



Designing Landscapes that include Bioenergy Systems: Modeling and Trade-Off Analysis

Researchers in the Center for BioEnergy Sustainability (CBES) at Oak Ridge National Laboratory (ORNL) use models to explore questions related to landscape designs and trade-offs associated with bioenergy. Related Fact Sheets for Multi-metric Spatial Optimization and Indicators of Sustainability are at <http://web.ornl.gov/sci/ees/cbes/factsheets.shtml>.

Approach – Our approach to incorporating bioenergy systems into landscapes is built around a process that includes stakeholder engagement, clear definition of problem/goals, use of indicators to measure change, and ongoing monitoring and assessment. ORNL is collaborating with others to apply this approach to develop a set of indicators to help quantify socioeconomic and environmental sustainability associated with bioenergy systems (McBride et al 2011; Dale et al. 2013). The approach is applicable to agriculture, forestry and other land management systems to assess sustainability attributes of different management options in a given context. We build from concepts developed around ecosystem services as applied to agriculture (Dale and Polasky 2007) and efforts to move toward more sustainable, multi-functional landscapes (Dale et al. 2013). We recommend a multi-step approach to designing landscapes: i) defining sustainability objectives (for example, minimize wastes and increase efficiency) and constraints, ii) defining spatial decision variables, iii) solving to obtain a range of solutions, iv) analyzing trade-offs and complementarities (Jager 2013; 2014), v) extracting generalizable rules, vi) implementing selected solutions and vii) monitoring to guide further improvements over time.

Multimetric optimization – ORNL has tools for simultaneous environmental and economic decision analysis to help users understand the interaction between multiple aspects of sustainability in the context of renewable energy. One such tool, the Biomass Location for Optimal Sustainability Model (BLOSM) determines appropriate locations for perennial bioenergy crop to meet specified environmental and economic objectives. We used BLOSM to maximize (1) farmer's profit estimates by county and sub-basin as derived from the Policy Analysis System (POLYSYS) model, (2) crop yields from a national grid of switchgrass yield potential based on yield observations from field trials conducted across the US, and (3) effects on water quality and quantity simulated by Soil and Water Assessment Tool (SWAT). At a watershed scale, BLOSM identified locations for planting switchgrass that achieved different sustainability objectives sustainability locations for the Lower Little Tennessee watershed (see Parish et al. 2012 and Factsheet). At a regional scale, we determined which crop replacements would lead to the greatest improvement in water quality for each subbasin (Jager and Baskaran 2013). We are continuing to develop new tools for multimetric optimization by considering multiple objectives such as biodiversity and methods for generalizing results.

Examples of models and tools – ORNL has used several models to address questions about sustainability of agricultural systems.

- BLOSM (Biomass Location for Optimal Sustainability Model) – watershed/regional scale (Parish et al. 2012)

- POLYSYS (Policy Analysis System) - USA agriculture and forestry sectors used to develop the Billion-Ton Update <https://www.bioenergykdf.net/content/billiontonupdate> and subsequent analyses for USDA and DOE - partial equilibrium model, county, state, national scales
- GTAP (Global Trade Analysis Project general equilibrium model; see Oladosu et al. 2013) – global scale <http://www.sciencedirect.com/science/article/pii/S0301421513006319>
- Causal Analysis applied to land-cover change – borrowing from the set of tools developed for epidemiology to allocate attribution for a defined effect among different types and strengths of causal drivers (Kline et al. 2011; Efrogmson et al., in prep) – multiple scales
- EPIC (Environment Policy Integrated Climate) <http://epicapex.tamu.edu/epic/> and other biophysical models – traditionally run at plot to field scale, recently demonstrated for global scales (see Kang et al. 2014 and Kang et al. in review)
- SWAT (Soil and Water Assessment Tool) <http://swat.tamu.edu/> and similar hydrologic models (e.g., APEX).
- Indexed Decomposition Analysis: statistical approach to examine relationships among factors within a production or energy system (Oladosu et al. 2011)
- DELTA (Dynamic Ecological- Land Tenure Analysis) (Dale et al. 1994)
- RSim (Regional simulator) use to explore multiple resource use and constraints in a five-country region <http://www.esd.ornl.gov/programs/SERDP/RSim/>
- ORNL collaborated with NREL and others in early stages of development of BioLUC, a dynamic land change model based on the STELLA platform, available here: <https://github.com/NREL/bioluc>

References

- Dale, VH, O'Neill, RV, Southworth, F and Pedlowski, MA. 1994. Modeling effects of land management in the Brazilian settlement of Rondônia. *Conservation Biology* 8:196-206.
- Dale, VH and Polasky, S. 2007. Measures of the effects of agricultural practices on ecosystem services. *Ecological Economics* 64:286-296.
- Dale, VH, RA Efrogmson, KL Kline, MH Langholtz, PN Leiby, GA Oladosu, MR Davis, ME Downing, MR Hilliard. 2013a. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. *Ecological Indicators* 26: 87-102.
- Dale VH, Kline KL, Kaffka SR, and Langeveld JWA. 2013. A landscape perspective on sustainability of agricultural systems. *Landscape Ecology* 28(6); 1111-1123.
- Dale VH, KL Kline. 2013. Issues in using landscape indicators to assess land changes. *Ecological Indicators*. 28:91-99. <http://dx.doi.org/10.1016/j.ecolind.2012.10.007>
- Jager, H. and R. Martinez. 2011. *Bi-Annual Report 2010-2011: Shaping pulse flows to meet environmental and energy objectives*. ORNL/TM-2010/228. Oak Ridge, TN: Oak Ridge National Laboratory.
- Jager, HI and LM Baskaran. 2013. Forecasting Water Quality and Biodiversity. Presentation to DOE Biomass Energy Technology Office Programmatic Review, April, 2013.
- Kang, S., N. Singh, K.L. Kline, et. al. 2013. Global simulation of bioenergy crop productivity: analytical framework and case study for a perennial bioenergy crop - switchgrass. *GCB Bioenergy* (2014) 6, 14–25, doi: 10.1111/gcbb.12047
- Kline KL, GA Oladosu, VH Dale, AC McBride. 2011 (Oct). Scientific analysis is essential to assess biofuel policy effects, *Biomass and Bioenergy* 35 (2011). <http://dx.doi.org/10.1016/j.biombioe.2011.08.011>
- McBride, A, VH Dale, L Baskaran, et al., 2011. Indicators to support environmental sustainability of bioenergy systems. *Ecological Indicators* 11(5) 1277-1289
- Oladosu GA and Kline KL. 2013. “A dynamic simulation of the ILUC effects of biofuel use in the USA.” *Energy Policy*. <http://www.sciencedirect.com/science/article/pii/S0301421513006319>
- Oladosu G., K. Kline, R. Martinez and L. Eaton. 2011. Sources of Corn for Ethanol Production in the United States: A Review and Decomposition Analysis of the Empirical Data. *Biofuels, Bioprod. Bioref.* 5:640-653. <http://onlinelibrary.wiley.com/doi/10.1002/bbb.305/pdf>
- 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.

Points of Contact:

Virginia H. Dale dalevh@ornl.gov, Keith L. Kline klinekl@ornl.gov, Debo Oladosu oladosuga@ornl.gov, Esther Parish parishes@ornl.gov, Henriette I. Jager jagerhi@ornl.gov

Oak Ridge National Laboratory

P.O. Box 2008, Oak Ridge, TN 37831 USA

Center for Bioenergy Sustainability <http://www.ornl.gov/cbes/>