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Viewpoint

Land Use as Climate Change Mitigation

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Mitigating climate change could be better achieved by regulating land use change than emissions reductions alone.


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As the international community works to develop a post-Kyoto framework for responding to climate change over the next several decades, policymakers should give serious consideration to broadening the range of management strategies beyond those conventionally defined as "mitigation". According to the Intergovernmental Panel on Climate Change (IPCC) mitigation concerns "implementing policies to reduce greenhouse gas (GHG) emissions and enhance sinks," thus strategies assume reductions in the atmospheric concentration of GHGs to be the sole mechanism through which ongoing changes in climate can be slowed or arrested (*1*). Under the current mitigation framework, non-emissions-related responses to climate change are characterized as adaptive to rather than preventive of warming phenomena and, as such, generally have not been prioritized in national and international climate change policy. However, an established body of evidence suggests that land use is playing a measurable and significant role in ongoing climate change at multiple geographic scales and through a set of mechanisms independent of GHG emissions (*2, 3*). In light of this evidence, a more comprehensive and, ultimately, effective framework for climate change management must respond to both the atmospheric and land surface drivers of warming. The development of such a framework will require not only a redefinition of the terminology employed in national and international agreements but a fundamental reassessment of the governmental structure through which the climate problem is best monitored and managed.

The significance of land use change to emissions of GHGs is well recognized, with approximately one-third of anthropogenic CO_2 emissions since 1850 attributed to land use activities (*4*). However, recent work suggests alterations in surface fluxes of moisture and energy resulting from land use activities may hold more direct implications for regional scale climate phenomena than associated changes in emissions. The extensive conversion of forested areas to cropland in the Amazon basin, for example, has been linked to markedly drier and warmer climates in that region (*5–7*); the impact of land use change on temperature was found to be comparable to that of GHG accumulation (*7*). Likewise, extensive deforestation in both tropical and higher latitude forests has been associated with reduced rainfall, reduced cloud formation, and enhanced shortwave radiative forcing and temperature (*8–10*). At larger geographic scales, analyses of surface and atmospheric temperature trends across the U.S. and China find land use change to have played an approximately equal or greater role in warming trends over the latter 20th century when compared to changes in atmospheric composition (*11, 12*). As concluded by a review in *Science* of this growing body of evidence "[a]long with the diverse influences of aerosols on climate. . . land use effects may be at least as important in altering the weather as changes in climate patterns associated with greenhouse gases" (*2*).

The influence of land use on climate is most pronounced at the scale of urbanized regions. Characterized as the "urban heat island effect", alterations in surface energy and moisture fluxes, combined with anthropogenic heat emissions, can enhance near-surface air temperatures by several degrees Celsius relative to proximate rural areas (*13*). Recent work has found the conversion of land from forest or cropland to urban uses to be associated with a greater average increase in minimum and maximum temperatures than rural land conversions (*14*). Further, cities have been found not only to exhibit higher temperatures than proximate rural areas but also to be warming over recent decades at a significantly higher rate (*11, 15–17*). While urbanized land accounts for only a modest fraction of the global land surface, a rapidly expanding urban population—now accounting for the majority of the global population (*18*)—is increasingly vulnerable to rates of warming exceeding that of the planet as a whole.

The influence of land use on climate change at the urban scale is clearly observed in temperature trend data for large U.S. cities. Figure 1 presents temperature anomalies (1951–1980 base period) for paired rural and urban weather

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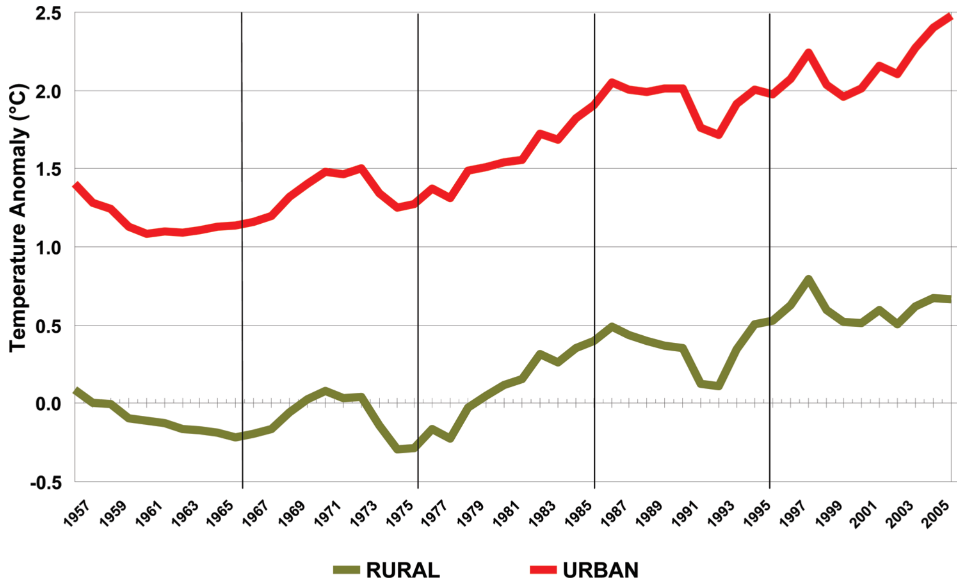

