WORLD RESOURCES INSTITUTE

POLICY BRIEF

UNDERSTANDING THE ANCILLARY EFFECTS OF CLIMATE CHANGE POLICIES: A RESEARCH AGENDA

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EXECUTIVE SUMMARY

Climate change policies are commonly evaluated on their potential to reduce greenhouse gas (GHG) emissions. They also have potential indirect or ancillary effects on various sectors such as public health, transportation and ecosystem health. It is important to understand the magnitude of ancillary effects of climate change policies in order to have a more complete picture of the potential consequences they have for the environment and the economy.

The purpose of this research agenda is to provide guidance both to potential sponsoring agencies and to the research community on issues that are important for understanding the ancillary effects of policies on climate change. The agenda originated from an Intergovernmental Panel on Climate Change (IPCC) workshop and encompasses a review of relevant recent literature. The workshop was organized by the Organisation for Economic Co-operation and Development (OECD), Resources for the Future (RFF), and the World Resources Institute (WRI), and was sponsored by the US Environmental Protection Agency (EPA).

Most of the research to date on ancillary effects of climate change policies focuses on their potential human health consequences. While methodological improvements are desirable, the knowledge base for developed countries is reasonably adequate. There are, however, serious data gaps in understanding the broad array and large number of ancillary health effects of climate change policies in developing countries.

The transportation sector is an important research area in terms of ancillary effects of climate change because it is a major contributor to carbon emissions. Research priorities are concentrated in the area of transportation technologies themselves, but also include filling in data gaps regarding baseline changes in the transportation sector.

The ancillary effects of climate change policies on ecosystems and more generally, on land-cover and land-use, are probably the least studied of all sectors, but understanding them is at least as important. Ecosystems are more difficult to consider in policy analysis because there may be no direct economic value associated with the services they supply. Research priorities include developing case studies and models to examine the links among climate change policies, pollution, human exploitation and ecosystems.

INTRODUCTION TO ANCILLARY EFFECTS

Changes in the Earth's climate are inextricably linked to human welfare, both through direct effects on the weather and climate, and indirectly through effects on other sectors: agriculture, forestry, water resources, and natural ecosystems, to name but a few. One of the inherent difficulties in documenting and understanding climate change is that climate and its consequences vary on a wide range of time scales: seasonal-to-interannual, decadal, and even over centuries and millennia. Disentangling the natural variation in climate and its consequences from the variation due to direct human influence is an enormously challenging task.

In its last scientific assessment of climate change, the Intergovernmental Panel on Climate Change (IPCC) reached several important conclusions (IPPC 2001a, b, and c). First, there is now a strong consensus that the available records of the physical climate itself show change over the period of roughly the last 150 years, particularly when compared to very long-term records from other proxy measurements, such as tree-rings and ice cores.

Second, there is a consensus within the international scientific community that the recent change in climate can be reasonably attributed to human influence. Third, the world is beginning to see changes in ecological and biological systems that are the result of changes in climate over the past several decades to a century. But even with a growing international consensus that climate change has already occurred, that it is likely due in part to human activities, and that we are beginning to see its consequences, the ability to forecast with high reliability what the future might hold for climate and its consequences is still limited. There are many reasons for this, including methodologies that are insufficiently powerful, the inability to predict precisely what emissions trajectories will be, and the lack of experimental and physical understanding of such phenomena as the radiative effects of aerosols and the quantitative response of ecosystems to increased concentrations of atmospheric carbon dioxide (IPCC 2001b). There are also methodological difficulties in disentangling the potential consequences of changes in climate from the potential consequences of changes in land-use, or from changes in the natural dynamics of ecosystems and climate. Analyses of potential impacts of climate change and the resulting consequences for policy audiences therefore must at some level be scenario-based, and use the best available scientific understanding to show what might happen, and to identify the degree of uncertainty associated with both methods and data.

The analogous problem exists for understanding the potential costs, benefits, and effectiveness of climate change policies. Policies that are designed to cap or reduce the emissions of greenhouse gases (GHGs), i.e. mitigation policies, are inextricably linked to economics and the environment at global, national, and regional scales. Adaptation policies that are designed to foster the adjustment of societies to the consequences of climate change that cannot be avoided are also inextricably linked to economic, land-use, ecological, and health issues at global, national, and regional scales. The existence of linkages between mitigation and adaptation policies and other policies and practices affecting energy, economics, and the environment has been recognized for several years (Watson et al 1998).

The effects of climate change mitigation policies on issues such as health, ecosystems, transportation, and land use are known as ancillary effects because they lie outside the realm of primary policy concern. Likewise, the consequences of climate change adaptation policies for other sectors and issues can also be thought of as ancillary effects. It is important to understand both the scope and magnitude of ancillary effects of climate change policies in order to have a more complete picture of the overall consequences such policies might have for the environment and the economy, should they be implemented. Failure to incorporate ancillary effects at all in policy analysis could potentially lead to significant errors in understanding the true range of costs and benefits of any particular policy, and therefore lead decision-makers astray.

A Framework for Analysis of Ancillary Effects

The importance of ancillary effects of GHG mitigation policies as a part of the climate change discussion demands an increased focus on the means of analyzing these effects. In order to use the results of ancillary effect research in policy formulation, a consistent conceptual framework needs to be developed. However, as Krupnick et al. (2000) indicate, while methodologies should be consistent, estimates will not necessarily be. Estimates can legitimately vary between studies, as the policy context may vary.

