Development of an Indicator Approach to Assessing Bioenergy Sustainability

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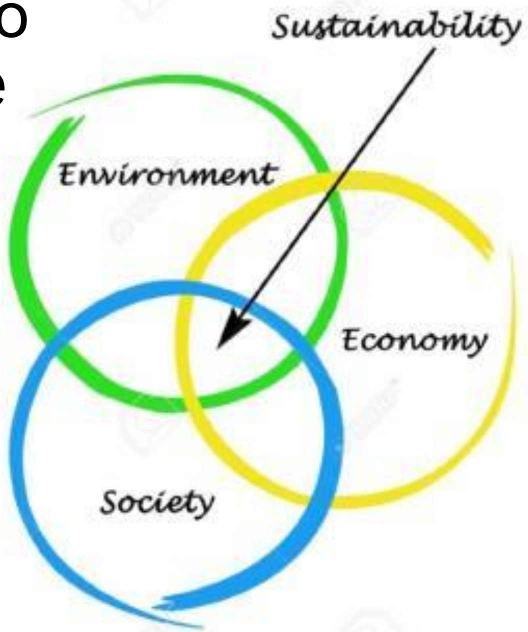
CBES
Center for BioEnergy Sustainability

ORNL is managed by UT-Battelle for the US Department of Energy

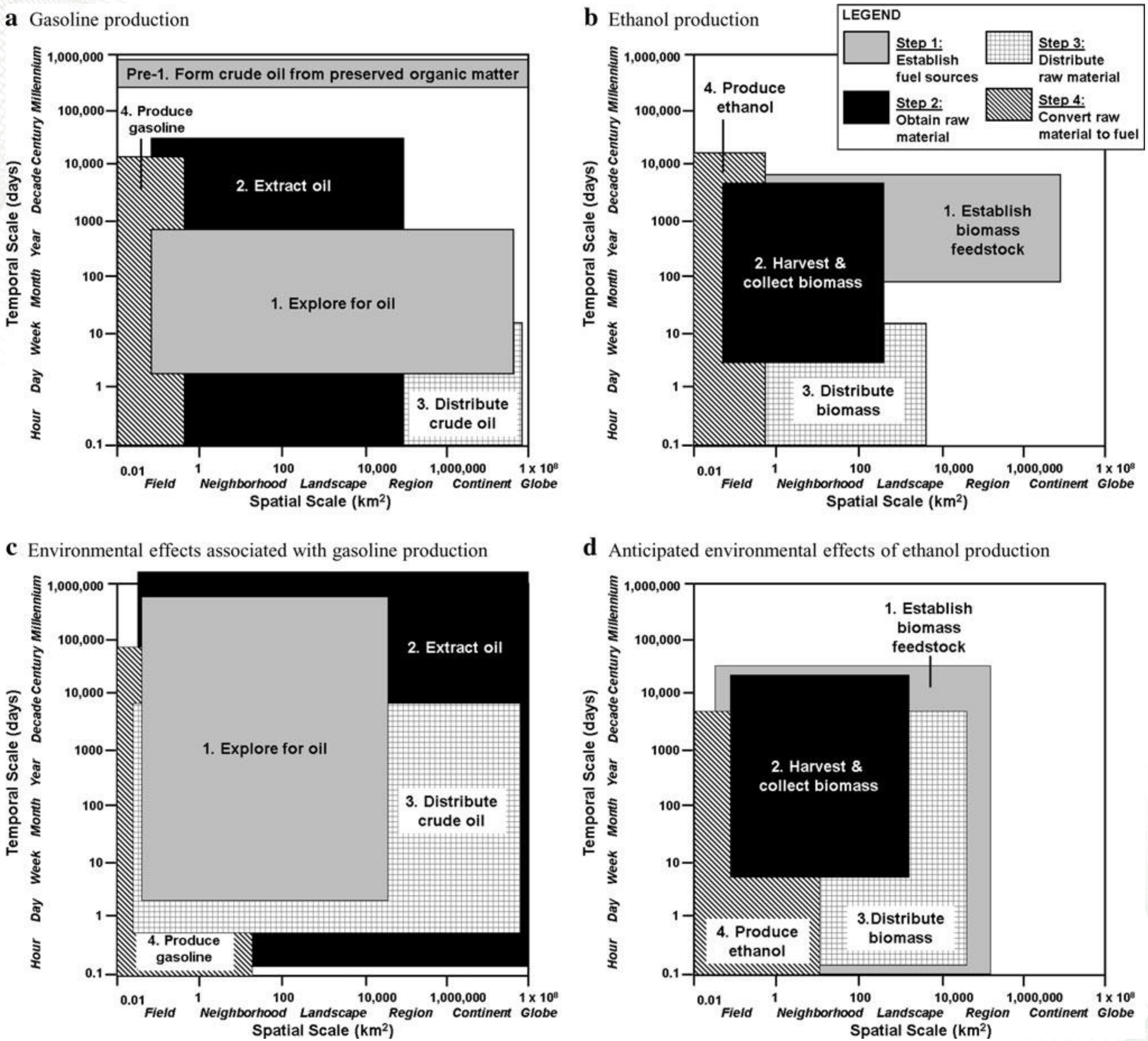
OAK RIDGE National Laboratory

ORNL's Bioenergy Sustainability Research for the US Department of Energy (DOE)

'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 definition of sustainability
  - Quantitative & consistent way to implementing indicators & methodology for evaluating & improving sustainability

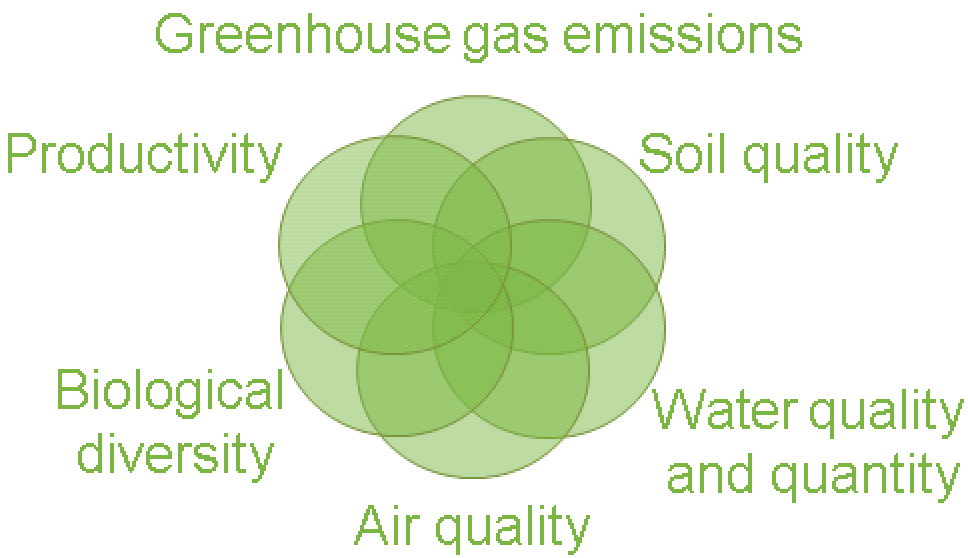


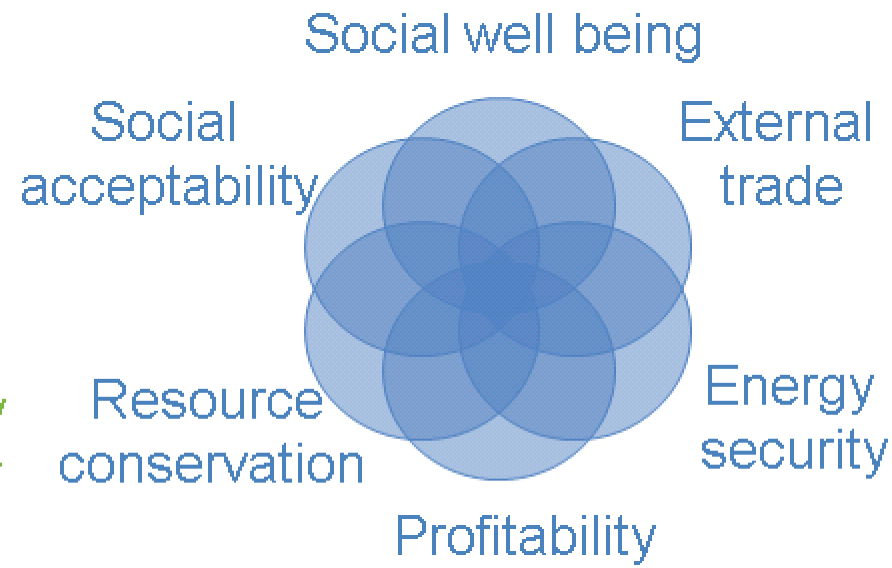
Spatial & temporal scales of energy supply & effects vary by fuel type

Parish et al. (2013) Comparing Scales of Environmental Effects from Gasoline and Ethanol Production. *Environmental Management* 51:307–338

ORNL's Bioenergy Sustainability Indicators

(35 indicators in 12 categories)





McBride et al. (2011)
Ecological Indicators
11:1277-1289

Dale et al. (2013)
Ecological Indicators
26:87-102.