FIGURE 1. Urban and rural temperature anomalies (5 year means) for 50 large U.S. metropolitan regions over the period of 1957–2006. These data are updated from an earlier analysis covering the period of 1951–2000 (*17*) and include first-order weather stations from GHCN (v2). Each urban station is paired with three proximate rural stations. Urban and rural stations were selected based on population thresholds and night light intensities and have been fully corrected for standard inhomogeneities, with the exception of an urban correction. Note that average anomalies computed for years following 2002 reflect less than five years of observations (*19*). These data were obtained from the NASA Goddard Institute of Space Studies. For a complete description of this analysis, see ref *17*.

stations in proximity to 50 of the most populous U.S. metropolitan areas between 1957 and 2006. These data are compiled from weather stations included in the Global Historical Climatology Network (GHCN) and adjusted for standard inhomogeneities, with the exception of an urban correction. Figure 1 attests to the significance of land use to climate change in two respects. First, at any point in time, urban weather stations are 1.2–1.8 °C warmer than proximate rural stations. The mean difference between urban and rural anomalies in any period is greater than the magnitude of the rural anomaly, suggesting that land use may be playing a more significant role in the warming trends of cities than the emissions-related effects present in both trends. Second, the mean decadal rate of warming across the urban stations is significantly higher than that of rural stations. Averaged over the full period, the mean decadal rate of warming for urban stations was found to be 0.08 °C higher than that of rural stations. This average rate of heat island growth—i.e., urban warming in excess of the rural trend—rises to 0.20 °C/decade over the most recent 20 years of observation.

The increasing divergence between rural and urban temperature trends in U.S. cities highlights the limitations of a climate policy framework focused on emissions reductions alone. If land use change is the dominant agent of climate forcing at the urban scale, Kyoto-based emissions trading schemes may fail to sufficiently safeguard human health in the most heavily populated regions of the planet. It is important to emphasize, however, that the phrase "urban heat island effect," much like the phrase "greenhouse effect," is a misnomer (Box). The physical mechanisms underlying warming trends in cities are limited neither to urban areas nor to small geographic regions. Rather, changes in surface moisture and energy balances accompanying land conversion processes across large swaths of the planet's land area are giving rise to changes in climate that may be of the same order of magnitude as changes brought about through the emission of GHGs. As such, the urban heat island effect should be understood to be only the most visible manifestation of a larger phenomenon occurring across multiple geographic scales—a phenomenon better characterized as a "green loss effect" than as something unique to urban areas.

> The phrase "greenhouse effect" is widely observed to be a misnomer due to the differing heat transfer mechanisms at work within the atmosphere and within the glass enclosure of a greenhouse. As explained by Burroughs, "The principal mechanism operating in a greenhouse is not the trapping of infrared radiation but the restriction of convective losses when air is warmed by contact with ground heated by solar radiation" (*20*).

Widely published evidence of the climate forcing effect of land use at urban, regional, and subcontinental scales strongly militates for a broadening of national and international climate management programs to encompass both the atmospheric and land surface drivers of climate change. The next round of international climate negotiations to take place in Copenhagen in December 2009 presents a critical opportunity to formally redefine mitigation along these lines and, in so doing, to develop an entirely new and complementary thrust in climate change management activities.

A key challenge posed by the broadening of mitigation strategies to encompass land use practices concerns the appropriate level of governance for policy development and implementation. If GHG emissions are understood to be the sole driver of climate change, international governance is recognized as needed due to the globally diffuse nature of the greenhouse effect. By contrast, the more regionalized impacts of land use on climate, as presently understood, have the effect of more directly localizing the benefits of land-based mitigation, potentially weakening the rationale for international cooperation in this area.