Climate mitigation policies operate through an economic and institutional system within a country that leads to reductions in GHGs, changes in other pollutants, and mitigation costs. The emission changes work through an ecological or environmental system that eventually feeds back into the economic system. Then, depending on conditions of the economic system and its institutions, such as labor markets, tax systems, existing environmental and other types of regulations these feedbacks may become environmental externalities (such as changes in conventional air or water pollution), non-environmental externalities (such as employment effects) and, of course, climate change externalities (such as leakage of carbon emissions). Ultimately, and from a country's efficiency perspective only, the net ancillary benefits/costs may be compared to mitigation costs and direct mitigation benefits, usually understood to be equivalent to the avoided costs of climate effects.

An analogous situation pertains to climate adaptation policies. These policies operate through their effects on underlying institutions, their practices, and economic systems within and between countries. Changes in ecosystems, natural resources, or health that result from these policies eventually feed back, in part, through those economic systems and institutions. As with mitigation policies, adaptation policies may also have environmental externalities, non-environmental externalities, and climate change externalities. The net effects of adaptation policies are therefore the combination of the direct costs and benefits of such policies with respect to climate change and the various externalities, analogous to the analysis of mitigation policies.

A key element of this schematic is the central importance of the economic system and institutions. This argues against the methodology used in early ancillary effects analyses, which implied fixed coefficients between greenhouse emissions and other effects. Different technological and regulatory structures, and differences in economic parameters, will make these relationships situation-dependent. For example, Barker and Rosendahl (2000) showed that changes in assumptions about the future price of oil can drastically change the measurement of ancillary effects as higher prices will themselves drive many of the improvements which climate change policies might support. Similarly, changes in the prices of agricultural commodities, which may occur for many reasons, will clearly affect the net effects of climate adaptation policies directed towards the agricultural sector.

The economic system and institutions are also important at the other end of the feedback loop. Health systems, consumer preferences and many other factors will have an impact on the effects and valuation of policy effects. The central importance of the economic system and institutions adds considerable complexity to the analysis of ancillary effects, and has implications for the types of analysis chosen. This raises questions of balancing analytical completeness with the need to limit the time and resources spent on analysis. Development of the analytic baseline—which includes projections of many of these institutional parameters—is clearly a vital element in analysis of ancillary effects.

Theory and Methodological Research Needs

The discussion above highlights three initial research needs, to which we will add a fourth. The first is the need for careful definition of the analytical scope of the research. In other words, the researcher must carefully define the scope of his/her analysis in order to have a consistent definition of which policy consequences will be calculated as direct and which will be assessed as ancillary. It can, however, make comparisons difficult across studies, especially if the definitions used by different researchers are so disparate that they cannot be reconciled. Because the international debate on climate mitigation and adaptation policies depends in part on being able to make such cross-cutting comparisons, the importance of consistent definitions is critical. The development of checklists for main effects and ancillary effects on which policy analysts can reach consensus is thus an important step for future research efforts.

The second methodological need is already well-known: an increased ability to express the non-market costs and the benefits of mitigation and adaptation policies in terms that can be incorporated into policy analysis. This problem is particularly acute in studies focusing on natural resources and ecosystems, which have values whose prices in markets are either not well-quantified or not easily captured. This problem bedevils analyses of ancillary effects of climate change policies equally as much as it does studies of other policies that govern the use of natural resources and the maintenance of biological diversity. It is beyond the scope of this paper to address all the research issues associated with improving the quantification of ecosystem goods and services.

Morgenstern (2000) has identified a third, less well-explored problem: identifying appropriate time-dependent baselines against which to measure ancillary effects. The underlying issue is relatively simple: to determine the benefits (or costs) of a specific policy, the researcher must model and compare two scenarios:

- What the world would be like with the new policy in place, and
- What it would be like without it (business as usual).

While simple in concept, these two scenarios are difficult to model in practice. They demand models or quantitative analyses that can generate reasonable time-series of cost and benefit information, depending on assumptions about the underlying economic and institutional systems through which the policies operate, as well as the physical and ecological systems they are meant to affect. Few ancillary effects studies have approached this level of sophistication, and investigated how the benefits (or costs) are expected to deviate from baseline levels in the absence of climate mitigation and adaptation policies.

The fourth research need is to look more closely at the impact on ancillary effects in developing countries. Most ancillary effects studies have taken place in Europe or the US. But because of the global nature of climate change, the geographic differentiation of potential climate consequences, as well as the geographic differentiation of regional economies, and the transboundary consequences of many of the ancillary effects of climate change policies, such as changes in air pollution, more work needs to be conducted in other parts of the world. Asymmetries in adaptive capacity between developed and developing countries make it imperative to consider the potential geographic consequences of both mitigation and adaptation policies.

Research Priorities

The initial recommendations for methodological and theoretical research are outlined below.

- Develop case studies in such a way that consistent and detailed checklists of main effects and ancillary policy effects can be agreed to by researchers. These checklists could be further developed through software that identifies likely ancillary effects of particular types of policies (Davis et al. 2000a). Because of the wide array of policies around the world, the checklists will need to be flexible, yet still have consistent endpoints. The use of checklists will help to ensure more systematic consideration of ancillary effects.

