Using a Broad-scale Perspective to Address Changes in Land, Climate, and Energy

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A broad-scale perspective on the nexus between climate change, land use, and energy requires consideration of interactions that were often omitted from climate change studies. While prior analyses have considered how climate change affects land use and vice versa (Dale 1997), there is growing awareness of the need to include energy within the analytical framework. A broad-scale perspective entails examining patterns and processes at diverse spatial and temporal resolutions.

An example of landscape pattern effects arises from considering how siting a city changes the nearby rural landscapes and energy supplies and vice versa. An example of process effects is how fertilizer production and use that may be associated with the production of biofuels may alter nutrient cycling, aquatic system productivity, and sanitation at various scales. Past land-use patterns and practices affect current land-use opportunities. While this broad-scale perspective is critical for effective decision making, it is relatively new to environmental science and largely builds upon the data, geographic information systems, and models that are only recently becoming available. Some aspects of this interaction are presented here, but a more detailed discussion is provided in Dale et al. (in review).

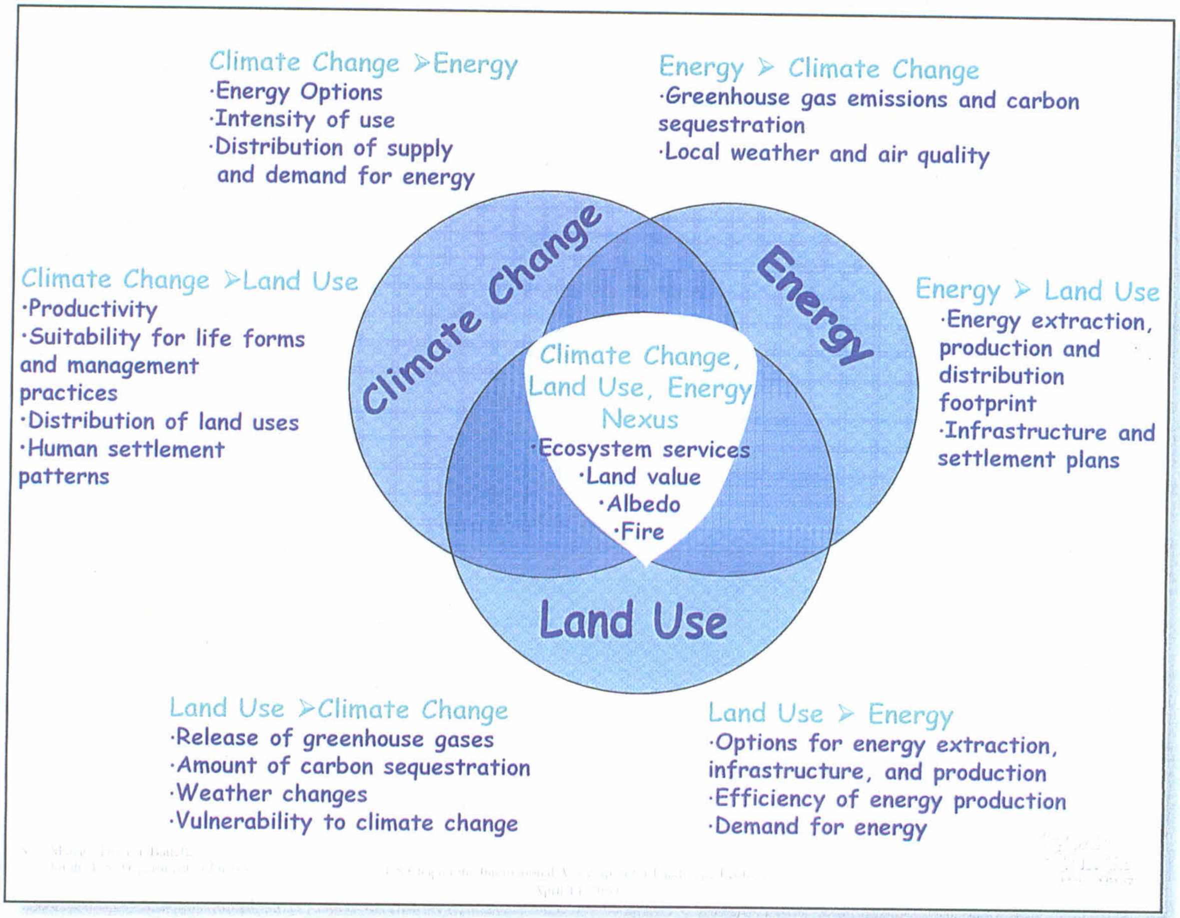
CLIMATE CHANGE and ENERGY

Interactions between climate change and energy are complex. Climate change affects energy via energy options, intensity of use, and distribution of supply and demand for energy. A direct influence of climate change on energy occurs via prevailing effects on energy demand, particularly in regard to climate control systems (i.e., heating and cooling) in most buildings and vehicles in the developed world. As climate changes over time in a certain area, so may energy demand. In the southeastern United States, for example, the use of air conditioning is likely to increase if the climate warms, and all climate change models project warmer temperatures for all months and all future years (IPCC 2007). The intensity of energy use may also change. As the climate gets physically warmer, air conditioning systems not only operate more frequently, but work harder to compensate for the larger temperature differentials between desired indoor temperature and outdoor temperatures. Operation of these systems pushes increasing amounts of waste heat into the local atmosphere, adding to urban heat sinks and to a cycle of increasing demand for air conditioning. Since current technologies for electricity production and cooling systems in the Southeast depend primarily on fossil fuels, the added requirements for fossil fuel combustion to support the increasing loads further exacerbates both heat emissions to the atmosphere from fossil fuel plants and the production of heat trapping greenhouse gases.

Energy use affects climate change through greenhouse gas (GHG) emissions and carbon sequestration, as well as local weather and air quality. An increasing concentration of GHGs in the atmosphere is attributed to human activities and is largely responsible for recent changes in the rate of climate change (IPCC 2007). Different energy options affect the atmospheric concentration of GHGs in different ways. The US National Research Council has noted that CO_2 is by far the largest single contributor to global climate change and is thus the focus of many mitigation efforts (NAS 2010). Nuclear and wind energy production have relatively little effect on CO_2 emissions; whereas fossil fuel combustion is responsible for the majority of global CO_2 emissions (80 - 92 percent) (Canadell et al. 2007, van de Werf et al. 2009, Le Quéré et al. 2009). There are many examples of how energy use can affect local land use, weather, and air quality, such as large hydroelectric projects that require an abundant water supply and can affect local groundwater tables and climate conditions.

LAND USE and CLIMATE CHANGE

