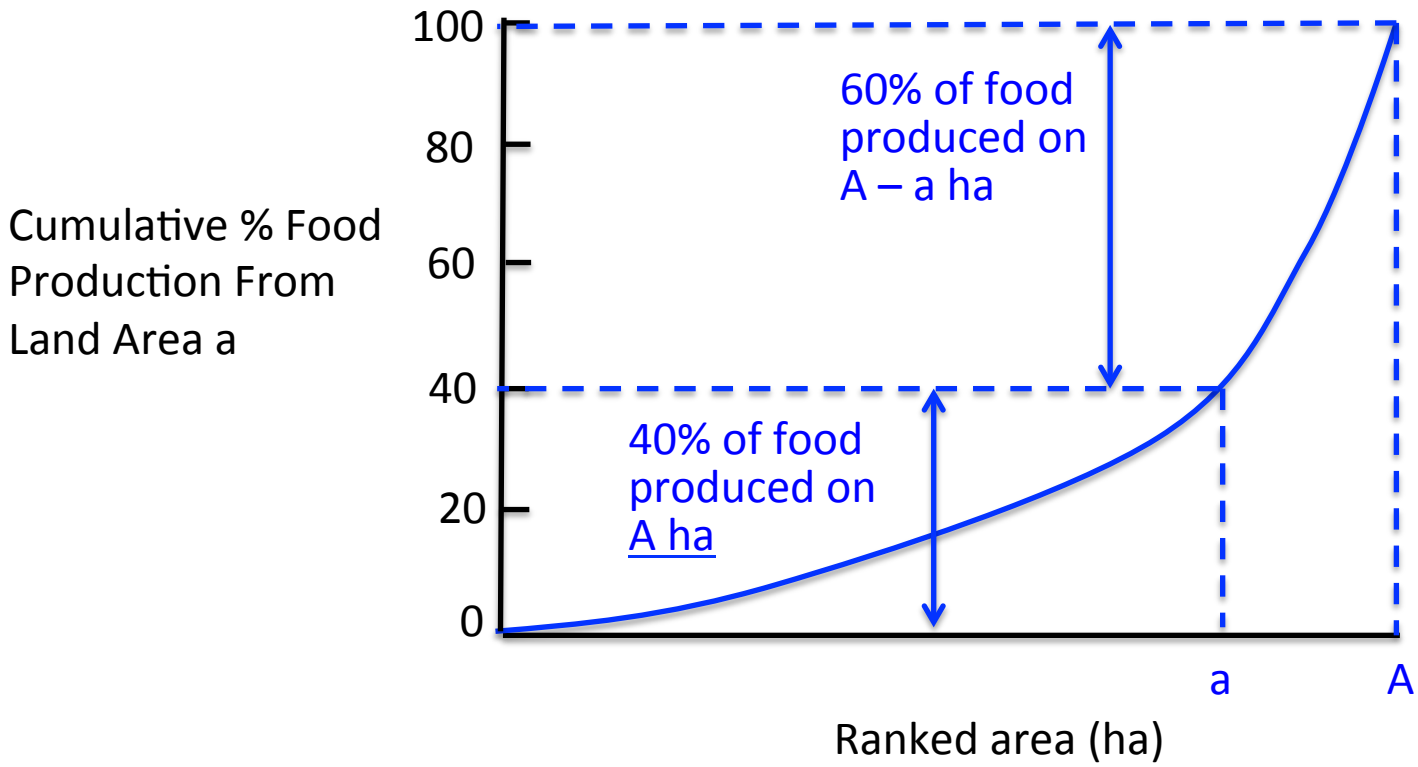
Poverty and food insecurity: More one problem than two

- ***All wealthy people have access to food***
- ***All involuntarily hungry people are poor***

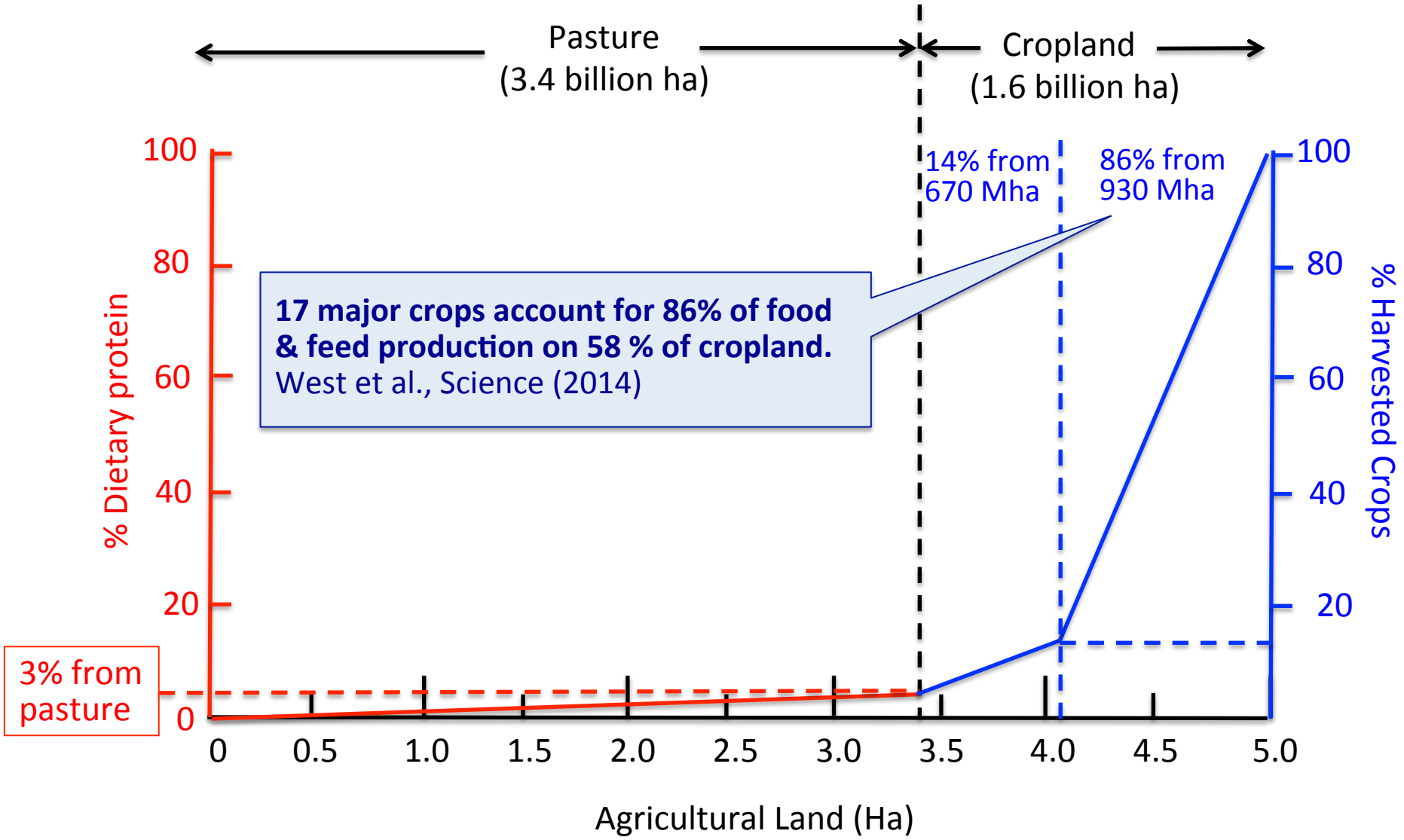
* Thurow, R, S. Kilman. Enough: Why the World's Poor Starve in an Age of Plenty. 2009.