- Improve analytical tools and methods to address the valuation of policy effects that are either not captured well in markets, e.g. the provision of freshwater by healthy ecosystems, or are not currently valued in markets, e.g. the maintenance of biological diversity.

- Devise explicit specifications of baseline conditions for analysis relevant to policy, technology, demography, and other crucial factors. Specifications of baselines should enable calculations of alternative policy scenarios so that ancillary benefits may be estimated over time (Morgenstern 2000).

- Expand studies to examine ancillary effects in developing countries. Improving the spatial detail of current models, for example, would assist policy makers in differentiating the economic or ecological consequences of policies at regional and/or sub-national scales.

Human Health Research Needs

Most of the current research done on the ancillary effects of climate change policies focuses on the potential human health consequences. Global climate change may have a wide range of impacts on human health throughout the world (IPCC 2001b). Effects range from thermal stress (deaths due to extreme cold or heat), extreme weather disasters such as floods and storms, air pollution, the spread of infectious diseases, waterborne disease, food yields and nutrition, and demographic and economic disruptions (IPCC 2001b). In this section, we will focus on air pollution, water issues and the spread of vector borne infectious diseases as specific examples of the broader suite of health-related issues.

Air Pollution

Current health-related air pollution problems are greatest in cities of developing countries, but continue to be of concern in developed countries (IPCC 2001b). Actions taken to reduce GHG emissions are very likely to have a positive impact on human health conditions throughout the world (IPCC 2001b). Mitigation policies dealing with reduced vehicular traffic and emissions (*See Box 1*), and those increasing the efficiency of indoor cookstoves will yield great benefits to health (IPCC 2001b).

As discussed in Davis et al. (2000b), most work on public health ancillary effects done to date has focused on risk assessments for air pollution changes. Many of the major effects of particulate matter (PM) and ozone (O_3) can be addressed quantitatively. For example, recent research done in Los Angeles, California has linked O_3 pollution not only to asthma attacks, but to new asthma cases (McConnell et al. 2002). However, there are some less severe effects that can affect many people but have not yet been quantified. In addition, the likely varying of PM toxicity by source (e.g., biomass burning vs. coal burning) is not accommodated by the presently available methodologies. For an expanded list of human health effects of air pollution, see Table 1.

Adequacy of Available Public Health Impact Evaluation Applications. There are many studies showing that there are indeed ancillary benefits to public health when GHG emissions are reduced. Although it is beyond the scope of this paper to do an exhaustive literature review, the following provide representative examples.

A recent study evaluated the reductions in adverse health effects that might be achievable over the next two decades in Mexico City, Mexico, New York City, USA, Santiago, Chile, and São Paulo, Brazil (Cifuentes, et al. 2001).Using projected emission patterns in these cities, and by applying health impact factors

Box 1 Transportation Sector Research Needs

Carbon dioxide emissions from transportation are expected to be 40% higher in 2010 than they were in 1990 in the European Union while US growth rates could be 28 percent or higher in 2010 than they were in 1990 in the European Union while US growth rates could be 28 percent or higher (DeCicco and Mark 1998 cited in Proost 2000). The growth of extremely large cities, the concentration of population within them and the surrounding sprawl make the resolution of transportation issues one of the most important environmental and quality of life concerns in much of the world.

The types of policies that can be applied to the transportation sector include GHG mitigation policies that apply directly to what types of vehicles and fuel are used and adaptation policies that include various ways to deal with congestion; improving mass transit, incentives for carpooling and fees for entering city centers (Bose 2000), to list a few. Ancillary benefits associated with these mitigation and adaptation policies are realized in the shape of reduction in air pollution and the resulting human health benefits. There is also investigation into the effects on economic and welfare categories including road surface maintenance expenditures, traffic noise, and congestion (Barker 1993).

The determination of the baseline of changes in transportation systems against which the ancillary effects of climate change policies may be measures is of considerable importance, yet very poorly understood. Most studies estimating ancillary effects of transportation sector policies have been conducted in the US and Europe. In OECD countries, they are generally though to consist of reduced congestion, with lesser benefits coming in the form of few accidents and reduced air pollution. Developing countries on the other hand are, in general, starting at a somewhat higher pollution baseline, making the ancillary health benefits seen there greater than in developed countries.

Aviation is another form of transportation we also need to consider. The IPCC has prepared a special report, Aviation and the Global Atmosphere, which includes a comprehensive review of the potential impacts of aviation on the climate system (IPCC 1999). Studies by the IPCC (1999) and recent experience in both Europe and North America indicate that the air traffic system is reaching saturation. According to these studies, although improvements in aircraft and engine technology and in the efficiency of the air traffic control system will bring environmental benefits, these will not fully offset the effects of increased emissions from the projected growth in aviation.

Research Priorities

The major priorities for research in studying ancillary effects in the transportation sector are:

- Enhance current transportation technologies and compare the next generation vehicles and fuel choices to existing technologies;
- Develop a more sophisticated and complete accounting of the baseline changes in the transportation sector against which changes due to climate change policies could be assessed especially in developing countries;
- Investigate the relationship between GHG mitigation and economic and health costs of traffic congestion, and its consequences;
- Understand better the patterns of consumer/traveler behavior in developed and developing countries. Research on this topic in the developing world is virtually non-existent. Modelers will need information on elastcities of transport demand, and well-designed case studies; and
- Investigate and test the policy options related to the aviation industry such as market-based options like environmental levies and emissions trading.

to population distributions for the time period 2001-2020, health benefits of using existing, readily acquirable technologies that reduce GHG emissions were calculated. They found that adopting readily available technology in these 4 cities could reduce PM and O_3 concentrations and avoid approximately 64,000 premature deaths, 65,000 chronic bronchitis cases and 46 million person-days of work lost. These findings illustrate that GHG mitigation can provide considerable local public health benefits from air pollution reduction alone to countries that choose to abate GHG emissions by reducing fossil-fuel combustion.