Yet, policies concerning land use change are needed at the international level for several important reasons. First, global commodities markets often provide the impetus for large scale land conversions to support agricultural or energy exports. The assessment of climate tariffs on land intensive exports through international agreements, for example, could provide a powerful tool for limiting surface climate forcing. Second, most forms of land-based mitigation carry direct co-benefits for emissions control. Containment of metropolitan decentralization, for example, has been shown both

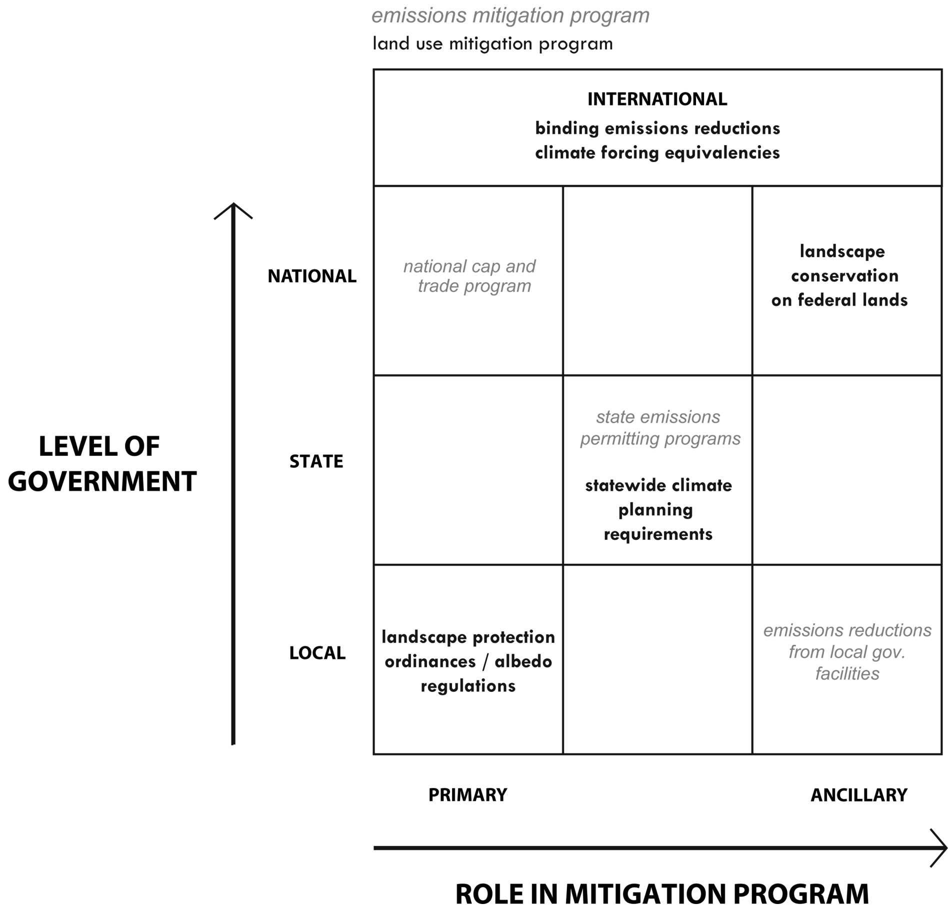

FIGURE 2. Proposed implementation framework for land-based mitigation in the U.S. context. Administrative responsibilities for an emissions mitigation program are presented in gray text, and administrative responsibilities for a potential land-based mitigation program are presented in black text. The horizontal axis displays the primacy of each governmental level in program administration, with the federal government principally responsible for the development of a national carbon trading program, while local governments assume principal administrative responsibility for the development of land-based mitigation programs. The vertical axis displays the level of government associated with each program element. International agreements establish the goals for both types of mitigation programs but are external to program implementation.

to preserve regional vegetative cover (*21*) and to significantly limit the growth of CO_2 emissions associated with transportation (*22*).

Two administrative challenges, in particular, must be addressed in the development of an international land-based mitigation framework. The first concerns the establishment of climate forcing equivalencies by an international body, such as the IPCC, through which the global warming potential of specific land cover changes (per hectare) is equated with the global warming potential of carbon emissions (per tonne). The development of such equivalencies is needed to enable a land-based mitigation program to function within the established framework of existing climate management programs, which employ carbon emissions reduction as a standardized metric for compliance with international agreements. While the degree to which land cover management can mitigate surface climate forcing varies by physiographic and climatic region, and by the management strategies employed, scientific understanding of surface energy budgets, as well as the instrumentation to measure surface energy and moisture fluxes, is sufficiently advanced to support the promulgation of such equivalencies.

Second, the development of a land-based mitigation framework for maximal benefit would require in many countries a governmental administrative structure different from that employed in cap and trade programs. For example, while the U.S. federal government is empowered to regulate industry directly, federal control of land use activities on private property is greatly limited. In general, the power to regulate land use resides with state and local governments, depending on the applicable property laws and other relevant state/municipal practices.