Land Use for Food Production

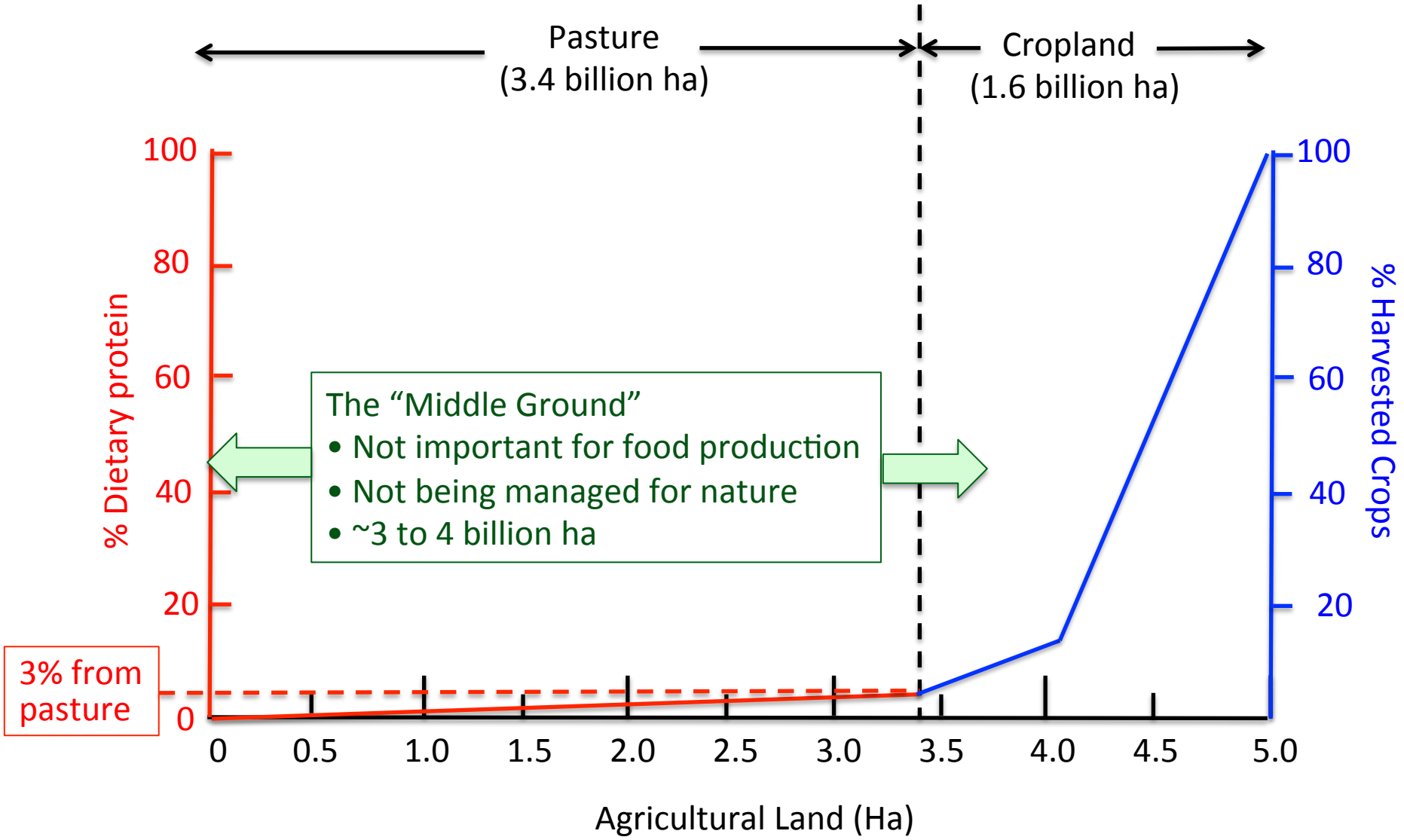
Visualization framework: Cumulative food supply curve



Land Use for Food Production

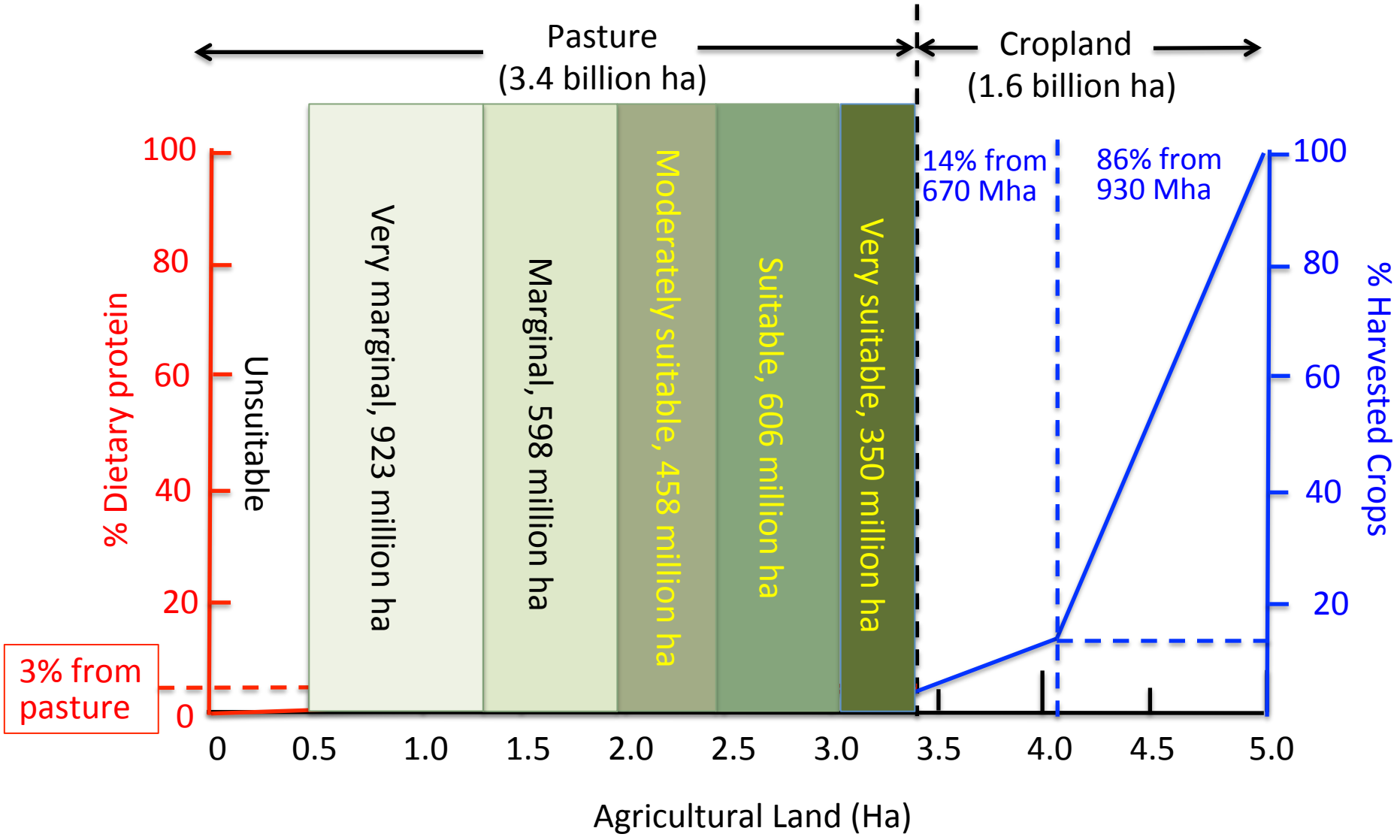


The Middle Ground



Is this middle ground with little contribution to food production inherently unproductive?