Recognize that measures and interpretations are <u>context</u>-specific

Efroymson et al. (2013) ***Environmental Management*** **51:291-306.**

Categories of environmental sustainability indicators

Environment	Indicator	Units
Soil quality	1. Total organic carbon (TOC)	Mg/ha
	2. Total nitrogen (N)	Mg/ha
	3. Extractable phosphorus (P)	Mg/ha
	4. Bulk density	g/cm^3
Water quality and quantity	5. Nitrate concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	6. Total phosphorus (P) concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	7. Suspended sediment concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	8. Herbicide concentration in streams (and export)	concentration: mg/L; export: kg/ha/yr
	9. storm flow	L/s
	10. Minimum base flow	L/s
	11. Consumptive water use (incorporates base flow)	feedstock production: m^3/ha/day; biorefinery: m^3/day

Environment	Indicator	Units
Greenhouse gases	12. CO_2 equivalent emissions (CO_2 and N_2O)	kgC_{eq}/GJ
Biodiversity	13. Presence of taxa of special concern	Presence
	14. Habitat area of taxa of special concern	ha
Air quality	15. Tropospheric ozone	ppb
	16. Carbon monoxide	ppm
	17. Total particulate matter less than 2.5µm diameter ($PM_{2.5}$)	$\mu g/m^3$
	18. Total particulate matter less than 10µm diameter (PM_{10})	$\mu g/m^3$
Productivity	19. Aboveground net primary productivity (ANPP) / Yield	gC/m^2/year

McBride et al. (2011) *Ecological Indicators* 11:1277-1289

Categories of socioeconomic sustainability indicators

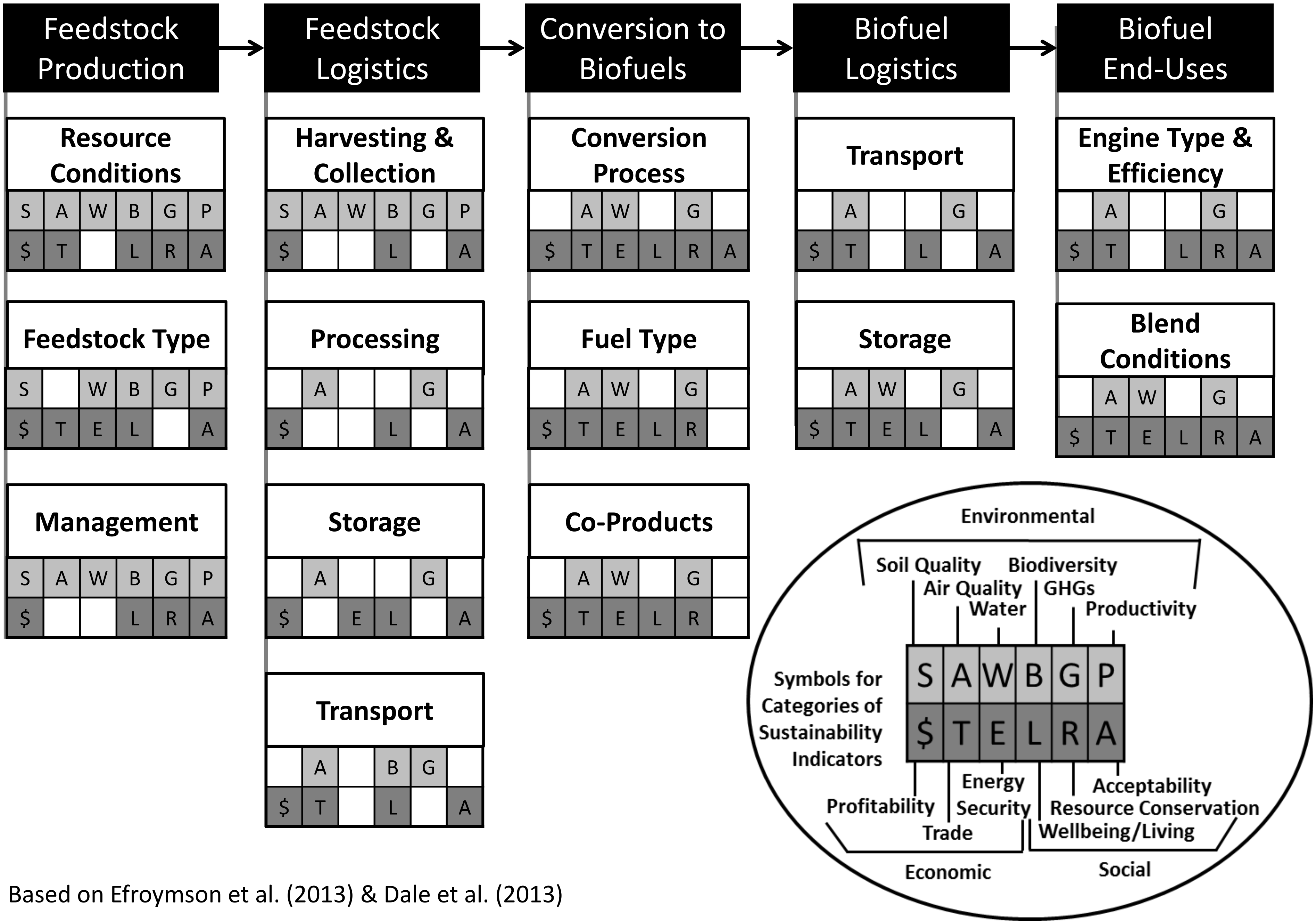
Ten minimum practical measures

Category	Indicator	Units
Social well-being	Employment	Number of full time equivalent (FTE) jobs
	Household income	Dollars per day
	Work days lost due to injury	Average number of work days lost per worker per year
	Food security	Percent change in food price volatility
Energy security	Energy security premium	Dollars /gallon biofuel
	Fuel price volatility	Standard deviation of monthly percentage price changes over one year
External trade	Terms of trade	Ratio (price of exports/price of imports)
	Trade volume	Dollars (net exports or balance of payments)
Profitability	Return on investment (ROI)	Percent (net investment/ initial investment)
	Net present value (NPV)[2]	Dollars (present value of benefits minus present value of costs)

Category	Indicator	Units
Resource conservation	Depletion of non-renewable energy resources	MT (amount of petroleum extracted per year)
	Fossil Energy Return on Investment (fossil EROI)	MJ (ratio of amount of fossil energy inputs to amount of useful energy outputt
Social acceptability	Public opinion	Percent favorable opinion
	Transparency	Percent of indicators for which timely and relevant performance data are reported
	Effective stakeholder participation	Number of documented responses to stakeholder concerns and suggestions reported on an annual basis
	Risk of catastrophe	Annual probability of catastrophic event

Dale et al. (2013) *Ecological Indicators* 26:87-102.

