Developing Baselines for Climate Policy Analysis

Additional guidance supporting UNEP's MCA4climate initiative:
A practical framework for planning pro-development climate policies

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1. Overview[1]

Careful decision-making regarding climate mitigation, adaptation policies, and national positions in global climate negotiations requires the best possible information about future outcomes. How will your nation and region grow and change over the coming decades or century? What impact will global greenhouse gas emissions have on your local climate, natural environment, and economy? What impact can national efforts have on emissions mitigation and adaptation measures aimed at avoiding climate damages?

Scholars, governments, and non-governmental advocacy organizations use models of the future climate and economy to create projections that are as reliable as possible. An important first step in climate economics modeling is the construction of a "baseline" or "business-as-usual" scenario that forecasts future economic and population growth, climate damages, and other macro-level developments of interest in the event that no serious new climate policy is adopted. Starting from this baseline, it is then possible to examine the likely effects of a proposed climate policy – at a global, regional, national or even local level.

This document contributes to UNEP's MCA4climate initiative (www.mca4climate.info) by presenting guidelines for developing baselines for climate policy analysis. These guidelines can help users establish baselines for use in national and regional analysis. Baseline analysis allows users to:

- identify of trends in greenhouse gas emissions by source, including agricultural and land-use sources;
- demonstrate links between emissions and the development of the energy system, especially where greenhouse gas emissions are rising quickly; and
- assist in the assessment of additionality for use in climate policy decisions[2]

It should be noted that while for some countries appropriate and up-to date baselines constructed by governments and international bodies (e.g. IEA's annual World Energy Outlook[3]) already exist. For many countries, however, the appropriate data for creating baselines will not be readily available from international statistics; detailed climate policy analysis, therefore, will require access to or development of national data sources.

How detailed and complicated should an economic model be? For national governments, the basic requirements for an appropriate model are fairly straightforward: it must be able to capture national economic and environmental details. Yet the model also needs to represent the rest of the world economy at some level, in order to model trade, technology transfer and other

[1] We would like to acknowledge the helpful comments received on an early draft of this report from peer reviewers, Terry Barker (University of Cambridge, UK) and Stephen DeCanio (University of California, Santa Barbara), as well as from UNEP's own internal reviewing received from Serban Scrieciu of the Division of Technology, Industry and Economics.

[2] See also, discussions of baseline analysis and additionality presented in the UNFCCC's Clean Development Mechanism Methodology, http://cdm.unfccc.int/methodologies/documentation/meth_booklet.pdf

[3] http://www.worldenergyoutlook.org/

international spillovers; in practice, the rest of the world will usually be modeled in a stylized and fairly simple manner.

Research on climate economics often uses "integrated assessment models," a type of relatively aggregated global model, sometimes broken down into several world regions. Examples include DICE, FUND, and PAGE – among many others. Integrated assessment models excel at providing overviews for large regions over 100 years or more, but are less appropriate for providing relevant policy information at the national level over the next few years. In such models, the focus is on the link between GDP and atmospheric greenhouse gas concentrations, and the degree of detail on energy and technology choices is typically limited.[4]

Most country-level climate impact and mitigation studies begin with specific information about the current economy, population, and climate in the area under study. The analysis first establishes a baseline projection for changes in each factor over time, assuming that trends, including increases in global greenhouse gas emissions, will continue. This "business-as-usual" scenario maps out the costs and benefits of inaction – that is, choosing *not* to implement climate policy. Ideally, a model should include both mitigation and adaptation options. In practice, many models focus primarily on the costs and benefits of mitigation options. This is in part because widespread recognition of the importance of adaptation is comparatively recent, and in part because adaptation is more difficult to model.

Adaptation to climate damages is essential in the near term. The earth's climate is already changing for the worse, and additional damages are already "in the pipeline," as the unavoidable consequences of recent emissions. For the hardest-hit countries, such as small island nations threatened by sea-level rise, adaptation can be a matter of survival. For all low-income and middle-income countries, it is important to strengthen the resilience of society in the face of unpredictable, damaging climate impacts. Even the highest-income countries need to invest in protection against a hostile climate, as was tragically shown by the deadly European heat wave of 2003 and the flooding of New Orleans from Hurricane Katrina in 2005.

For several reasons, however, it is difficult to incorporate adaptation in an economic model. Adaptation measures are highly site-specific; they are much less standardized than mitigation measures, which often involve new energy technologies or efficiency measures. Adaptation often means improvements in public health, water and sanitation, transportation, storm barriers, and other infrastructure; it can be hard to distinguish between adaptation in specific and economic development in general. Finally, adaptation does not directly reduce emissions or slow the process of climate change; as time goes on, it will become more and more difficult to adapt to the worsening impacts of climate change, unless mitigation also reduces emissions.