FAO Land suitability evaluation



Crops can be grown on most of the middle ground. Lots of unused capacity.

Further perspective on pasture: Sheehan et al. climate binning analysis of global pasture (in review)

In brief

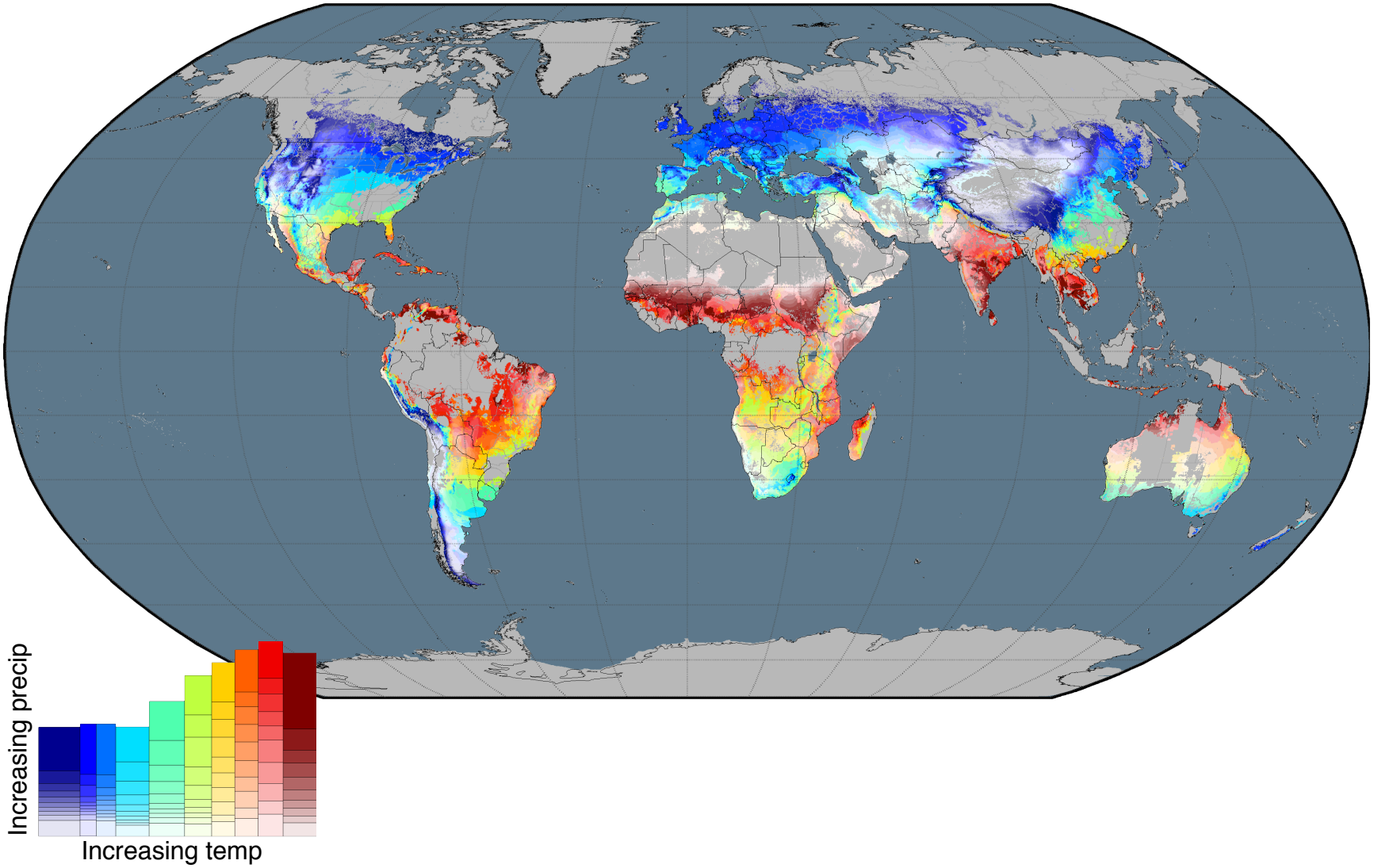
Global pasture land divided into equal area bins defined by annual precipitation and temperature (degree days)

Stocking densities within each bin rank ordered according to area percentile

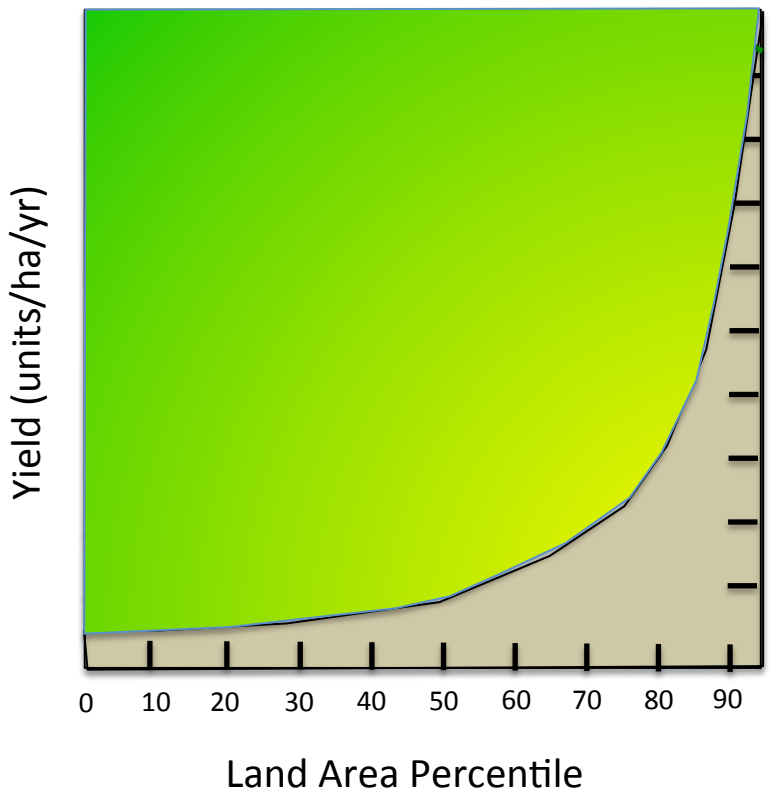
Populations in each area percentile added to get cummulative populations

% currently attained performance estimated by comparing actual populations to 95^{th} percentile population

Climate Binning of Global Pasture Land



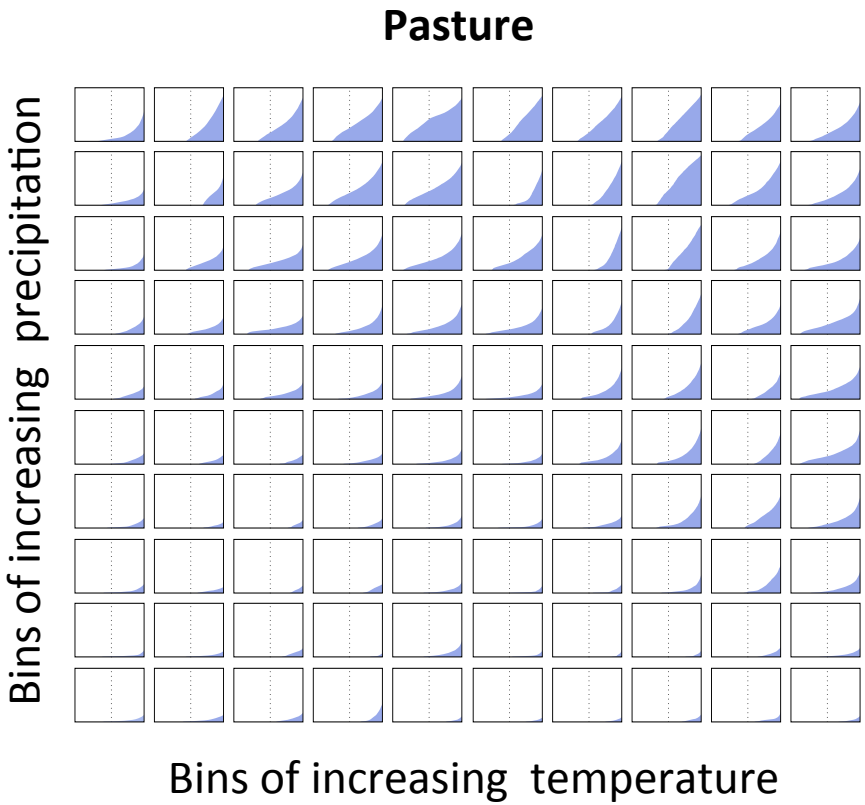
General Framework for Visualizing Actual Pasture Stocking Density in Relation to Currently-Attained Performance