Sustainability Indicator relevance across Biofuel Supply Chain



Based on Efroymson et al. (2013) & Dale et al. (2013)

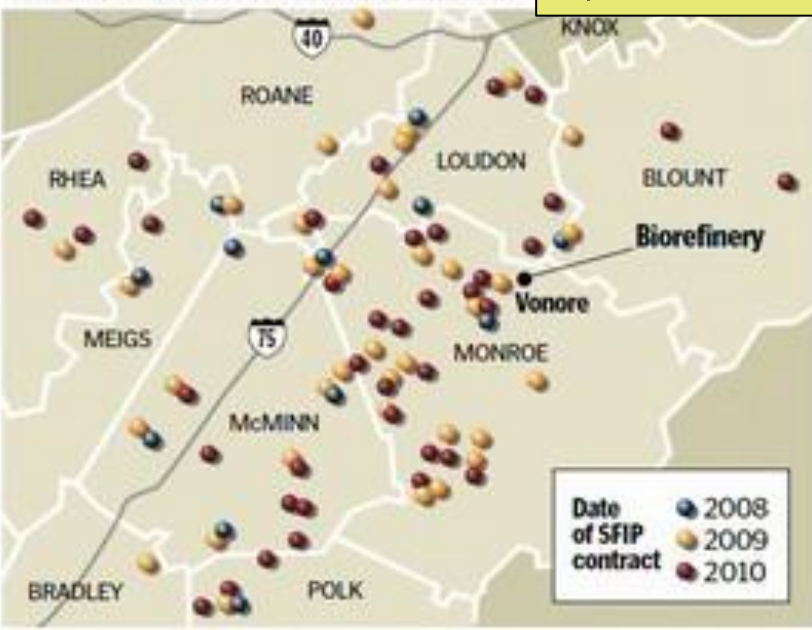
First case study: Switchgrass in east TN

- Dale et al. (2011) Ecological Applications 21(4):1039-1054.
- Parish et al. (2012) Bioprod. Bioref. 6(1):58-72.
- Parish (2016) Auburn Speaks: On Biofuels in the Southeast
- Parish et al.(2016) Ecosphere 7(2):1-18.

5-year Vonore, Tennessee switchgrass-to-ethanol experiment

SWITCHGRASS CONTRACT FARMS

2,064 ha total



County	Total acres	Farmers
Monroe	2,205.3	26
McMinn	818.1	10
Loudon	553.9	6
Blount	469.5	4
Bradley	354.7	2
Polk	291.9	3
Rhea	258.1	5
Roane	118.8	4
Hamilton	58.6	1
Meigs	33.3	2
Totals	**5,162.2**	**63**

Year	New farmers	Total production in tons
2008	16	1,000
2009	24	6,000
2010	21	*15,000

*Estimated

Farmer type	Farmers
Full time	31
Part time	30

Source: Genera Energy LLC NEWS SENTINEL

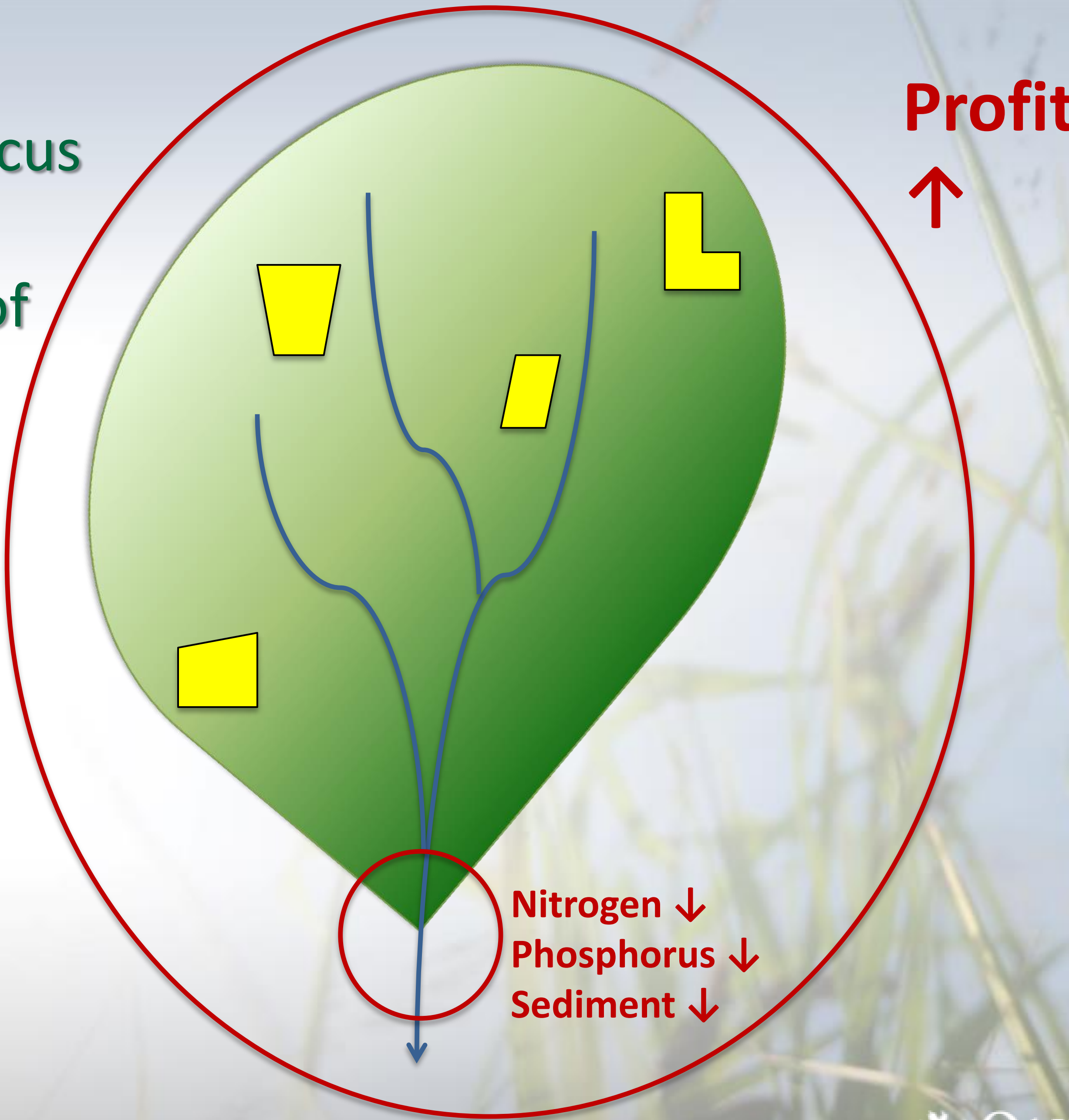
Demonstration-scale cellulosic biorefinery (250Mgal/yr) + Switchgrass from 10 counties

Photos from Genera Energy LLC

Vonore was previously the focus area for BLOSM modeling study of potential sustainability tradeoffs at a watershed scale

Research Question:

Which crop configuration maximizes sustainability objectives while achieving target production?