Presently, local government capacity is largely unharnessed in climate management structures under consideration by the U.S. Congress. Cap and trade programs establish a top-down implementation framework, through which the federal government sets emissions reduction mandates by industrial sector and relies on state governments for the administration of emissions permitting programs. Presumably, municipal and county governments have only a limited role—e.g., reducing emissions from municipal facilities—in such a management structure. Yet local governments possess extensive powers to manage the land use activities underlying surface climate forcing, in both urban and rural contexts. The development of a framework to more fully exploit these powers would better harness overall national governing capacity to manage climate change and may further reinforce the workings of emission reduction programs if co-benefits from land-based mitigation (e.g., carbon sequestration) are realized.

Figure 2 presents a potential governance structure for a mitigation framework responsive to both the atmospheric and land surface drivers of climate forcing. The actions appearing in gray text illustrate the general emissions management framework instituted by the Kyoto Protocol and those presently under consideration by the U.S. Congress.

Through this framework, binding targets for emissions reductions are put in place through international agreements. Then national governments establish programs to achieve these reductions, with state and local governments playing a more limited or ancillary role. While such a top-down structure is suitable for a national cap and trade program, it is ill-suited to land-based mitigation in the U.S. context, as the primary authority for regulating land use resides with local and state governments.

The actions presented in black text illustrate a potential structure for a land-based mitigation framework. The land use planning activities of municipal and county governments, with the exception of federally managed lands, provide the most direct regulatory means of managing surface energy and moisture fluxes so as to minimize land-based climate forcing. State governments can play a central role in such a framework through requiring all municipal and county governments to develop land-based mitigation programs: the framework is thus best understood as a bottom-up administrative structure. In a rural context, such activities may take the form of forest restoration or incentives for crop rotation practices designed to limit sensible heat transfer. In an urban context activities may take the form of enhanced tree protection ordinances or albedo requirements enacted through building codes. In reversing the primary administrative jurisdiction from local to state to federal, the coupling of a land-based mitigation framework with a conventional emissions mitigation framework more fully marshals the capacity of government at all levels to manage the climate change problem.

Most importantly, the recognition of land use mitigation in international agreements could render more effective programs for emissions reductions by expanding the range of mitigation activities. The promulgation and standardization of climate forcing equivalencies by international bodies would provide signatory nations greater flexibility to meet binding reduction targets. This approach has the inherent advantage of maintaining CO_2 as the global currency of climate change management, while an expanded array of mitigation activities may enhance the political feasibility of more aggressive reduction targets. At the very least, land-based mitigation may provide the most viable mechanism for addressing the likely shortfall between the emissions reductions *required* to avert catastrophic warming and the emissions reductions *achievable* through the international political process.

Such an approach may prove particularly advantageous in broadening international participation in climate change mitigation programs. Largely limited to CO_2 control strategies under the present climate management framework, developing nations often lack the technological means to achieve significant emissions reductions. In such nations, large scale reforestation programs, if recognized through international agreements to generate benefits in the form of climate regulation, could attract significant international investment. The availability of remote sensing tools to monitor compliance with land-based mitigation agreements may render this approach more easily enforceable than carbon reduction agreements.

Land-based mitigation strategies further hold the potential to yield measurable climatic benefits over the period of one or two decades, in contrast to the much longer time period generally required for CO_2 to cycle through the atmosphere. At the urban scale, as indicated by the data presented in Figure 1 and elsewhere (e.g., ref (*23*)), urban governments may realize greater success in offsetting warming trends over the near term through strategies designed to restore predevelopment moisture and energy balances than through emissions reductions alone. Aggressive vegetation and, in lower latitudes, albedo enhancement strategies must be recognized as a primary form of climate change mitigation in urban environments. Similarly, at the scale of regions, extensive reforestation efforts hold the potential to restore moisture and energy balances to predisturbance levels over a time scale measured in decades rather than in centuries (*24*).

Finally, international consensus on the scientific basis for climate change, including both the atmospheric and land surface agents of climate forcing, is critical to stimulating action at all levels of government. Despite compelling evidence that land use is having a more profound effect on the climates in which the majority of the U.S. population presently resides, climate management policies at all jurisdictional levels in this country are almost exclusively oriented toward emissions controls. This focus demonstrates the effectiveness of international climate accords in shaping domestic policy. Thus, in this period of an emergent post-Kyoto framework negotiation, a formal redefinition of climate change mitigation that encompasses land use strategies will provide an essential first step in combating the growing challenge of climate change on all fronts.

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