A World Health Organization (WHO) study in Austria, France and Switzerland showed that traffic-based air pollution leads to increases in developmental defects, allergies, lung cancer, and emergency response time. For example, long term air pollution triggered an extra 21,000 premature deaths per year from respiratory or heart diseases in these countries which is more than the total number of annual deaths from traffic accidents. In addition, the WHO found that air pollution from cars lead to 300,000 extra cases of bronchitis in children, 15,000 additional hospital admissions for heart disease, and 162,000 asthma attacks in children in these three countries (WHO 2001).

Despite the amount of research showing ancillary public health benefits resulting from the reduction of GHG emissions and other mitigation polices, there are also some ongoing controversies. These include questions about the methods used in calculating estimated results, and the choice of pollutants being assessed, as well as uncertainty

Table 1. Scope of Human Health Effects of Air Pollution

QUANTIFIABLE HEALTH EFFECTS	NON-QUANTIFIED / SUSPECTED HEALTH EFFECTS
Mortality	Neonatal mortality
Bronchitis - chronic and acute	Induction of new asthma
New asthma cases	Fetus/child developmental effects
Respiratory hospital admissions	Increased airway responsiveness to stimuli
Cardiovascular hospital admissions	Non-Bronchitis chronic resp. diseases
Emergency room visits for asthma	Cancer
Lower respiratory illness	Behavioral effects (e.g., learning disabilities)
Upper respiratory illness	Neurological disorders
Shortness of breath	Altered host defense mechanisms (e.g., increased susceptibility to respiratory infection)
Respiratory symptoms	Increased airway responsiveness to stimuli
Minor restricted activity days	Respiratory cell damage
All restricted activity days	Decreased time to onset of angina
Days of work loss	Morphological changes in the lung
Moderate or worse asthma status	

(Adapted from: U.S.EPA 1999)

about the functional relationships (e.g. whether thresholds exist) and the valuation of various health endpoints. In addition, the cost of mitigating greenhouse gases and/or ozone and particulate matter is also of contention; the costs of implementing mitigation strategies being modeled need to be considered as well as the resulting health benefits in order to draw effective policy conclusions from these public health impact studies.

Present State of Ancillary Cost-Benefit Methods. The present state of ancillary cost-benefit analysis methods vary in adequacy, depending on the pollutant and health outcome being considered and whether developed or developing nations are being considered. Current models require accurate data inputs, such as changes in energy use, the associated air pollution levels and the resultant effects on human health. The availability of such data varies widely. Methods for the assessment of short-term mortality are generally adequate, while long-term mortality estimates and some health data are less certain. Developing countries often have the less available data. At a minimum, we need validation of data extrapolation from developed nation studies to developing country applications. Ideally, more research could be done in developing countries to determine the ancillary health effects of climate change on a local or regional level rather than applying data from other parts of the world.

Critical Links in the Public Health Evaluation Process. There are certain steps in the public health effect and valuation estimation process that are critical in defining the conclusions drawn from these analyses. One key critical link is the economic valuation of life, which may vary widely from culture to culture. Errors in estimating air pollution concentrations are often as large as the health response itself. Baseline estimates (i.e., what controls/health changes would happen anyway); the estimation of secondary (as opposed to directly emitted) PM emissions, and the estimation of long-term air pollution exposure effects are additional important uncertainties.

In developing nations, there are further weaknesses, such as the common assumption of constant relations between activities and emissions over time, which is often not valid. Furthermore, emissions/air quality projections may be less accurately known than in more developed nations, where technological change is not so rapid as in the developing nations. In addition, the pollution sources in less developed and rapidly developing nations are different from those in developed nations, and there is more often a lack of toxicity information for air pollution sources that may be changed by GHG mitigation (e.g., indoor biomass burning). Thus, there are numerous unknowns in the critical links for the less developed and developing nations.

Water Issues

Climate change will have an effect on the world's water systems, affecting the quantity and quality of water available for human use and consumption. Models show there will be changes in the amount, timing, and distribution of precipitation and runoff which will lead to changes in water availability, quality, and also to competition for water resources (NAST 2000). In addition, climate change will affect flood and drought timing, duration and intensity as well as the number of extreme weather events such as tornadoes and hurricanes (NAST 2000). Water quality issues also include the potential for increased water-borne diseases after flood events (NAST 2000). All of these changes can affect human health and are thus another link between climate change and human health.

Unlike the air pollution sector, the climate policies that we are examining in this section will deal primarily with adaptation strategies. Because changes are already observed in the climate system and in related ecological systems, and since current international agreements will at best slow the rate of increase in greenhouse gas concentrations by a relatively small amount during the first fifteen years of this century, it is clear that some adaptation to changes due to climate change will be necessary (IPCC 2001b).