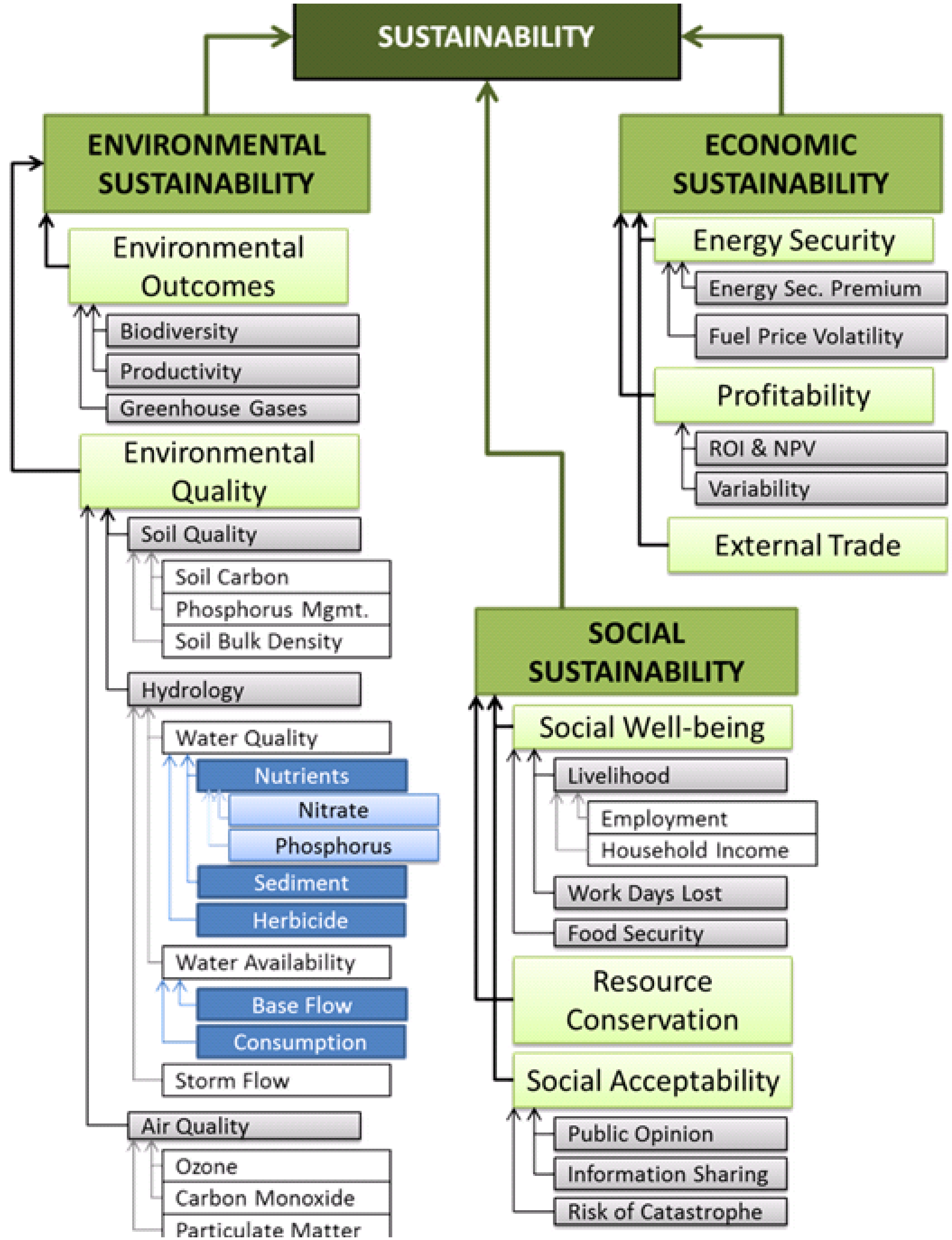


Schematic based on Parish et al. (2012) Multimetric Spatial Optimization of Switchgrass Plantings Across a Watershed. *Biofuels, Bioproducts & Biorefining* 6(1):58-72

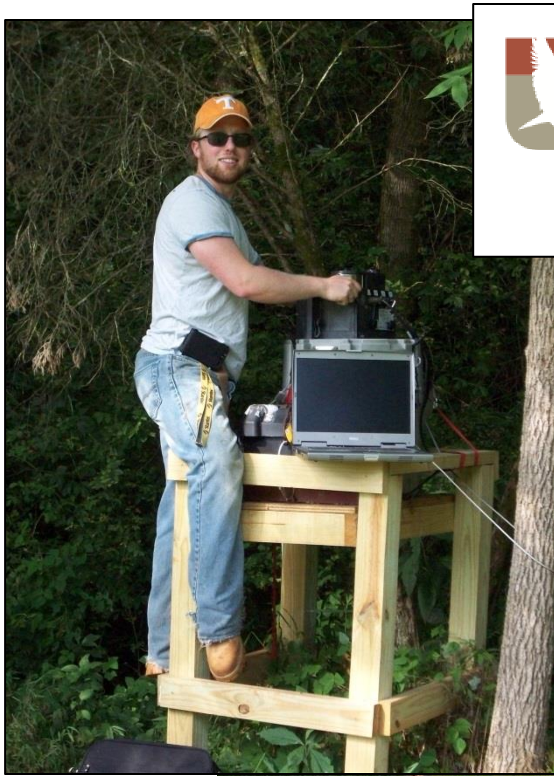
Case Study goals:

- Collect data for as many of the 35 recommended ORNL bioenergy sustainability indicators as possible
- Appropriately aggregate them within a framework that can be adjusted according to stakeholder priorities.

Parish, ES, VH Dale, BE English, S Jackson, and D Tyler (2016) Assessing multimetric aspects of sustainability: Application to a bioenergy crop production system in East Tennessee. *Ecosphere7(2):1-18*



We combined data gathered from the Vonore switchgrass experiment with modeling results, literature values & expert opinion using a modified Delphi process.



IBSS
Southeastern Partnership for
Integrated Biomass Supply Systems

Qualitative ratings were developed for nearly all of the 35 sustainability indicators in all 12 categories.

Parish, ES, VH Dale, BE English, S Jackson, and D Tyler (2016) Assessing multimetric aspects of sustainability: Application to a bioenergy crop production system in East Tennessee. *Ecosphere7(2):1-18*

We compared 3 agricultural scenarios

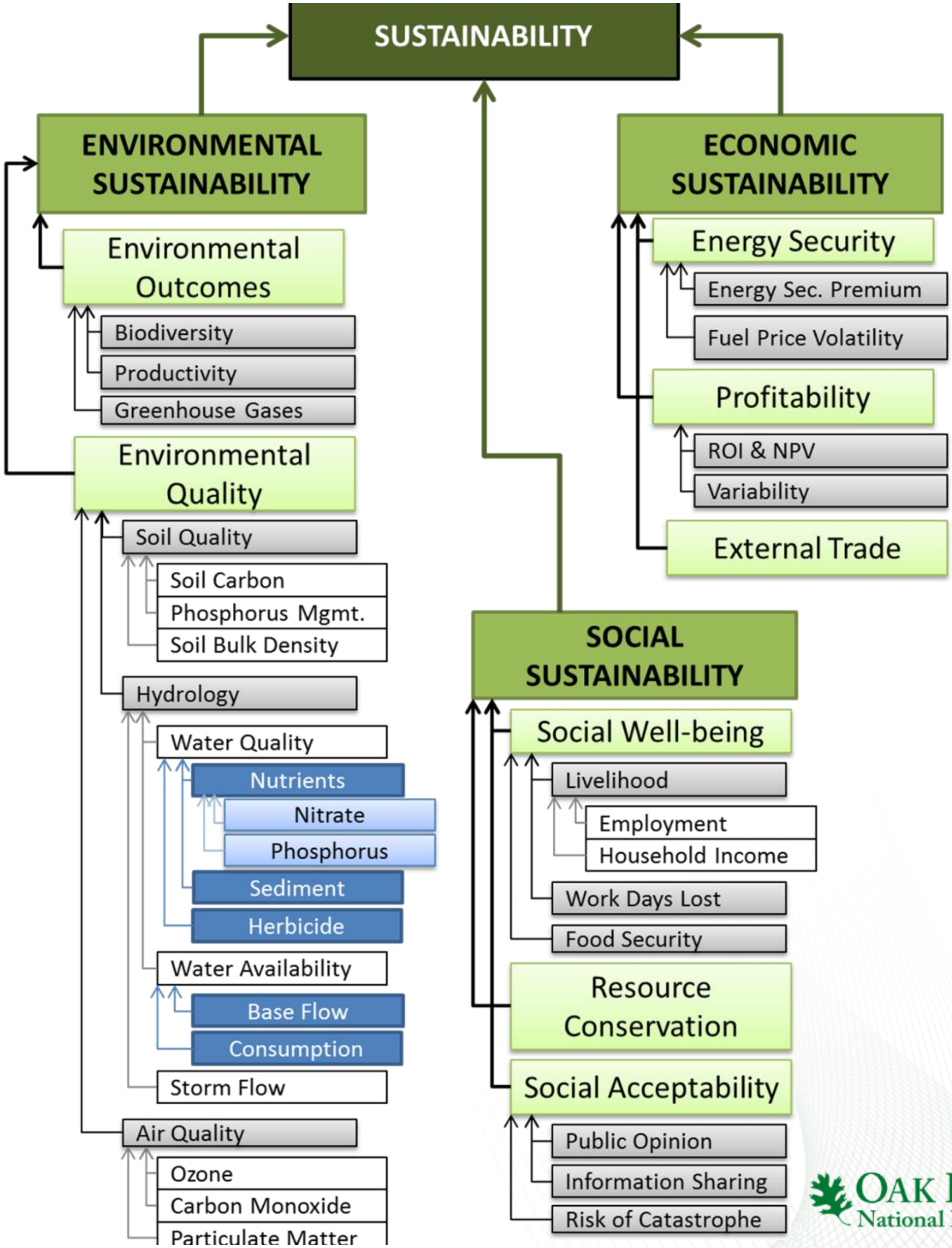
Parameter	NO-TILL SWITCHGRASS	TILLED CORN	UNMANAGED PASTURE
Time of planting	Establish once in spring; no replanting	Plant annually	Already established
Tillage Type	No-till method with a drill is preferred	Planted conventionally	No need for replanting
Harvesting equipment	Conventional hay equipment	Combine	Harvest by cows (1.5 acres/cow)
Harvest Frequency	Once per year (after Nov. 1 or first killing frost)	Once a year (October)	Continuous
Storage	Round bale tarped	Trucked off farm	None
Herbicide Application	1-3 applications of glyphosate herbicide prior to planting	Annual application of glyphosate herbicide	No herbicide used
Fertilizer Application	Apply 40 lbs/acre when soil test is “Low” for P and K	Apply 100-160 lbs/acre when soil test is “Medium”	No fertilizer used
Typical Yield	6-8 tons/year after 3rd year	114.5 bushels/acre (average for 2007-2013)	2.1 tons/acre (estimated as mixed hay)
Price information	$450/acre actual contract price; estimated delivered price= $71.23/ton ($3.25/ton storage)	$5.04/bushel (2007-2013 average)	$90.79/ton (2007-2013 average)
Final Destination	50 million gallon/year Biorefinery within a one-hour’s drive	Multiple uses of corn grain throughout the region	On-site cattle roughage