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[4] van Vuuren, D.P., Lowe, J., Stehfest, E., et al. (2009). "How well do integrated assessment models simulate climate change?" *Climatic Change* 104(2), 255–85. DOI:10.1007/s10584-009-9764-2.
For detailed discussions of integrated models, see Stanton, E.A. and Ackerman, F. (2009). "Climate and Development Economics: Balancing Science, Politics, and Equity." *Natural Resources Forum* 33(4, special issue on climate change and sustainable development), 262–73. DOI:10.1111/j.1477-8947.2009.01251.x.
Also, see Stanton, E.A., Ackerman, F. and Kartha, S. (2009). "Inside the Integrated Assessment Models: Four Issues in Climate Economics." *Climate and Development* 1(2), 166–84.

Where adaptation measures are of particular importance, modelers can and do include them in an economic model.[5] There is no standard method for doing so; they should be treated like any area of investment, with the added benefit of reducing the estimated damages from climate change.

Climate modeling involves many choices, few of which have definitive right or wrong options. Good choices regarding modeling assumptions, techniques, and data will vary from nation to nation and from model to model. In this document, we lay out some of the key components to be included in a national or regional climate-economics model, along with multiple options for each modeling choice. Recommendations for what, in our judgment, are the preferred choices are offered in the context of what is a very wide variation in national circumstances. Of particular importance in constructing baselines and applying them in a policy context is the fundamental uncertainty that underlies the climate problem. For a detail discussion of uncertainty in climate policy analysis see the supporting MCA4climate guidance document entitled, "Risk and Uncertainty in Climate Assessment."

[5] See Agrawala, S., Bosello, F., Carraro, C., de Bruin, K., De Cian, E., Dellink, R. and Lanzi, E. (2010). *Plan or React? Analysis of Adaptation Costs and Benefits Using Integrated Assessment Models*. OECD Environment Working Papers, No. 23. Paris: OECD Publishing. Available at http://www.oecd-ilibrary.org/environment/plan-or-react_5km975m3d5hb-en
Also, see de Bruin, K., Dellink, R. and Agrawala, S. (2009). *Economic Aspects of Adaptation to Climate Change: Integrated Assessment Modelling of Adaptation Costs and Benefits*. OECD Environment Working Papers, No. 6. OECD Publishing. Available at http://www.oecd-ilibrary.org/environment/economic-aspects-of-adaptation-to-climate-change_225282538105

2. Model design and data inputs

Most greenhouse gas emissions are the direct result of economic activity. Thus the anticipated growth in production and consumption is a major factor in future emissions. Faster-growing economies will tend to have faster-growing emissions; slowdowns in growth will tend to slow emissions growth as well. The worldwide economic slump that began in 2008 has lowered emissions below the levels that were projected on the assumption of full employment. Other macro-level events and assumptions will also affect emissions.

Many macroeconomic variables are potentially important, if they affect the rate of growth of production and consumption. Savings rates, national debt, and other factors may affect economic growth; economic forecasting models typically include many such factors. There is a choice to be made about how much economic modeling to include in a climate assessment model; this will determine how many macroeconomic variables are needed.

2a. Critical macroeconomic variables to consider

The scale of economic activity, and, therefore, greenhouse gas emissions and assets at risk of damage from climate change, depends in part on the size of the population. In many models, either GDP divided by population (GDP per capita) or, where available, consumption per capita is used as an important measure of welfare. For larger study areas, the geographic distribution of the population can also be an important component of baseline projections. Where health impacts are among the expected climate damages, distributions by age, and by race or ethnicity, may also be of particular relevance. The age distribution may also help determine the fraction of the population that is actually or potentially in the labor force, which is important for economic modeling. Employment by economic sector can be useful for tracking climate impacts when damages are expected to have strong effects on certain sectors, such as agriculture or tourism.

Increased exports will usually increase the emissions from production; similarly, increased imports will often reduce a country's domestic emissions, because they reduce emissions in production. A new, complementary approach in modeling emissions, calculating a country's emissions on a consumption basis, reframes the impact of foreign trade: under this approach, a country is responsible for all emissions, regardless of location, that result from the country's own consumption.[6] On a consumption basis, countries are not responsible for the emissions resulting from producing exports, since those are sold to customers elsewhere; they are, instead, responsible for the worldwide emissions resulting from their imports. While there is a logical and equitable argument for consumption-based modeling (as supplemental information to the standard production-based inventories) in theory, it is difficult to implement in practice; it requires detailed data on worldwide emissions and trading patterns, stretching far beyond an individual country's own data sources. Most assessments use the simpler, traditional approach, in which emissions are attributed to the country where they are produced.