Land use affects climate change via release of GHGs, impacts on albedo (reflectivity of Earth's surface), latent heat (flux of energy from Earth's surface to atmosphere associated with transpiration and evaporation), rates and amounts of carbon sequestration, and local weather changes. Land-use options are in turn influenced by changes in climate. While the land-use changes involved in conquering new frontiers (including resource extraction and deforestation) were historically a large contributing factor to GHG emissions and thus climate change, more recent models and bookkeeping calculations have



found that contributions to atmospheric CO_2 that derive from land-use changes—e.g. those associated with forest clearing (fires) and intensive agriculture—represented about 1.2 Pg C yr-1 or 12 percent of total anthropogenic CO_2 emissions in 2008 (Le Quéré et al. 2009). Furthermore, terrestrial systems including forests and croplands absorbed an estimated 4.7 Pg C yr-1 in 2008, or nearly four times more than the estimated land-use emissions (Le Quéré et al. 2009). The relative contributions to anthropogenic CO_2 emissions associated with deforestation have slowed considerably in the past two decades as fossil fuel use has risen and access to forests to exploit and clear has decreased due to several factors including improved policies and enforcement, and the diminishing area of natural forests. The major contributors to GHG emissions are fossil fuels, and their relative importance is likely to predominate until those resources also begin to run dry. Given the tremendous opportunity for land management to contribute to enhanced GHG sequestration, efforts to conserve remaining forest ecosystems, reforest, and improve management of other land areas merit priority attention when considering energy, land-use, and climate in an integrated manner.

Climate affects land use by means of its influence on productivity, suitability for particular life forms and management practices, frequency and intensity of major disturbances (floods, fires, droughts), and distribution of land uses and human settlement patterns. The climate of a particular area, combined with its soils, has great influence on how productive an area might be. That influence is often expressed through suitability of an area for certain life forms and for specific kinds of management practices. These considerations affect the distribution of land use as well as human settlement patterns. Human settlement is concentrated in the more habitable portions of the Earth, but areas suitable for human habitation are likely to change as climate changes.

ENERGY and LAND USE

Energy affects land use via the footprints and processes involved in energy exploration, extraction, production, and distribution as related to settlement patterns and infrastructure. Above and below-ground mining, for example, have very different effects on potential land uses in a region. Flooding for hydroelectric dams is another energy extraction process that greatly affects the land. In addition, infrastructure and settlement plans have historically been associated with energy developments ranging from suitable river sites for hydropower, to major mining towns in areas that would otherwise be unlikely candidates for habitation. The transportation infrastructure built to support oil and gas exploration and exploitation, for example, has often been the primary conduit for human colonization and occupation of areas that previously had been inaccessible forests and wild lands. Even today, in much of the developing world, a single road built through public lands and jungle to access a preferred site for hydro-electric or fossil fuel projects, or to establish transmission or pipelines for movement of energy products, creates a new opportunity for impoverished groups and others seeking land. A new road allows other products (timber and non-timber forest products, wildlife, etc.) to be extracted and sold and new settlers quickly clear and deforest areas to stake their claims. Over time, clearing and settlement patterns increasingly expand into the interior forests following the access provided by new road (and port) infrastructure.