Parish, ES, VH Dale, BE English, S Jackson, and D Tyler (2016) Assessing multimetric aspects of sustainability: Application to a bioenergy crop production system in East Tennessee. *Ecosphere7(2):1-18*

We aggregated the indicators within a hierarchical

Multi-Attribute Decision Support System (MADSS)

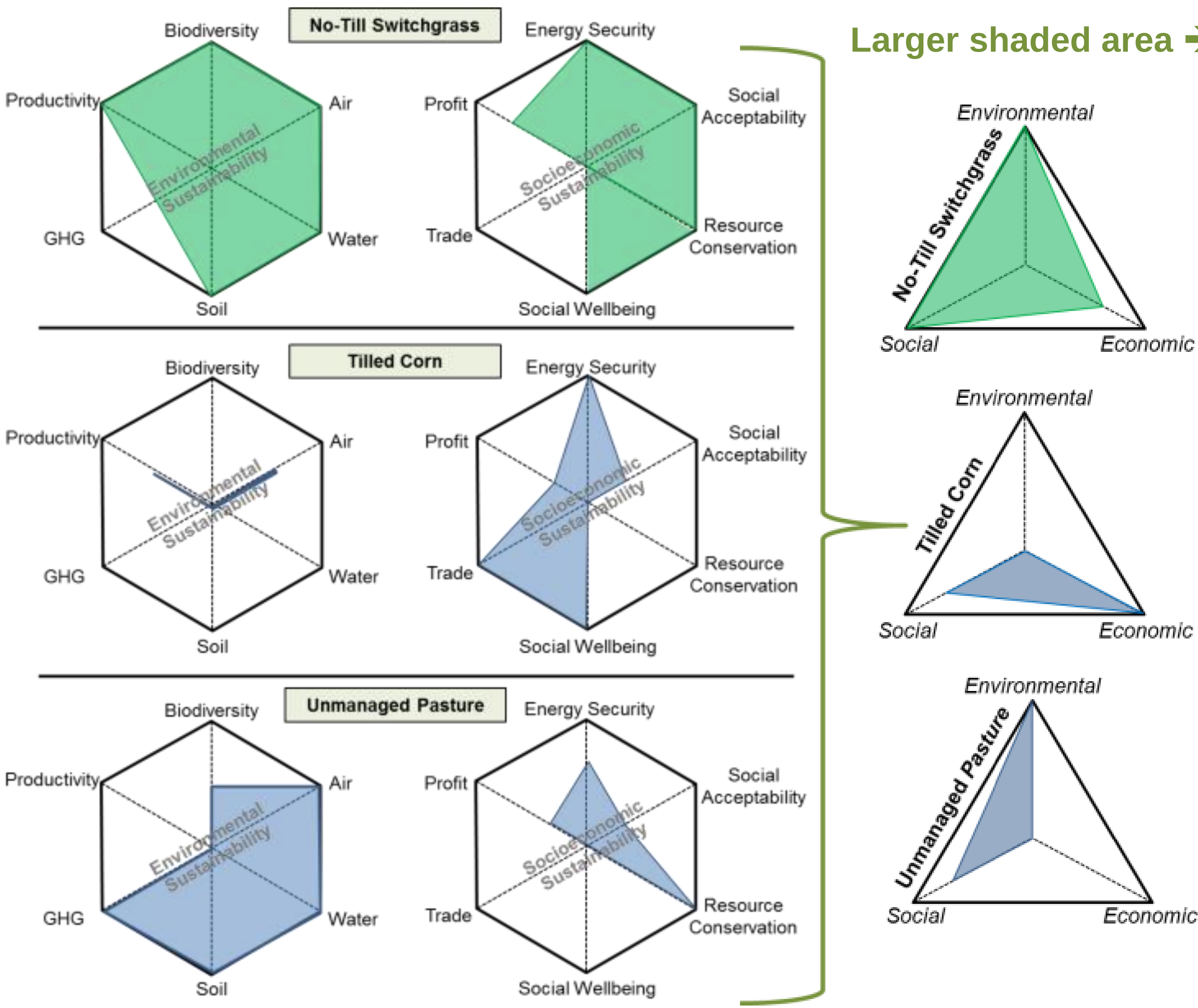
built with freely available DEXi 4.0 software



Parish, ES, VH Dale, BE English, S Jackson, and D Tyler (2016) Assessing multimetric aspects of sustainability: Application to a bioenergy crop production system in East Tennessee. *Ecosphere7(2):1-18*

Case study aggregation of qualitative sustainability indicators

Larger shaded area → more sustainable



Conclusion

East TN switchgrass production:
- Improves environmental quality
- Can provide income & jobs.

Parish et al. (2016) Ecosphere

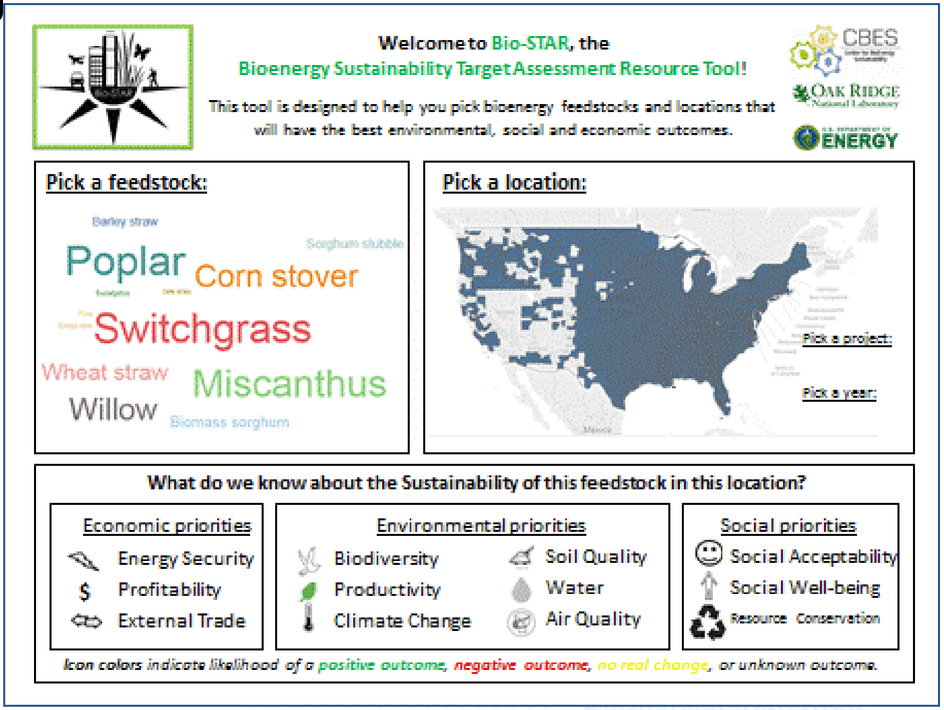
Developing BioSTAR* tool to visualize progress toward sustainability

- **Purpose:** Helps users move from amorphous concept of "sustainability" to priority conditions that can be measured & monitored.