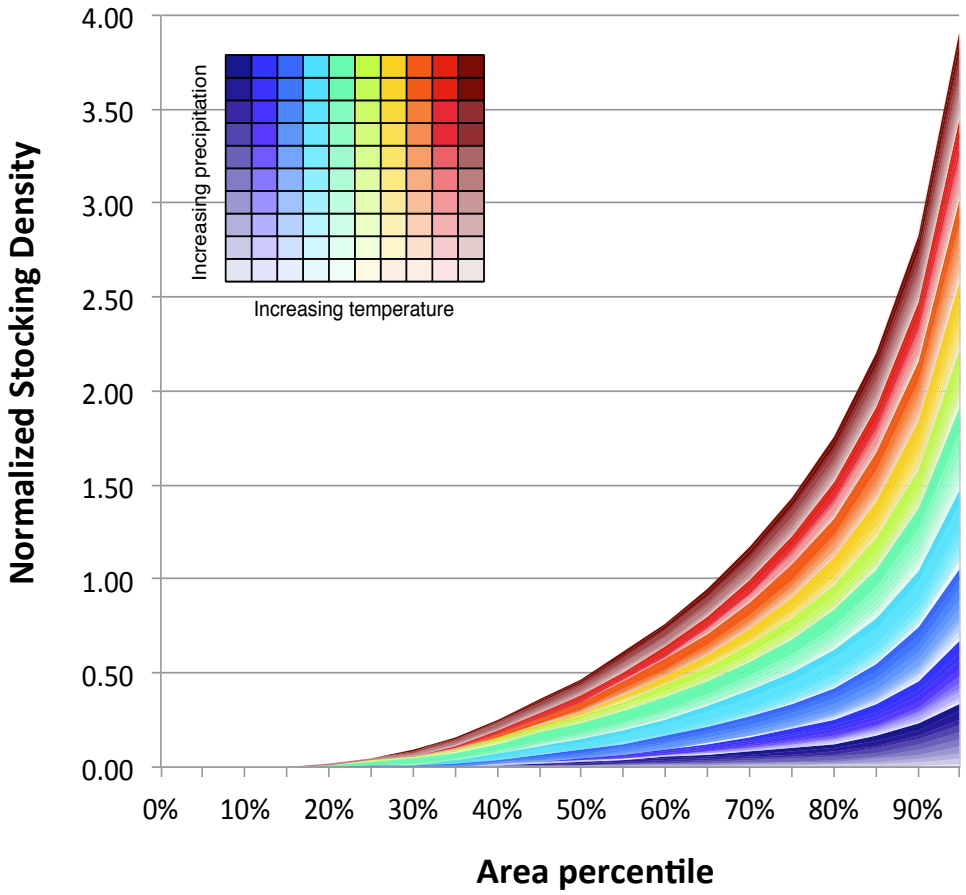
Realized productive potential

Unrealized productive potential

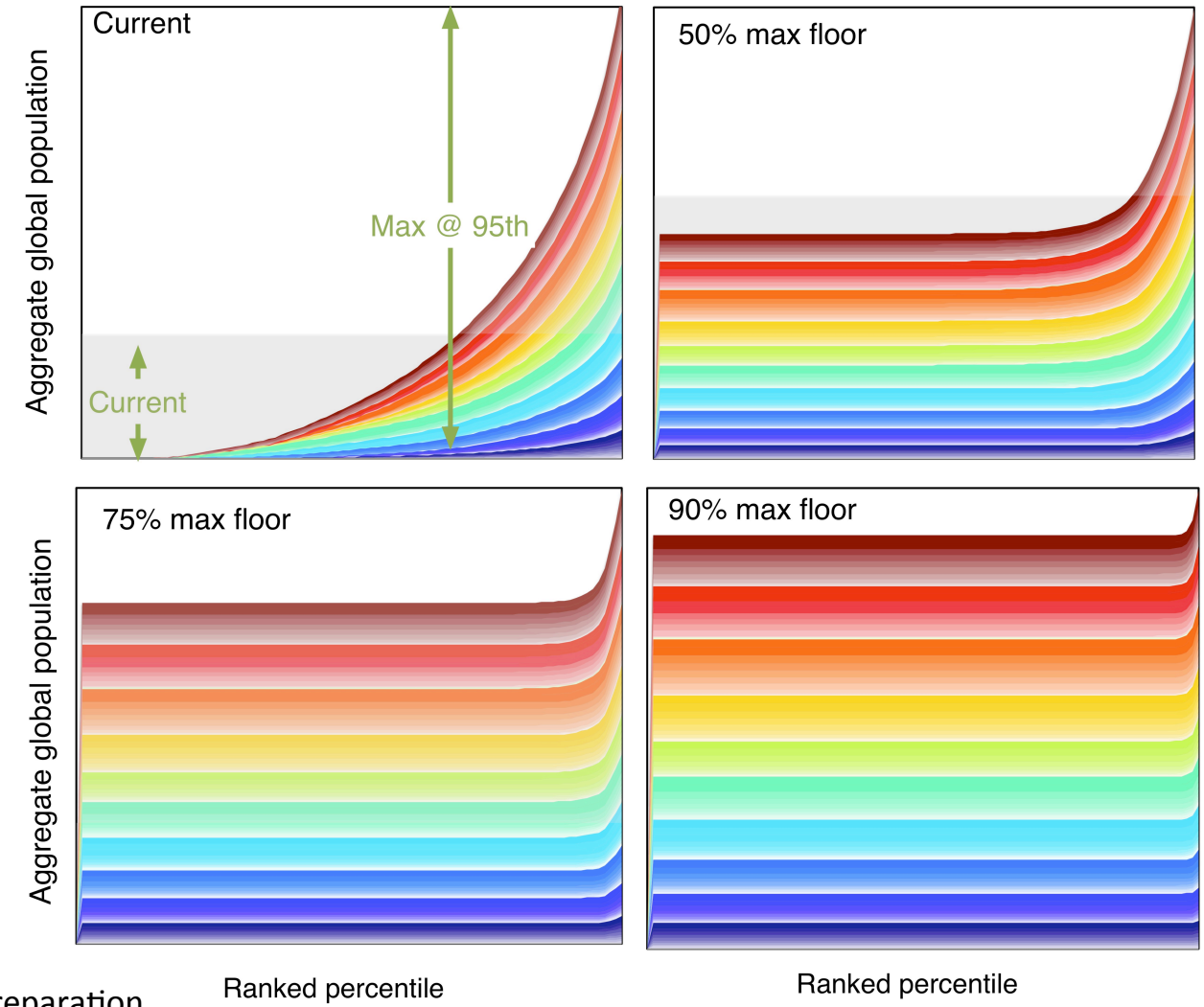
Visualizing Actual Pasture Stocking Density in Relation to Currently-Attained Performance: Bin-by-Bin