There are a wide range of adaptation strategies that have been developed and could be applied in the water sector. Examples include changing operations of dams and reservoirs, building new infrastructure, water conservation, use of reclaimed wastewater, restoring watersheds, improving monitoring and warning systems for extreme weather events, and increasing water prices (encouraging efficient use) (IPCC 2001b and NAST 2000). Water sector adaptation policies are largely independent from climate change, however, the changes in water management practices under these policies will significantly impact how climate change affects the water sector (IPCC 2001b). Water managers in some countries are beginning to consider climate change in water resource planning. For example, in the UK, water supply companies are required to "consider" climate change (among other factors) in estimating their future resource projections (Subak 2000 in IPCC 2001b)

The methodologies and abilities for considering climate change in water management practices are not yet well defined and they vary between and within countries based on the institutional foundations for long-term water planning (IPCC 2001b). Techniques for assessing the adaptation alternatives become complicated when trying to incorporate the uncertain nature of climate change. Decision-making under such uncertainty also poses problems, but water resource planners often deal with uncertainty by adding a safety factor to design estimates (IPCC 2001b). Further research regarding how specific climate changes will affect water quantity and quality and, therefore human health, should be a priority as well as research assessing the alternative adaptation strategies for water resources.

Disease

Many infectious diseases, especially in tropical areas, are transmitted by vector organisms. Many of the important vector organisms are cold blooded and are therefore sensitive to external temperature and humidity (IPCC 2001b). Furthermore, most vector-borne diseases exhibit a seasonal pattern which suggests that they are sensitive to weather (NAST 2000). It is believed that increased temperatures, altered rainfall, and sea-level rise resulting from climate change will affect the potential transmission of infectious disease by altering the distribution of vector species (IPCC 2001b) although the details depend on the specific organism involved. Transmission of human diseases like malaria and dengue is contingent upon more than just climate and weather. There are other sociological and environmental factors that come into play as well including, human population density, water quality, wastewater management, irrigation systems, and vector control programs (IPCC 2001b). Although it is a possibility that climate change could lead to a resurgence of vector-borne diseases, there is little evidence to date that it has played any role (IPCC 2001b).

To reduce the increased risks of vector-borne diseases, adaptation measures need to be enacted. Such adaptation strategies include surveillance, and epidemic preparedness that may benefit from new tools that predict the seasonality and risks of epidemics using satellite or on-the-ground meteorological data (IPCC 2001b). For instance, it has been shown that cholera epidemics can be related to climatic events, such as El Niño. Monitoring via remote sensing and satellite imagery can be used to predict conditions conducive to cholera outbreaks or epidemics (Colwell 1996). Other adaptation strategies mentioned by the IPCC include controlling vectors via pesticides, vaccination, health education, and water storage practices (IPCC 2001b).

Research/Data Priorities

Like all other aspects of climate change research, research relating to the human health effects of climate change needs to be conducted at an international level with a high degree of information exchange between scientists, agencies, and institutes. Based on the above evaluations of the present state of ancillary cost-benefit analyses methods, input data availability, the adequacy of methodology applications, and of the critical links in the public health evaluation process, the following research needs have been identified.

- Conduct more epidemiological studies in order to better understand the relationships between climate variability and human health.
- Develop methodologies to estimate health effects in developing countries and obtain improved estimates for the valuations of health effects in these countries. Use these methodologies to conduct ancillary benefit case studies in these areas to fill data availability gaps.
- Investigate ways to develop alternative indicators or proxies of exposures (e.g., population density, school locations relative to stationary sources).
- Investigate the effects of reducing GHG emissions on air pollution and climate variability. Combining this step with the first research need of investigating the relationships between climate variability and human health will be the key to understanding and predicting ancillary effects of GHG mitigation policies.
- Because water- and vector-borne diseases are among the most prevalent environmentally-related diseases, special attention should be paid to adaptation policies that may affect water quality and the spread of disease, as these will certainly have a wide variety of other benefits and costs associated with them.

Ecosystems and Land-Use Research Needs

The ancillary effects of climate change policies on ecosystems and more generally, on land-cover and land-use, are probably the least studied of all sectors, but it is already clear that understanding them is at least equally important as other sectors. It is also more difficult in some respects because in addition to those goods that are traded in the market, ecosystems also provide services that are unpriced, or whose prices are poorly captured in markets. Ecosystems also change for many different reasons, only some of which have to do with climate change. Prices of commodities and other agricultural products clearly influence how much land is devoted to agriculture, and therefore how much land is available for other purposes. Crops and natural vegetation respond to climatic variation, but also to atmospheric concentrations of carbon dioxide, and to ozone and other air pollutants. Erosion, loss of soil fertility, the successional stage of ecosystems, and the presence of pathogens or invasive species, can all have effects on ecosystem functioning and the goods and services that are provided.

In addition, ecosystems and the natural resources and services that they provide are themselves sources or sinks of GHGs, thereby potentially being both the direct object of climate change policies as well as undergoing the ancillary consequences of those policies. The challenges for understanding the ancillary effects of climate change policies on ecosystems therefore include better characterization of the baseline, better quantification of ecosystem values, and better understanding of the potential links between changes in ecosystems and other important policy outcomes. We will examine each of these issues in turn.