- **Process:** Develop & test visualization tool (starting with switchgrass case study)
  - Displays information about progress being made toward bioenergy sustainability
    - In a particular contexts
    - As defined by the users
    - As characterized by a suite of environ-mental, social & economic indicators
  - Mathematically robust
  - Allows consideration of tradeoffs

- **Audience**: Diversity of stakeholders: public, landowners, NGOs, industry, researchers, etc.

- **Input from stakeholders:** March 28, 2017 workshop



*BioSTAR = Bioenergy Sustainability Target Assessment Resource

Quantitative case study of 2 fuelsheds exporting pellets:

- Savannah : mostly intensively managed pine plantations
- Chesapeake: both pine & mixed hardwoods

***Fuelsheds*: Counties within 120 km (75 miles) of pellet mills that supply ports**

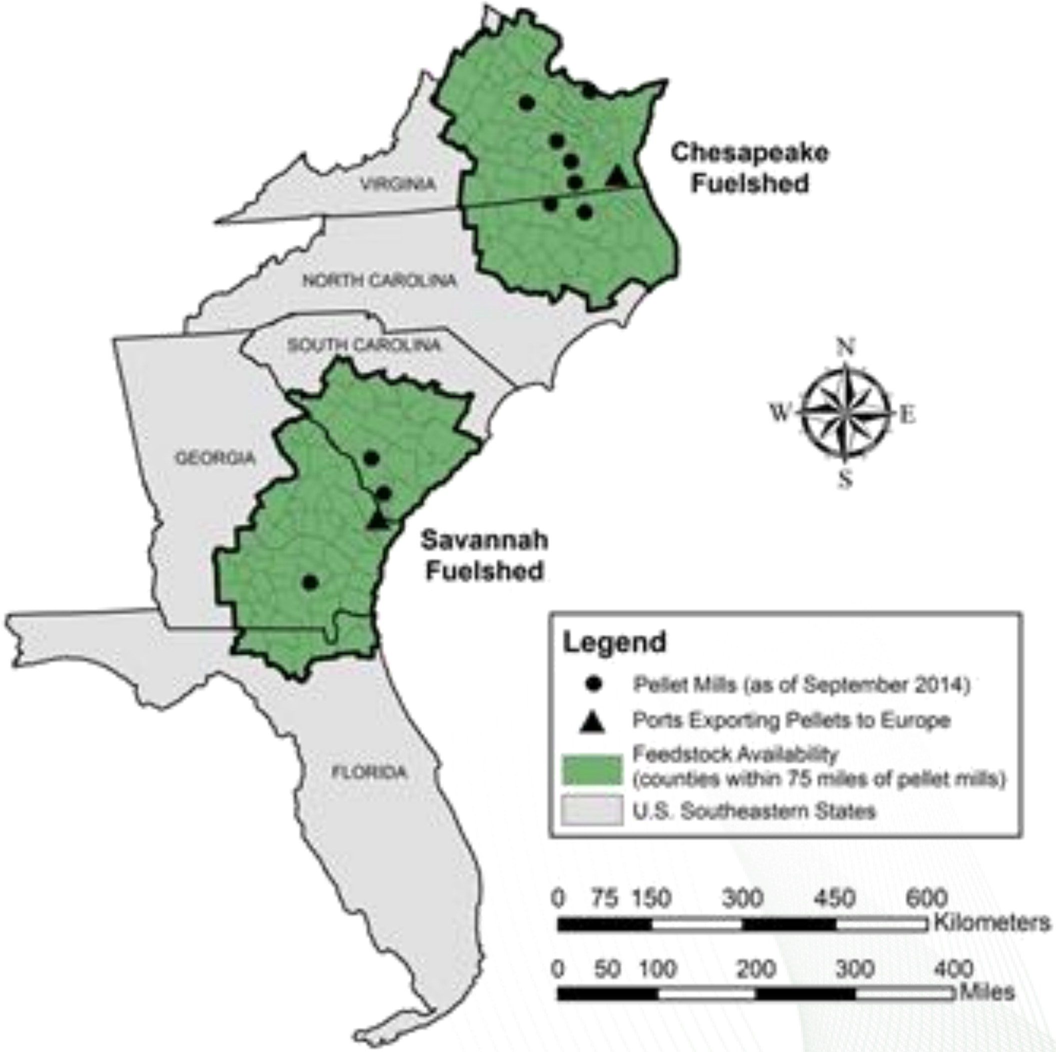
Each fuelshed area has an area of ~12 million ha.

Chesapeake Fuelshed:

- 33 NC counties
- 69 VA counties

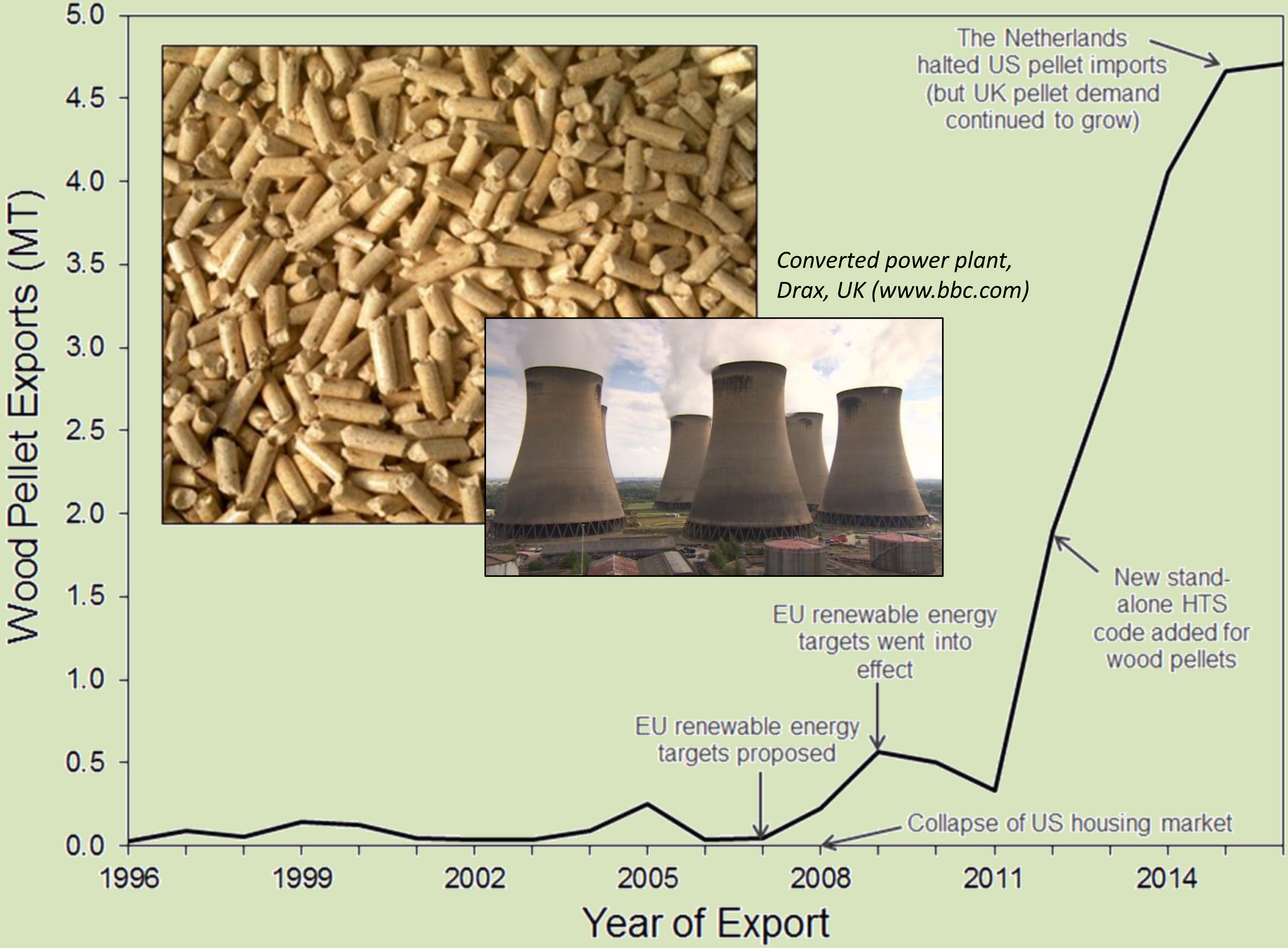
Savannah Fuelshed:

- 22 SC counties
- 54 GA counties
- 7 FL counties



Dale et al. (2017) *Forest Ecology & Mgmt*

US industrial wood pellet trade has been growing



Converted power plant, Drax, UK (www.bbc.com)

From E. Parish, A. Herzberger, C. Phifer, and V. Dale (in press) *Ecology & Society*

Are pellet exports affecting SE US forests?