Visualizing Actual Pasture Stocking Density in Relation to Currently-Attained Performance: All Bins

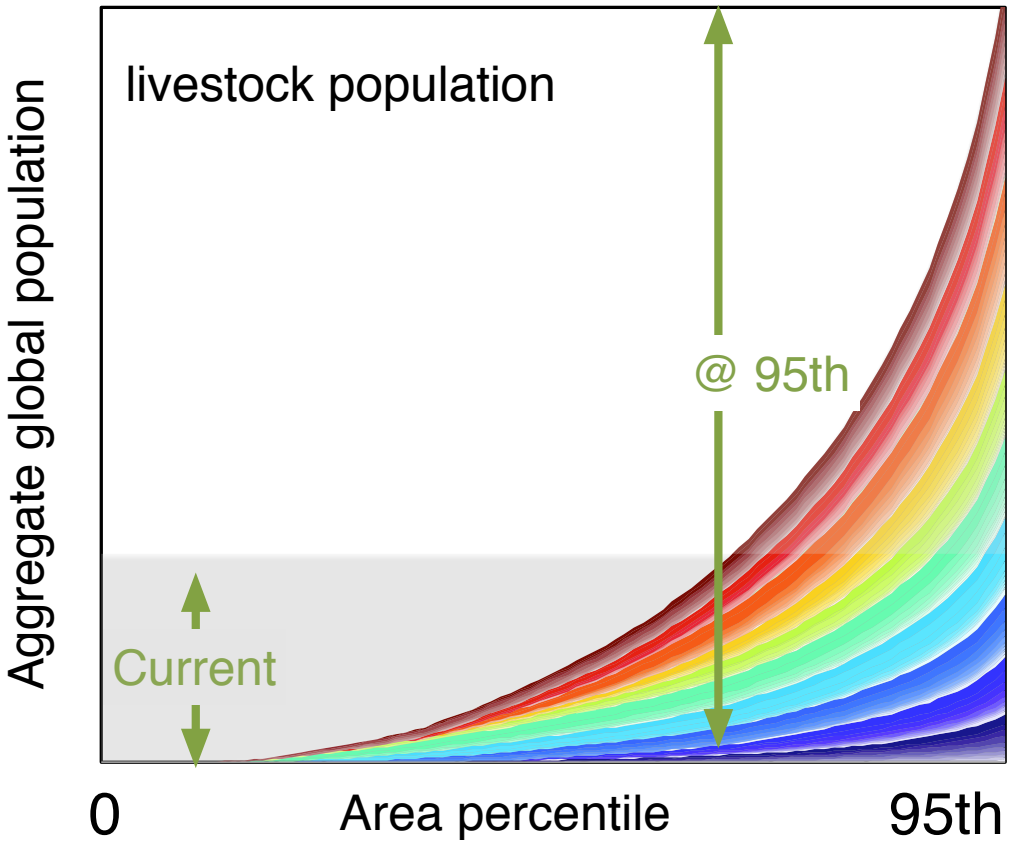


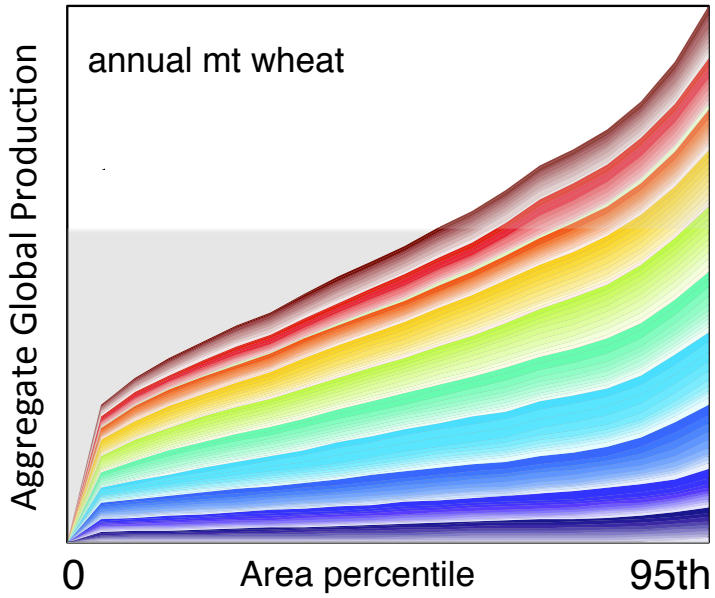
Raising the minimum performance level to various fractions of the maximum achievable density

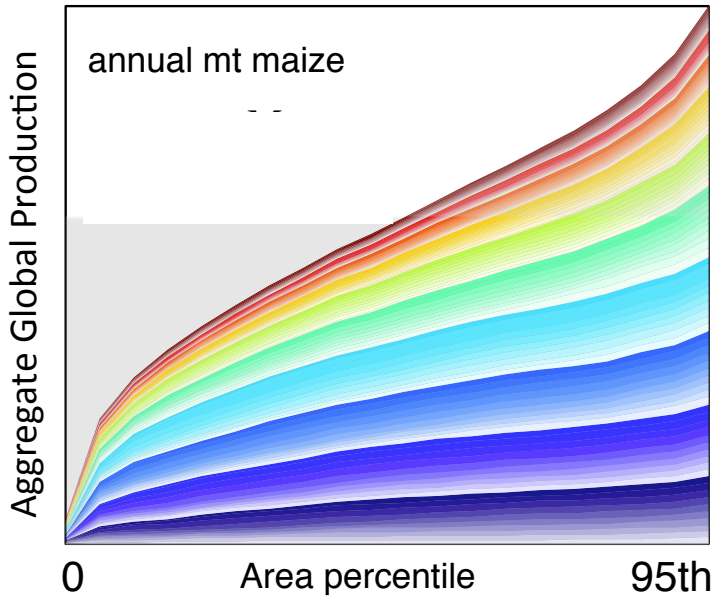


Sheehan et al., in preparation

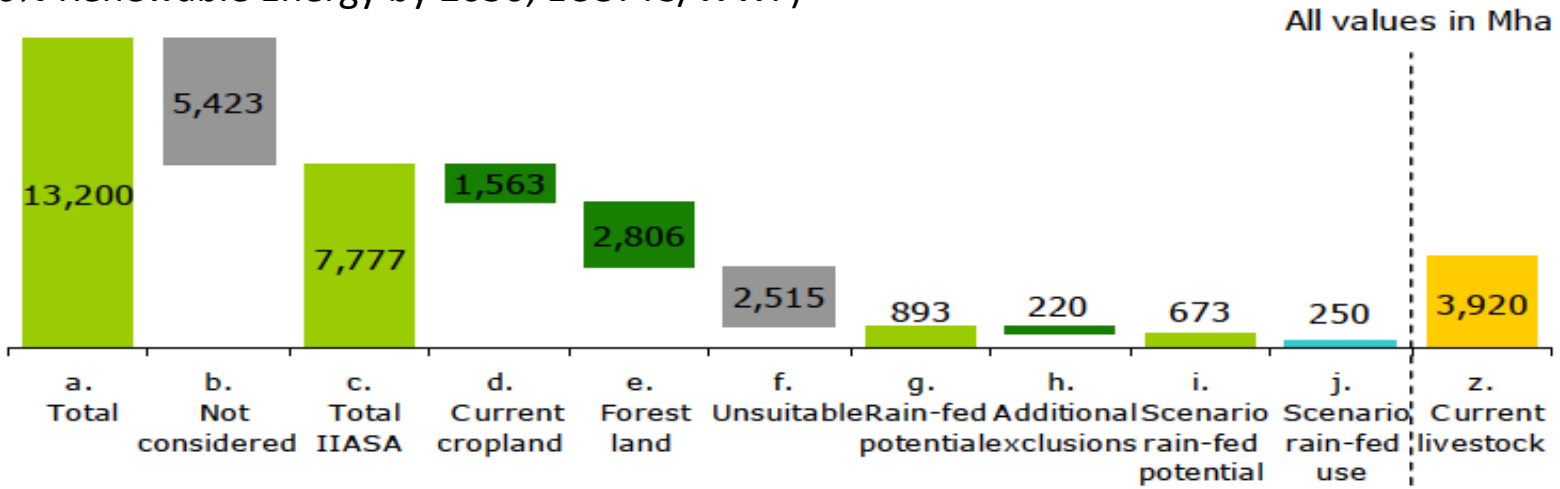
Comparison of pasture to maize and wheat