Baselines. The baseline against which ancillary effects of climate change policies on ecosystems and land-use should be evaluated is one that presumes that no climate specific climate change policies have been undertaken. But this baseline itself depends on having an accurate characterization of the current land-cover and land-use as well as information and indicators about the functioning of those systems (NRC 2000). Such information about land-cover, land-use and ecosystem functioning is largely available in the US and most developed countries, although it may be dispersed over many different institutions inside and outside of the government. However, such data can be difficult to acquire for many countries in the developing world, even for information as important as the amount of forest or arable land under production. Generally, developed countries have a higher capacity to conduct monitoring for land use and land cover change and in many cases have been doing so for a long period of time. Surveys have typically been conducted to keep track of goods that have a value in the market place such as timber, agricultural goods, and certain wildlife game species. For example, the US Forest Service has been monitoring the amount of forested land in the United States since before 1850, while the US Department of Agriculture (USDA) has been monitoring farm numbers and acreage since its formation in 1862.

On the other hand, systematic regular monitoring is rarely conducted in developing countries primarily due to cost limitations. As a result, data from many countries are limited. For example, in the latest Forest Resources Assessment published by the Food and Agriculture Organization of the United Nations (FAO), national figures were not available from many developing countries, including many of the larger countries in Africa and some key forest countries in Asia. Of the 137 countries surveyed for the 2000 report only 22 have systems in place for continuous forest monitoring. Of the remainder, only 77 countries have conducted national forest survey(s) since or before 1990, 33 countries have only a partial forest inventory, and 28 are without any forest inventory (Matthews 2001).

Nevertheless, there are beginning to be regional and even global datasets on the current distribution of land-cover that are systematically collected, validated, and are replicable over time. The IGBP Discover 1km resolution land-cover product (Townshend et al. 1994; Loveland et al. 2000; Hanson et al. 2000; DeFries et al. 2000) is the first of these, but several others are currently in development or have been released (DeFries et al. 2000) as research products. The wide availability of these datasets, as well as the availability of finer resolution datasets derived from other sources (Skole and Tucker 1993; Matthews et al. 2000; Wood et al. 2000) make the current evaluation of land-cover and some aspects of land-use stronger than it has ever been. The main challenge now is to address those systems for which good characterizations do not yet exist, e.g. wetlands, and to ensure that land-cover data are collected systematically over time in order to ensure that land-cover change can be unambiguously detected.

As important as it is to establish the current distribution of land-cover and ecosystems, it is also critical to understand how that distribution might change in the absence of climate change policies, in order to have a firmer understanding of the importance of the ancillary effects of those policies. Most of the existing research on this topic with respect to global issues has been focused on the problem of how both managed and natural ecosystems might respond to changes in atmospheric carbon dioxide and climate. IPCC (2001b) has summarized most of the international studies. The recent National Assessment of the Potential Consequences of Climate Variability and Change (2000) has done so for the US. In both cases, the basic analyses have assumed that no climate-specific policies have been put in place, and therefore that GHG emissions will continue to rise through the 21st century. The potential consequences of those climate changes, and to some degree, socioeconomic changes in the US have been analyzed, and the uncertainties and needs for further research outlined (Parsons et al. in press). Results of various modeling studies for the US for the expected distribution of ecosystems without the intervention of climate change policies show that redistribution of major tree and other plant species is expected due to changes in climatic conditions. Depending on the severity and rapidity of the change in the climate system, the redistribution of major vegetation types may result in the northward expansion of currently more southerly species, or it may be as profound as tree species in the Southeast not being able to reproduce themselves after fire and pest disturbances and being replaced by shrubs and grasslands (NAST 2000; Dale et al. 2001; Aber et al. 2001; Hansen et al. 2001). The US National Assessment also investigated potential changes in ecosystem functioning, using process-based ecosystem models. Results showed that for the next several decades at least, it would be reasonable to expect that total ecosystem carbon storage would increase, largely due to the effects of increased atmospheric carbon dioxide concentrations. These results are highly dependent on how the ecosystem models parameterize the effects of increased carbon dioxide, how that increase affects water use efficiency, and whether other growth limitations come into play (VEMAP 1995). Thus, they show both the importance and the difficulty of establishing a baseline against which the potential ancillary effects of climate change policies might be evaluated.

Results for water resources varied significantly by region, pointing out again the need for regionally specific case studies and increased model sophistication. In the eastern US, where there is relatively little storage capacity, the expected increase in the frequency of wet and dry years could lead to the need for changes in the way that hydrologic systems are managed, including perhaps the need for more storage capacity. In the western US and northern plains, however, where water supply is heavily dependent on the winter snowpack, all the climate scenarios examined show a reduction in snowpack and earlier snowmelt. These conditions would lead to significant operational challenges for water managers in those regions, including having less water overall during the year, with more of the annual water supply coming much earlier in the year than current peak demand.

Agriculture susceptibility to climate in the US also varied significantly by region. From a national perspective, analyses suggested that US food production would be secure, certainly for the next several decades (NAST 2000). However, on a regional basis, agriculture would likely become more difficult in those areas that are already marginal for production, such as the dryland agriculture in the northern plains states. But it is true that US agriculture, at least, is a highly adaptable industry, and autonomous adaptation on the part of producers might well be expected to accommodate much of the additional stress from a change in climate.

Analyses of potential climate impacts for Europe (Parry 2000) give similar results to the US National Assessment. Agricultural systems exhibit much potential for autonomous adaptive responses; water resource issues vary tremendously between the moist northern European countries, and their southern, semi-arid Mediterranean neighbors, and natural ecosystems exhibit more vulnerability, in general, than do managed ecosystems.