Analyzed FIA data for changes in:

- timberland volume & area (natural vs. plantation)
- tree diameters
- # of standing dead trees
- carbon pools
- etc.

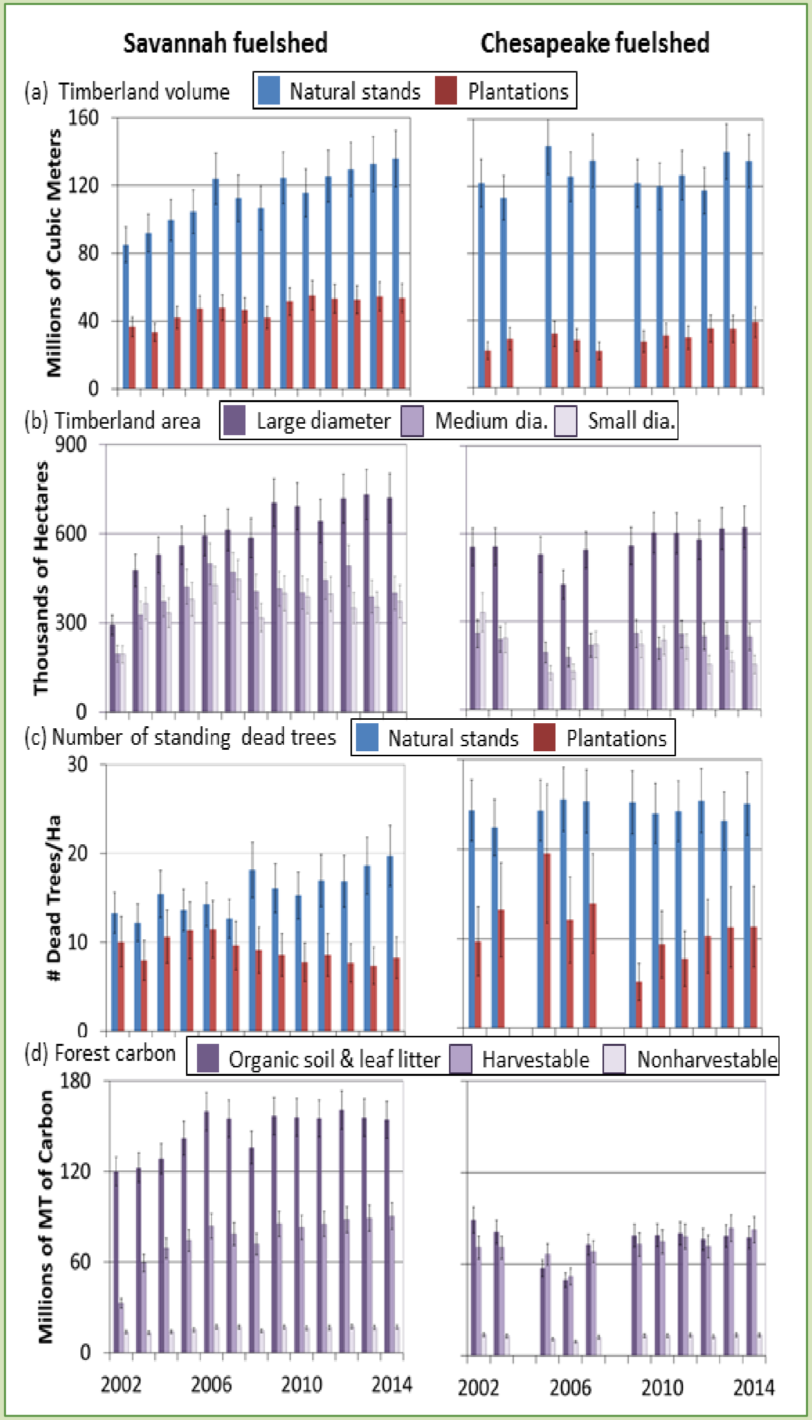


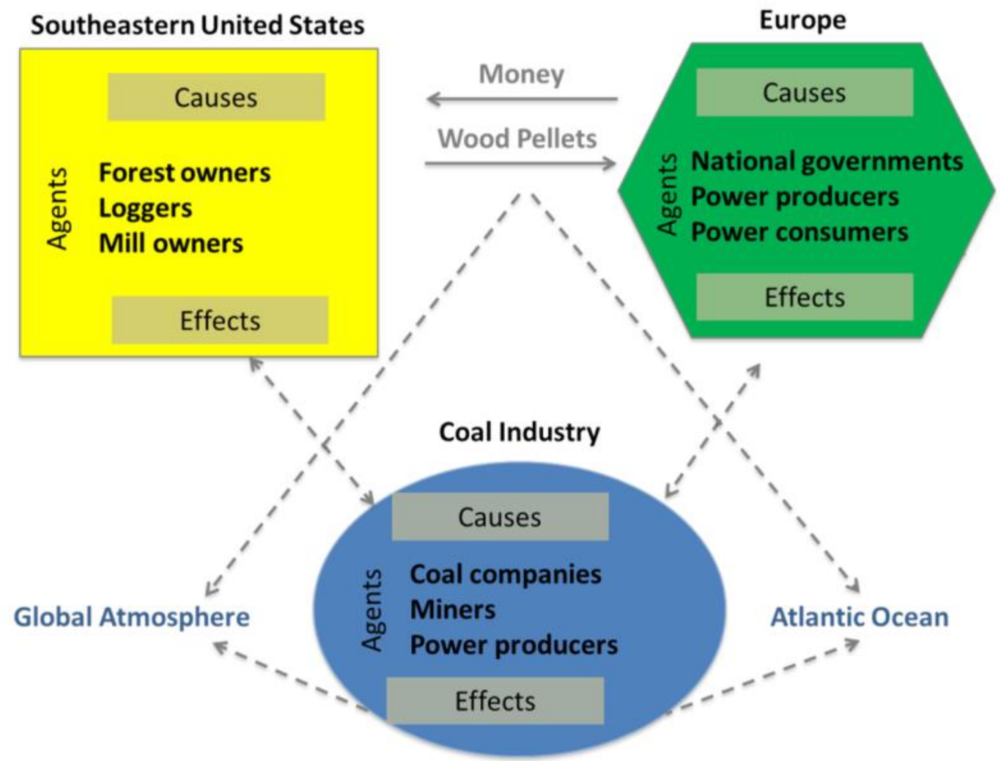
Figure 1 from V. Dale, E. Parish, K. Kline & E. Tobin (2017)

Telecoupling framework developed by Jack Liu* et al. improved our understanding of the sustainability of transatlantic wood pellet trade

System can provide benefits for both SE US & Europe.

