Development of an Indicator Approach to Assessing Bioenergy Sustainability

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‘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

ORNL’s Bioenergy Sustainability Indicators
(35 indicators in 12 categories)

Recognize that measures and interpretations are context-specific

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


<table>
<thead>
<tr>
<th>Environment</th>
<th>Indicator</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil quality</td>
<td>1. Total organic carbon (TOC)</td>
<td>Mg/ha</td>
</tr>
<tr>
<td></td>
<td>2. Total nitrogen (N)</td>
<td>Mg/ha</td>
</tr>
<tr>
<td></td>
<td>3. Extractable phosphorus (P)</td>
<td>Mg/ha</td>
</tr>
<tr>
<td></td>
<td>4. Bulk density</td>
<td>g/cm³</td>
</tr>
<tr>
<td>Water quality and quantity</td>
<td>5. Nitrate concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>6. Total phosphorus (P) concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>7. Suspended sediment concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>8. Herbicide concentration in streams (and export)</td>
<td>concentration: mg/L; export: kg/ha/yr</td>
</tr>
<tr>
<td></td>
<td>9. storm flow</td>
<td>L/s</td>
</tr>
<tr>
<td></td>
<td>10. Minimum base flow</td>
<td>L/s</td>
</tr>
<tr>
<td></td>
<td>11. Consumptive water use (incorporates base flow)</td>
<td>feedstock production: m³/ha/day; biorefinery: m³/day</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Environment</th>
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</thead>
<tbody>
<tr>
<td>Greenhouse gases</td>
<td>12. CO₂ equivalent emissions (CO₂ and N₂O)</td>
<td>kgC_{eq}/GJ</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>13. Presence of taxa of special concern</td>
<td>Presence</td>
</tr>
<tr>
<td></td>
<td>14. Habitat area of taxa of special concern</td>
<td>ha</td>
</tr>
<tr>
<td>Air quality</td>
<td>15. Tropospheric ozone</td>
<td>ppb</td>
</tr>
<tr>
<td></td>
<td>16. Carbon monoxide</td>
<td>ppm</td>
</tr>
<tr>
<td></td>
<td>17. Total particulate matter less than 2.5μm diameter (PM₂.₅)</td>
<td>μg/m³</td>
</tr>
<tr>
<td></td>
<td>18. Total particulate matter less than 10μm diameter (PM₁₀)</td>
<td>μg/m³</td>
</tr>
<tr>
<td>Productivity</td>
<td>19. Aboveground net primary productivity (ANPP) / Yield</td>
<td>gC/m²/year</td>
</tr>
</tbody>
</table>

McBride et al. (2011) *Ecological Indicators* 11:1277-1289
### Categories of socioeconomic sustainability indicators

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

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

Sustainability Indicator relevance across Biofuel Supply Chain

Feedstock Production
- Resource Conditions
  - Extraction & Collection
    - Soil Quality
      - S
    - Water
      - A
    - Biodiversity
      - W
    - GHGs
      - B
    - Productivity
      - G
    - Profitability
      - P
  - Transport
    - Economic
      - S
    - Security
      - A
    - Trade
      - W
    - Acceptability
      - B
    - Resource Conservation
      - G
    - Wellbeing/Living
      - L
    - Social
      - R

Feedstock Logistics
- Harvesting & Collection
  - Processing
    - Fuel Type
      - A
    - Storage
      - A
  - Co-Products
    - Transport
      - A

Conversion to Biofuels
- Conversion Process
  - Engine Type & Efficiency
    - A
  - Storage
    - A

Biofuel Logistics
- Transport
  - Engine Type & Efficiency
    - A

Biofuel End-Uses
- Blend Conditions
  - Engine Type & Efficiency
    - A

Based on Efroymson et al. (2013) & Dale et al. (2013)
First case study: Switchgrass in east TN

- Parish (2016) Auburn Speaks: On Biofuels in the Southeast
5-year Vonore, Tennessee switchgrass-to-ethanol experiment

2,064 ha total

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?

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.

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

Qualitative ratings were developed for nearly all of the 35 sustainability indicators in all 12 categories.
We compared 3 agricultural scenarios

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

We aggregated the indicators within a hierarchical Multi-Attribute Decision Support System (MADSS) built with freely available DEXi 4.0 software.

Case study aggregation of qualitative sustainability indicators

**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 environmental, 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

The Netherlands halted US pellet imports (but UK pellet demand continued to grow)

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

EU renewable energy targets went into effect

EU renewable energy targets proposed

Collapse of US housing market

New stand-alone HTS code added for wood pellets

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

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


Telecoupled wood pellet trade system


*Jianguo (“Jack”) Liu leads the “Center for Systems Integration and Sustainability” at Michigan State University
ORNAL approach for assessing progress toward sustainability

1. Define scope
   - Purpose
   - Options to be compared
   - Context

2. Identify & prioritize indicators
   - Stakeholder selection
   - Process for their input
   - Measurement protocols

3. Establish baselines & targets
   - Data sources
   - Defining a reference case
   - Who sets the targets

4. Evaluate indicator values
   - Time frames
   - Normalization
   - Tools/models for projections

5. Analyze trends & tradeoffs
   - Method to compare costs & benefits
   - How to rank options
   - Document & share results

6. Develop & evaluate good practices
   - Selection of preferred option
   - Responsibilities & timeline for monitoring
   - When to review process & outcomes

**Crosscutting topics**

- Transparency
- Stakeholder engagement
- Timely communication
- Monitoring
- Continual improvement

# Step in process
- Decisions to be made
ORNL is using Sustainability Approach to develop a set of environmental metrics for hydropower.
Thank you! Questions?

ACKNOWLEDGMENTS
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Publications and factsheets related to ORNL’s Bioenergy Sustainability research

https://cbes.ornl.gov/