But the situation for the baseline in much of the developing world is quite different. IPCC (1996, 2001b) has consistently shown that for similar climate scenarios, developing countries appear to be much more vulnerable in terms of ecological impacts. As much as a third of forested ecosystems globally could be affected to some degree, creating an additional stress on terrestrial biodiversity, and agricultural systems are not as adaptable technologically, economically, or practically as those in the developed countries. Therefore, the context within which ancillary effects of climate change policies are to be evaluated is both significantly different than in the US and other developed countries, and significantly less well understood.

The final issue with respect to better understanding and quantification of the baseline is the need to incorporate the effects of other reasonable scenarios for changes in ecosystems due to factors other than climate. These factors range from the known growth responses of some tree and many crop species to chronic stress from ozone pollution, to acidification of lakes and soils due to acid deposition, to the continued demand for timber and pulp from forests (Johnson and Fernandez 1992; Matthews and Hammond 1999; WRI 1998, 2000). In addition, consideration of the direct economic value of crop and timber production in global markets with many other factors, such as very different consumer preferences in different regions, is a critical feature of establishing a reasonable baseline scenario.

Not all of these factors can be taken into account in any one analysis, of course. But it is clear that a much better understanding of the response of ecosystems to multiple stresses is needed for good scenario-based case studies. In addition, it is clear that the effects of changes in factors other than climate, both positive and negative, need to be considered when trying to understand the possible ancillary effects of climate change policies.

Mitigation of sources and enhancement of sinks. Policies that seek to mitigate the emissions of GHGs might usefully be divided into three categories. The first are those that seek to reduce emissions from the broad suite of industrial, transportation, and household sources. It is beyond the scope of this paper to summarize the extensive literature on such policy options. However, it is important to recognize that policies directed at these sources will almost certainly have ancillary effects on ecosystems, mediated mostly through changes in air and water pollution. In addition, policy choices that emphasize the growth of green power options, such as some hydropower projects, biomass fuels, and geothermal energy, deserve investigation with respect to their ancillary effects on ecosystems. As an example, while it certainly appears feasible to increase the land available for biomass plantations, the water and fertilizer needed to ensure high growth rates of the woody plant species used, and the consequences for natural biodiversity are very poorly understood, and require significantly more study.

Second are those policies targeted at agricultural practices, such as overfertilization with nitrogen, or methane emitted from ruminants, that seek to directly reduce those emissions. In these cases, the ancillary effects of such policies should be able to be determined relatively straightforwardly (Faeth 2000) both from an environmental and an economic perspective.

The third category are those policies that are focused either on preventing land-use conversion (largely conversion from forested land to agricultural uses) that would otherwise result in emissions of GHGs, or on enhancing the sequestration of carbon on landscapes. In these cases, the assessment of ancillary effects of climate change policies will be more complicated, since they clearly involve differentiating among different land-use scenarios, and therefore have multiple environmental and socioeconomic consequences. Again, as in establishing a non-climate policy baseline, the policy and land-use scenarios to be evaluated for this class of policies must be differentiated regionally and nationally, and there is significantly less information available about potential futures in the developing world. The studies that exist at a global level tend to be focused on particular issues (Sala et al. 2000), and would need to be adapted to the task of assessing ancillary effects of climate change policies.

A particular need for understanding the ancillary effects of climate mitigation policies on ecosystems, land-cover and land-use is the careful elaboration of case studies that are regionally specific, so that the links between changes due to potential climate change policies can be clearly delineated, and so that reasonable baseline scenarios for those regions can be worked out.

Adaptation. The second major category of climate change policies having to do with ecosystems and land-use issues is adaptation. The IPCC (2001b) has distinguished between autonomous adaptation and purposeful adaptation, i.e. between changes in policies and practices that would have occurred anyway, and changes that are put in place specifically to deal with stresses from climate change.

This distinction is obviously important also from the standpoint of assessing the ancillary effects of climate change policies, as it affects both the baseline scenario against which ancillary effects are measured as well as the direct policy consequences themselves. Differentiating clearly between those changes in ecosystems and land-use that might be expected to occur anyway due either to natural variation or to changes in societal pressures and preferences and those changes that are the results of directed climate adaptation policies will be necessary if analyses on different sectors and in different geographic regions are to be comparable. For example, the oft-cited example of New York City protecting its water supply through agreements with landowners upstream to maintain current land-use practices could be seen through the lens of climate adaptation. Its original motivation was clearly not to deal with climate change, but to avoid the cost of constructing expensive water treatment plants for a growing urban population. Such a project may well have ancillary effects that will prove to be adaptive for potential climate change impacts (NAST 2000), but it could not be portrayed as having large ancillary effects as a climate policy. It should more properly be regarded as part of the baseline against which additional ancillary effects of climate change policies should be evaluated.

It will equally be important to differentiate between those changes that are directly due to climate adaptation policies, and those ancillary changes in other parts of the economy or in other natural resource sectors. For example, seawall construction for coping with sea-level rise is one of the potential adaptation strategies in some parts of the US and other countries (Titus et al. 1991, NAST 2000, IPCC 2001b). But aside from the obvious questions about the costs and effectiveness of seawalls as a strategy to cope with sea-level rise, there would clearly be consequences for local employment, raising of capital, ongoing maintenance, and additional environmental consequences that are very poorly understood. Adaptation policies that might be put in place to deal with the water resource issues may very well be effective with respect to ensuring a sustainable supply of fresh, potable water. However, even if they are effective, there would certainly be ancillary effects on other environmental conditions, such as the availability of water to maintain healthy ecosystems, and on other socioeconomic conditions, such as the competition for water between agricultural and household uses. Case studies of such tradeoffs are clearly required in order to get a sense of the magnitude of the potential ancillary effects of climate adaptation policies.