- **Environmental benefits**
  - Enhanced management of SE US forests using income from bioenergy products can benefit water quality, biodiversity, carbon sequestration, & forest productivity
  - Reduction in
    - Toxic air emissions related to coal combustion
    - GHG emissions from energy production
    - Air pollution due to reduced burning of woody debris
  - Preservation of EU forest land & associated ecosystem services
- **Social economic benefits**
  - Additional market opportunity for woody biomass helps SE US land remain in forest
  - Avoided job losses in rural SE US & increased jobs in Europe
  - Reduced risk of wildfires due to increased forest management

Telecoupled wood pellet trade system



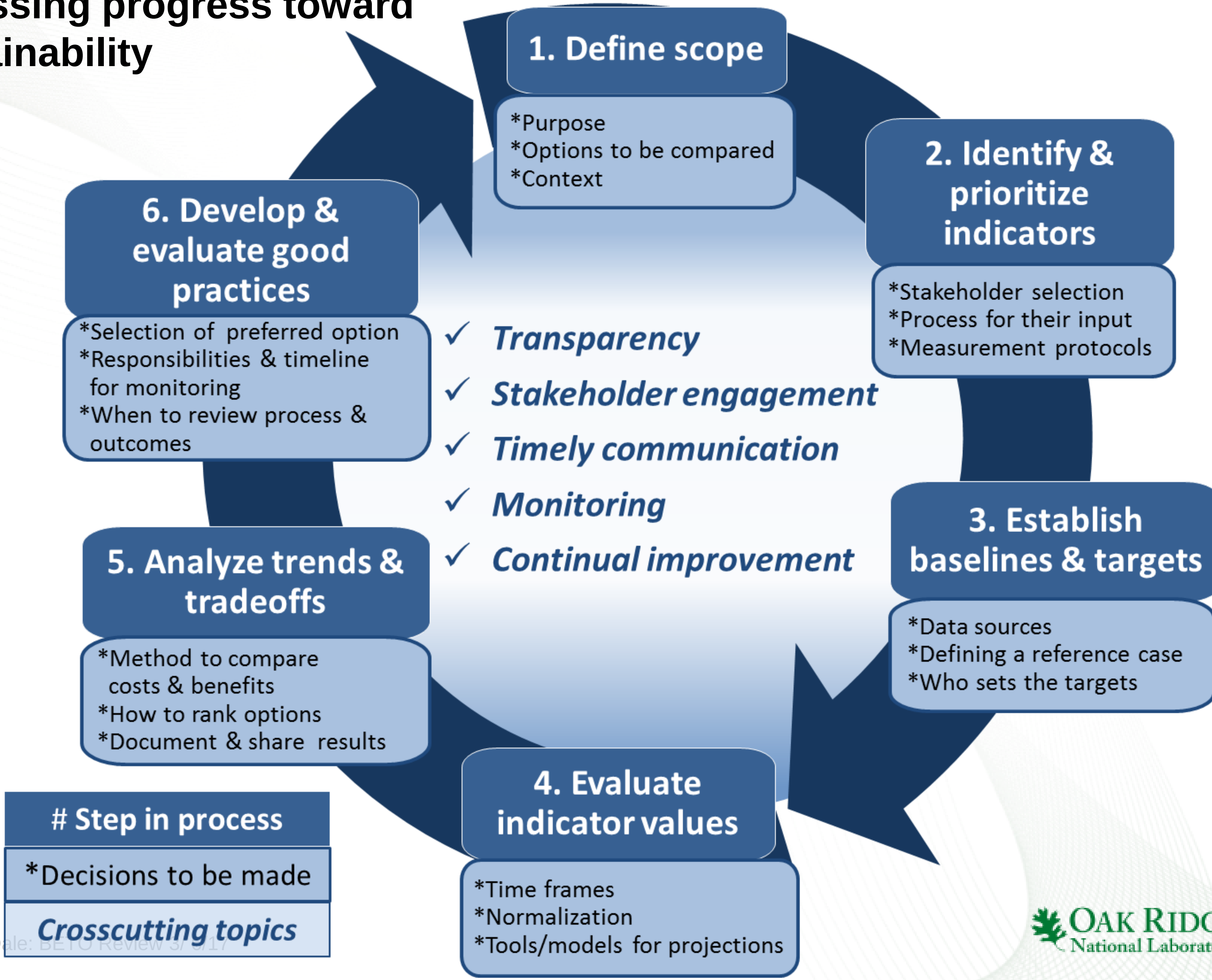
Parish, Herzeberger, Phifer, & Dale (in press) *Ecology & Society*

****Jianguo ("Jack") Liu leads the "Center for Systems Integration and Sustainability" at Michigan State University***

Oak Ridge National Laboratory

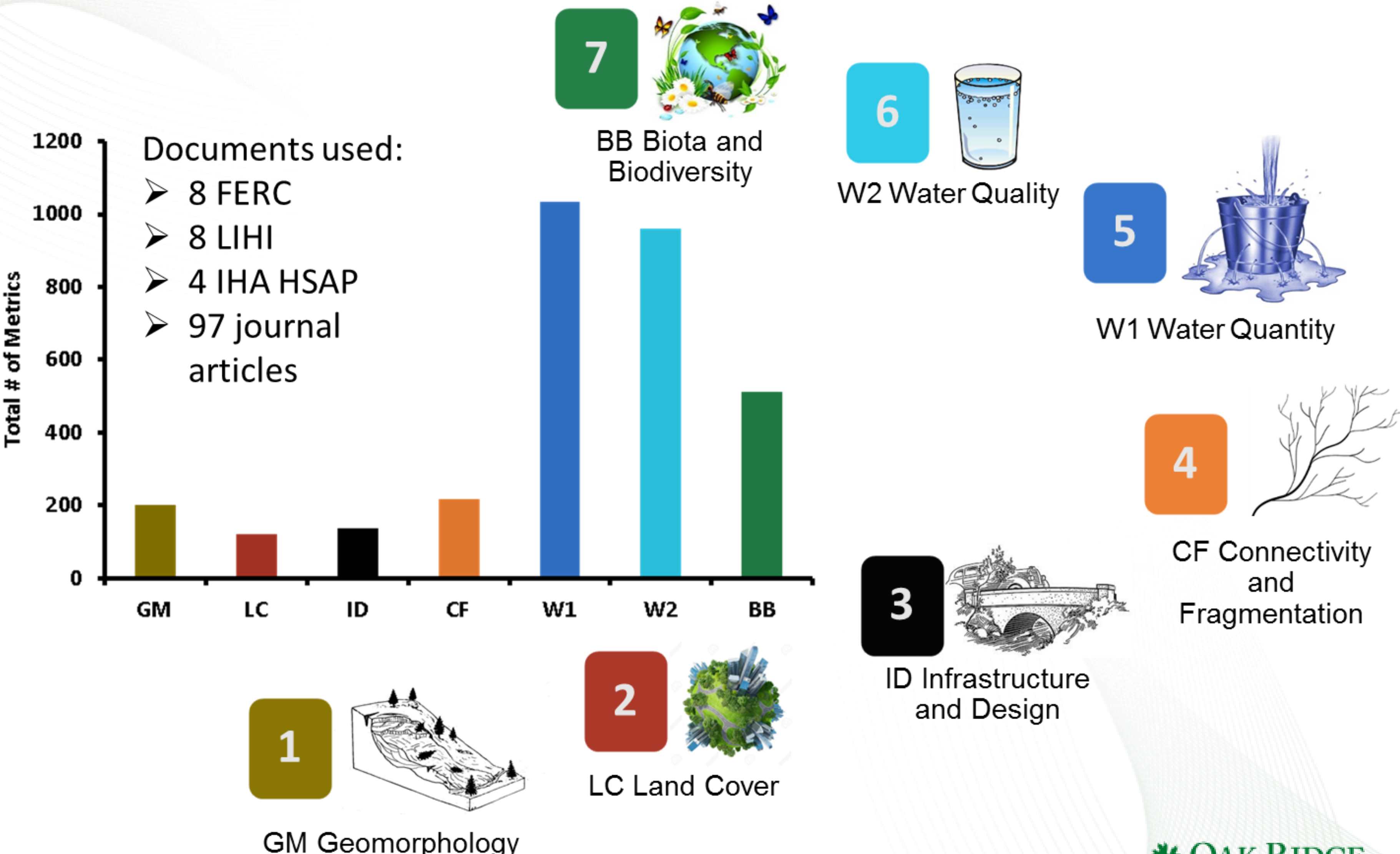
ORNL approach for assessing progress toward sustainability

Dale, Kline, Parish (in preparation)



OAK RIDGE National Laboratory

ORNL is using Sustainability Approach to develop a set of environmental metrics for hydropower



Thank you!
Questions?

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https://cbes.ornl.gov/

Publications and factsheets related to ORNL's Bioenergy Sustainability research

ACKNOWLEDGMENTS

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