Results of the Energy Scenario Assessment of Land Potential of Rainfed Cultivation of Energy Crops.
(100% Renewable Energy by 2050, ECOFYS/WWF)



a. Total global land mass (excluding Antarctica)
b. Excluded: protected land, barren land, urban areas, water bodies
c. Total land considered in the IIASA study
d. Excluded: current agricultural cropland
e. Excluded: unprotected forested land
f. Excluded: not suitable for rain-fed agriculture
g. Potential for rain-fed agriculture
h. Excluded: additional land for biodiversity protection, human development, food demand
i. Energy Scenario potential for energy crops
j. Energy Scenario: land use for energy crops
z. Current land used to support livestock (for reference only; overlaps with other categories)

Figure 5 - 5 Results of the Energy Scenario assessment of land potential for rain-fed cultivation of energy crops.

40% of rainfed potential, with many exclusions → 40% of global primary energy in 2050.
"The assessed potential is located on grassland and non-densely vegetated woodland. Most land of these types is currently used as low-intensity grazing lands for livestock."

Widespread view

Land is used either for food or nature

Food production is operating at near capacity

Thus if bioenergy is produced on land that could produce food nature suffers and people will go hungry

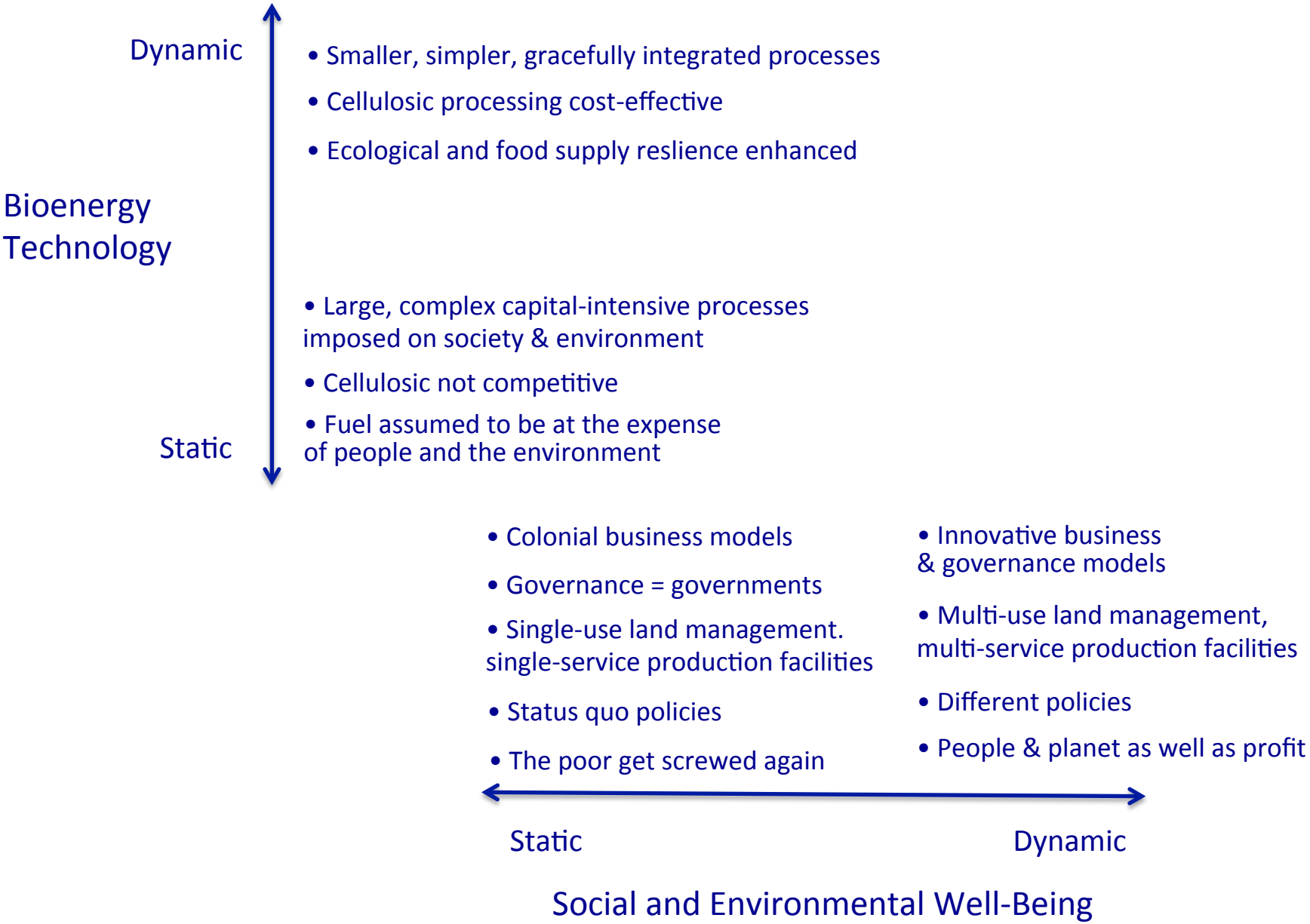
Alternative working hypothesis

Most food produced on < 20% agricultural land

Thus bioenergy can be grown within the footprint of existing managed lands

… with substantial environmental and economic development benefits

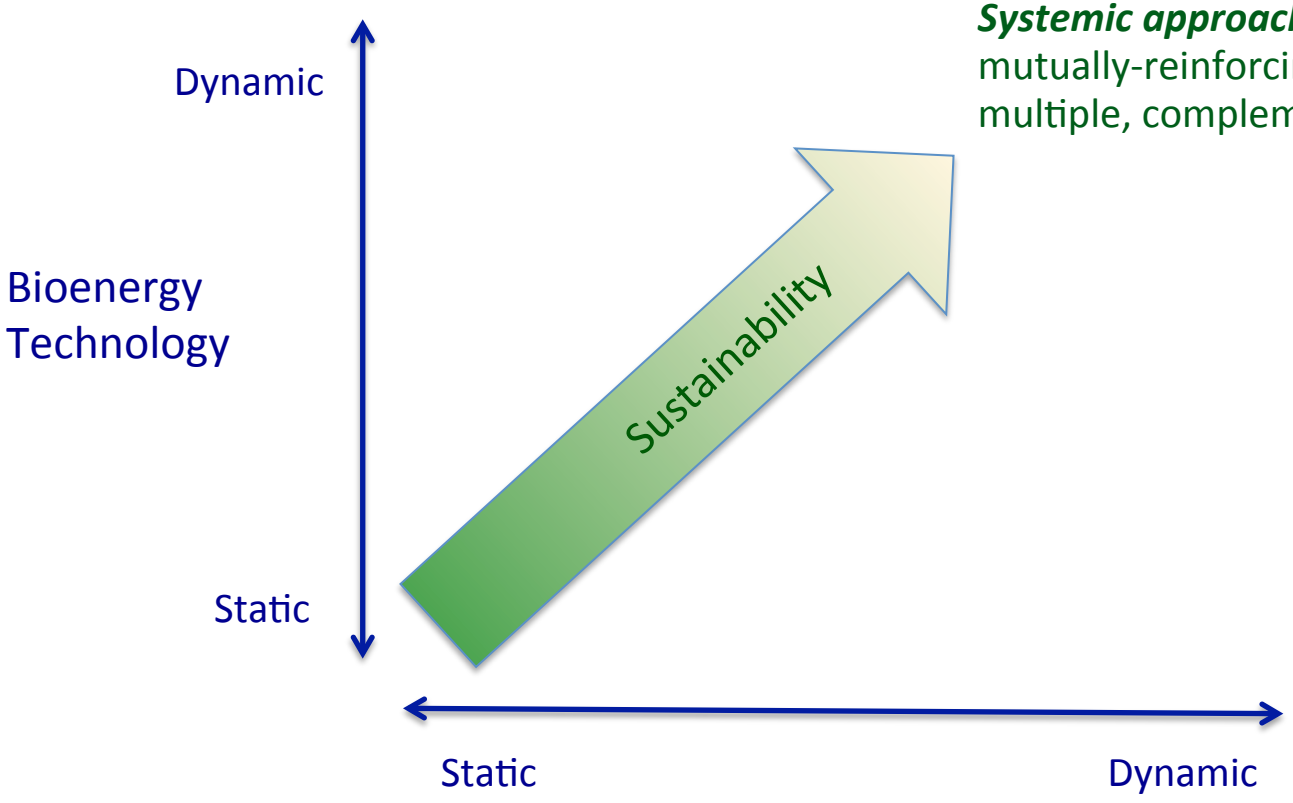
Technologically-dynamic bioenergy scenarios are often considered in a static social context, and socially-dynamic scenarios are often considered in a static technological context.

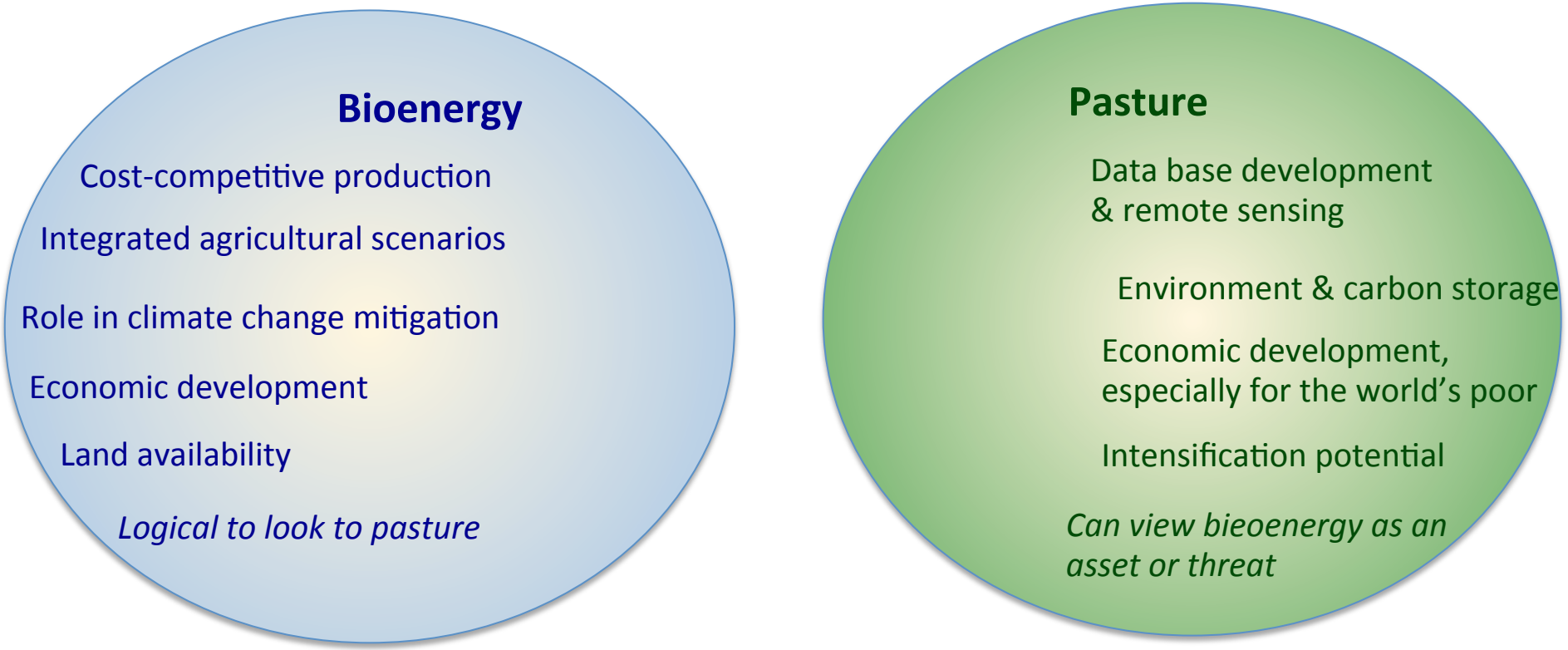


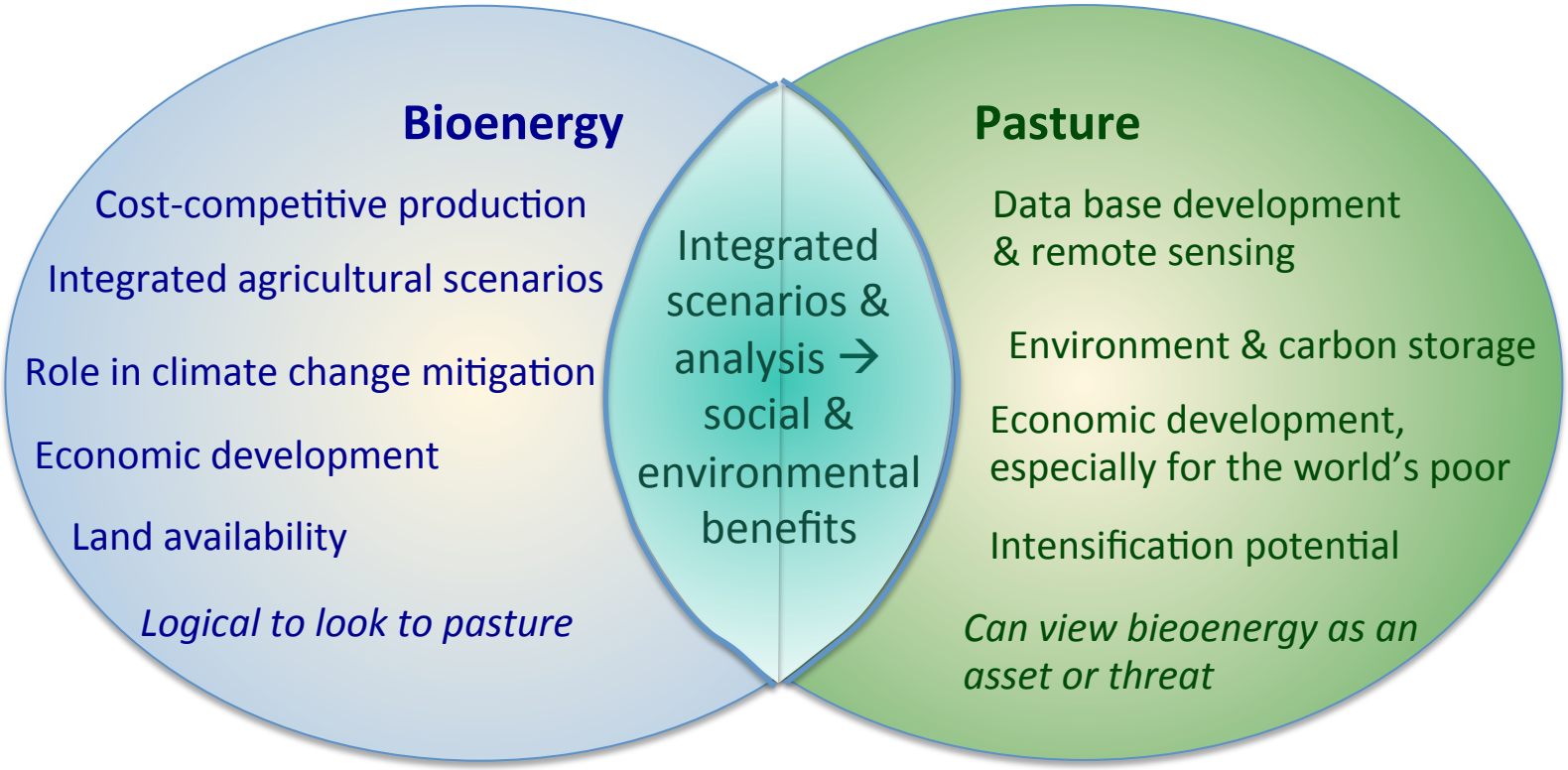
Navigating the sustainable resource revolution, all sectors