Research Priorities

The preceding discussion leads to several research priorities for ecosystems and land-use issues.

- Valuation issues continue to be among those that are the highest priority for investigation. These include studies to define better the market and non-market values of ecosystem goods and services, but also should include studies that look directly at policy options that might more successfully capture the value of ecosystem services in markets (Perrings et al 1995).

- Case studies that develop good time-series of ecosystem and land-use changes are clearly necessary, both in developed and developing countries. These time-series would have multiple benefits from an ancillary effects perspective: they would help to establish reasonable baselines, they could show the benefits of improved methods of change detection and subsequent evaluation of goods and services, and they would assist the research community in reaching consensus on an appropriate definition of which consequences should be considered ancillary.

- Both experimental and model studies, supplemented by direct observations, of how natural and managed ecosystems respond to multiple stresses will be required, in order to have a more quantitative appreciation both for changes in the baseline and for changes due to climate change policies. Modeling studies need to be more highly resolved spatially than currently is the case, and in addition, should in principle be able to give reasonable results over fairly short time periods (years to decades). This may require substantial computing resources for ensemble runs of process-based models, or may be achieved through multiple simulations with much simpler models.

- Case studies on mitigation policies that are targeted on other sectors, but that have ancillary effects on ecosystems and land-use options are clearly necessary. Studies on the ecological and economic consequences of alternative energy sources are among the most important to undertake.

- Similarly, case studies on mitigation and sequestration policies that are targeted at biological sources and sinks of GHGs need to be undertaken, especially as the prospect for applying such policies grows internationally.

- Finally, case studies and model development to evaluate the cost, effectiveness, and potential ancillary effects of adaptation policies are clearly needed. For the most part, such studies are currently rare in the literature for both developed and developing countries.

Table 2. Summary of Research Priorities

Area of Research	Research Priorities
Theory and Methodology	• Develop case studies with consistent and detailed checklists. • Develop improved analytic tools to address valuation of policy effects. • Devise explicit specifications of baseline conditions. • Conduct studies in areas that have been studied less in the past.
Public Health	• Conduct more epidemiological studies to gain better understanding of adverse health effects associated with climate change. • Improve estimates of health effects in developed countries. • Investigate alternative indicators of exposure. • Investigate valuation schemes.
Transportation	• Acquire information about next generation vehicles and fuel choices. • Develop a more complete accounting of the baseline changes. • Investigate patterns of consumer/traveler behavior in developed and developing countries. • Develop better tools for measuring the effects of land use infrastructure decisions on the transport sector.
Ecosystem and Land-Use	• Investigate valuation schemes. • Case studies that develop good time-series data. • Experimental and model studies of how ecosystems respond to stressors. • Case studies on policies that are targeted at other sectors, but still affect ecosystems. • Case studies on policies targeted at biological sources and sinks of GHGs. • Case studies on the evaluation of cost, effectiveness, and potential ancillary effects of adaptation policies.

Conclusions

The research priorities outlined in this paper for theory and methodology, and for each of the individual topic areas, constitute an ambitious package of potential activities. There are clearly needs for further research in both developed and developing countries, where the context for climate change policies is substantially different. The development of clear consensus on definitions of ancillary effects and methods for creating reasonable baseline scenarios for analysis are also paramount. The entire area of the ancillary effects of either mitigation or adaptation policies on ecosystems and land-use has received very little attention, to the extent that even very preliminary studies could be expected to yield important new insights. Intrinsic to considering ecosystem and land-use effects are the development of case studies and models that treat the response of ecosystems to multiple factors, including air pollution and human exploitation, as well as climate change. Finally, the need for more complete documentation of the costs and potential effectiveness of adaptation policies for ecosystems and natural resources is critical to continued progress.

The research needs outlined above are inherently interdisciplinary, and as such demand three sorts of partnerships. The first are active collaborations among researchers: economists and policy analysts working with ecologists and public health experts, for example. There is abundant evidence that such collaborations are possible: the original IPCC workshop that was the motivation for this paper attracted economists, public health experts, and ecologists. The second requirement is that collaborations and comparable studies be regionally and internationally implemented. The wide geographic participation in the IPCC process serves as one model for moving forward, as does the implementation of regional assessment studies within the US. The original IPCC workshop attracted researchers from across the US, Europe, and some developing countries. The final requirement is institutional: the only realistic way in which to make rapid progress on all these fronts is to seek collaborations among potential sponsors. Some of the research needs outlined above could be met through collaboration between institutions sponsoring policy research on transportation issues with those sponsoring research on health effects; or collaborations between institutions sponsoring research on alternative energy sources and those sponsoring ecological research.

Attaining collaboration on all these fronts—interdisciplinary, international, and institutional—will certainly pose a major challenge. But it is a challenge that is commensurate with the challenge of climate change itself. An issue that cuts across so many other fundamental societal concerns, from food production to energy use to the fate of nature, can only be addressed by a greater appreciation of the consequences of the policies chosen to address it.

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