As energy affects land use, land use also has impacts upon energy, specifically on our options for energy extraction, infrastructure, and production; realized efficiency; and demand for energy. In most countries, decisions about where urban lands are sited are based largely on historical settlement patterns initiated by transportation routes, trade routes, energy resources, and so forth, but not upon any strategic management plans based on available natural resources. The unplanned colonization and clearing that has followed road infrastructure into forests around new hydro-electric projects has often undermined the utility and useful life of the projects by accelerating erosion and sedimentation and affecting stream flows. The way land is used also affects the demand for energy; for example urban and industrial areas require more energy than rural areas. As another example, the delivery of energy in rural settings often involves long-distance travel to small populations.

THE NEXUS

The nexus of climate change, land use, and energy is what occurs at the center of these overlapping issues. There are four critical factors: ecosystem services, land values, albedo, and fire. Ecosystem services that occur at the center of the nexus include water quality and quantity, biodiversity, and air quality. Albedo, or surface reflectivity, is another integrating factor, for reflectance is changed by land-use practices and has an effect upon the energy as well as the climate of the Earth. Fire is also very much an integrating factor. Much of the land in the developing world is regularly burned for energy, heat, or, in some instances, as a way to have some control over the land, to establish ownership, for example. Another classic example of the energy, climate, land-use nexus is related to the use of biomass for domestic cooking fuel in poor urban centers. The need for this fuel contributes to the clearing of land near these centers, leading to increased demand for other sources of energy or charcoal (which is cheaper to transport longer distances), leading to further forest clearing and lower efficiencies.

BROAD-SCALE CHALLENGE

By focusing on the land-energy-climate change nexus, it is clearly not possible to make informed choices about where and how the environment is used without considering these three factors. However, in many situations, positive benefits of choices involving climate change, energy, and land use can be achieved with landscape design.

A key challenge we currently face is to identify the extent and location of underutilized, "available suitable" agricultural land, and the key policies and socio-economic conditions which influence management (or mis-management) of these lands. Definitions of which lands are "marginal" are inconsistent, in part because global data on land cover are incomplete and inconsistently measured and classified and in part because definitions vary depending on circumstances.

Another challenge is understanding indirect effects that may occur within the nexus. For example, global equilibrium economic models developed to understand trade among commodities have been used to estimate the indirect effects of bioenergy choices, but these models do not consider the many potential drivers of land-use change and cannot address how local politics, local lifestyles, road access, and local agricultural practices affect choices. Hence it is clear that there is a need for a variety of perspectives on the nexus, both global and local. A final challenge is documenting sustainability benefits and metrics for different energy and land-use options under specific climate conditions.

There are many contributions that a broad-scale or landscape perspective can make to the energy-climate change-land use nexus. In particular, policy makers and managers can tailor landscape designs to determine energy choices that are more likely to be robust and resilient in the face of uncertainties such as climate changes. The areas and types of land affected by any project should be characterized in terms of the potential effects upon ecosystem services.

Global changes in land use, climate, and energy that are induced by humans, when viewed from the perspective of process and pattern, can offer insight into climate change and dynamic approaches to meet energy needs in light of changes in land-use activities. There are complications and benefits of examining all three forces at once. Decision makers should use an integrated approach to consider the changes that can occur in climate, land use, and energy use, including their implications for the environment.

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REFERENCES

Canadell JG, Mooney HA, Baldocchi DD, Berry JA, Ehleringer JR, Field CB, Gower ST, Hollinger DY, Hunt JE, Jackson RB, Running SW, Shaver GR, Steffen W, Trumbore SE, Valentini R, Bond BY (2000) Commentary: Carbon Metabolism of the Terrestrial Biosphere: A Multitechnique Approach for Improved Understanding. *Ecosystems* 3:115-130.

Dale VH (1997) The relationship between land-use change and climate change. *Ecological Applications* 7:753-769.

Dale VH, Efroymson RA and Kline KA (In review) The land use – climate change – energy nexus. *Landscape Ecology.*

IPCC. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment. London: Oxford University Press.

Le Quéré C, Raupach MR, Canadell JG, Marland G, Bopp L, Ciais P, Conway TJ, Doney SC, Feely RA, Foster P, Friedlingstein P, Gurney K, Houghton RA, House JI, Huntingford C, Levy PE, Lomas MR, Majkut J, Metzl N, Ometto JP, Peters GP, Prentice IC, Randerson JT, Running SW, Sarmiento JL, Schuster U, Sitch S, Takahashi T, Viovy N, van der Werf GR, Woodward FI (2009) Trends in the sources and sinks of carbon dioxide. *Nature Geoscience* 2:831-836.

van der Werf GR, Morton DC, DeFries RS, Olivier JGJ, Kasibhatla PS, Jackson RB, Collatz GJ, Randerson JT (2009) CO_2 emissions from forest loss. *Nature Geoscience* 2:737-738.