Doing things differently than we do them now. it is unreasonable to expect an extrapolated future to be different from the present.

Systemic approach. Multiple, mutually-reinforcing approaches to achieve multiple, complementary objectives.




Bioenergy
Cost-competitive production
Integrated agricultural scenarios
Role in climate change mitigation
Economic development
Land availability
Logical to look to pasture
Pasture
Data base development
& remote sensing
Environment & carbon storage
Economic development,
especially for the world's poor
Intensification potential
Can view bieoenergy as an
asset or threat



Need and opportunity for work at this intersection supported by fundamental observations

Bioenergy needed for climate change mitigation, without which the world's poor will suffer

Economic development addresses the biggest impediment to food security

Agricultural development offering the largest benefits to the worlds rural poor

Access to energy commonly limits economic development

There is a great deal of land operating at less than capacity. Particularly pasture land

Global Sustainable Bioenergy Initiative "GSB Initiative" (http://bioenfapesp.org/gsb/)

Motivation: The world likely needs bioenergy - for low-carbon energy supply, economic development, and benefits to agriculture - yet seems inclined to turn away from it.

Objective: Expand understanding of the possibility of beneficially producing bioenergy on a very large scale - e.g. 25% of primary energy supply in 2050, consistent with recent low carbon scenarios.

Working hypotheses:

1. That it is physically possible to "make room" for large scale bioenergy while honoring other land use priorities.

2. That a systemic approach to food and bioenergy production could positively and synergistically impact multiple urgent human needs.

Structure

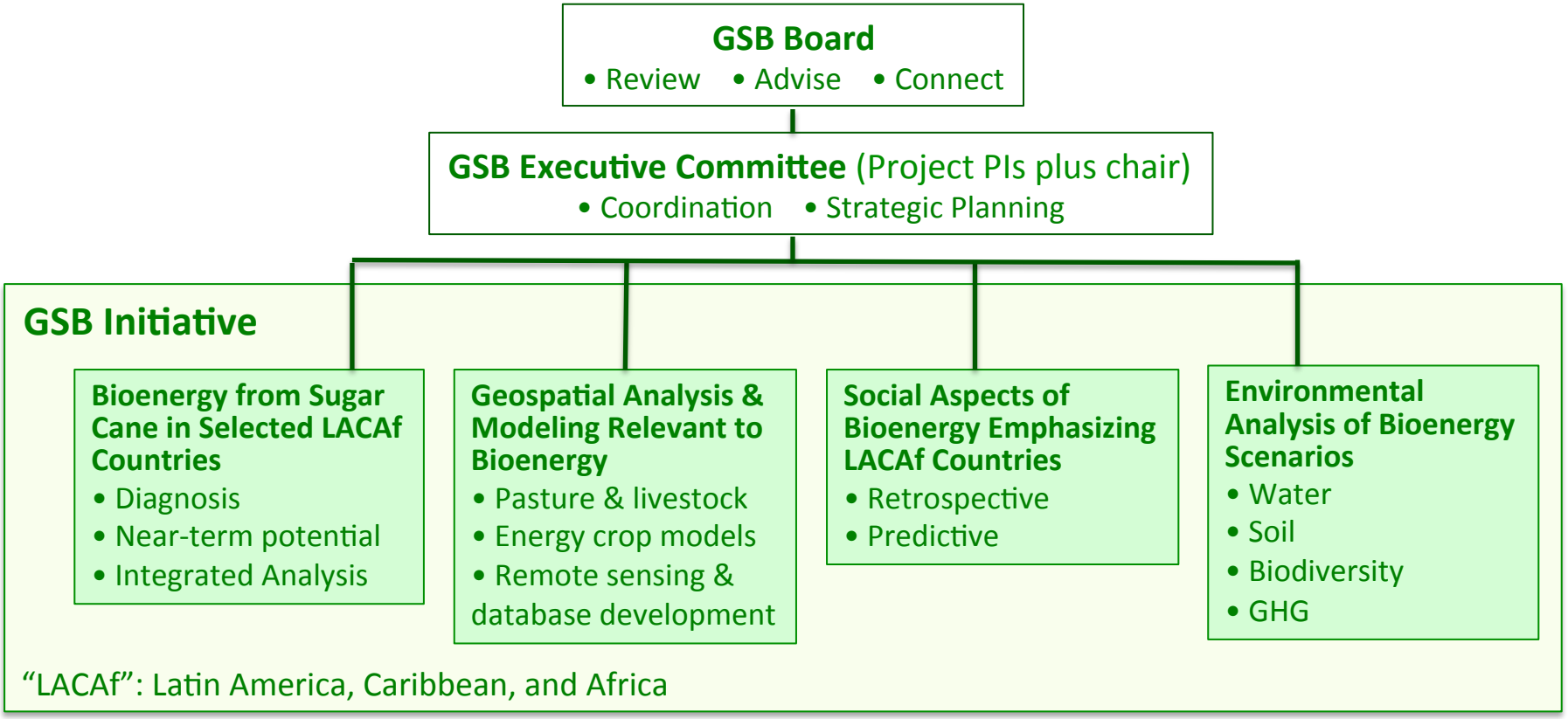
Stage 1. Continental Conventions (completed)

- Gather input on framing stages 2 and 3
- Continental resolutions
- Recruit participants & funds

Stage 2. Address working hypothesis, unconstrained by current realities.

Stage 3. Analyze implementation paths, recommend policies

Global Sustainable Bioenergy (GSB) Initiative



Scholar Exchange Program (accessed from http://bioenfapesp.org/gsb/)

Supported by the Sao Paulo Research Foundation (FAPESP) BIOEN Program

Brazilian scholars studying abroad

International scholars studying in Brazil

Several days to a year

GSB Key Words:
Convergent, Predictive, Ground-Breaking, Integrated, Impactful, Analysis