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[6] See Peters, G.P. and Hertwich, E.G. (2008). "CO_2 Embodied in International Trade with Implications for Global Climate Policy." *Environmental Science & Technology* 42(5), 1401–7. DOI:10.1021/es072023k.

One of the most important influences on emissions intensity is the price of oil (and other fossil fuels). Higher oil prices will induce more energy-saving technology, and they will increase the economic benefit of energy conservation measures. Major studies of climate impacts and policy costs have differed widely on this point, with climate policy "optimists" often assuming higher oil prices than "pessimists."[7] The effects of higher oil prices on consumers are the same as the effects of a carbon tax or energy tax; the difference is that with high prices, the revenues end up in the hands of oil producers, rather than the government. Higher oil prices and/or carbon taxes will have the greatest effect on the most fossil-fuel-intensive sectors, such as transportation and basic materials industries; less energy-intensive sectors such as services, and many consumer products industries, will be less affected.

Important macroeconomic variables to consider for use in a climate economics baseline include:

- Population, by sub-national region where appropriate
- Distribution of age, race-ethnicity, and income
- Health status of the population, such as distribution of major diseases
- Employment by economic sector
- Gross domestic product, and the share of GDP in energy-intensive economic sectors
- Investment
- Exports and imports
- Prices of fossil fuels
- Taxes or other government policies that affect the prices of fuels or emissions
- Prices and quantities of key commodities impacted by climate change

Option 1: Use a basic set of data, such as population, GDP, employment, and emissions by economic sector.

Option 2: Use the full range of data items identified above.

Recommendation: The appropriate choice will depend on the available data and modeling resources. There is in fact a spectrum of choices ranging from Option 1 to Option 2; countries with limited data and resources will fall closer to Option 1, while those with greater statistical information and modeling capabilities will employ a broader range of data, closer to Option 2. Consistency across projections taken from different data sources is an important concern. Ideally all the projections would come from the same source and be derived consistently from one standard set of underlying assumptions.

[7] See Ackerman, F., Stanton, E.A., DeCanio, S.J., et al. (2009). *The Economics of 350: The Benefits and Costs of Climate Stabilization*. Portland, OR: Economics for Equity and the Environment Network. Available at http://sei-us.org/publications/id/31.
Also, see Ackerman, F., Stanton, E.A., DeCanio, S.J., et al. (2010). "The Economics of 350." *Solutions* 1(5). Available at http://www.thesolutionsjournal.com/node/778.

Data are often chosen for consistency with other planning studies in the same country. For instance, some countries have statistical offices that offer preferred projections of economic growth. This promotes compatibility with the broader policy discourse within the country. Alternatively, there are international sources available for many data series (see box); use of these sources allows comparison to similar studies in other countries. To aid policymakers in interpreting model results and comparing baseline assumption to those used elsewhere, it is useful to report the annual growth rates implied by GDP and population projections.

For multi-year analysis, it is important to use data adjusted for inflation. This is a virtually universal convention, and is required for comparability with other studies. There are a variety of terms for inflation-adjusted economic data: inflation-adjusted GDP, for instance, can be described as *real* GDP, or GDP in *constant dollars* (or euros, or any other currency), or GDP *at 2005 prices* (or any other year's prices). Avoid the use of unadjusted data – which may have names such as *nominal* GDP, or GDP in *current dollars* (or other currency), or GDP at *current prices*. Be sure to specify the base year for the inflation adjustment – that is, what year's prices are being used?

A second important consideration is the method of comparing economic data across countries. Such data are commonly compared or aggregated using one of two systems: market exchange rates, or purchasing power parity. At market exchange rates, each country's data, in the national currency, are compared to other countries by converting them at the prevailing exchange rate. Data from India, for example, which are originally measured in Indian rupees, can be converted to dollars, euros, or other currencies at the exchange rate for the rupee.

At purchasing power parity (PPP) rates, each country's data are expressed in "international dollars," defined as representing the same amount of local purchasing power as a U.S. dollar has in the United States. In lower-income countries, prices are often lower for services, housing and other construction, and other local products – so the local purchasing power of the Indian rupee, for example, is much greater than its value at market exchange rates. In 2009, India's gross national income per capita was US $1,220 at market exchange rates, or $3,280 at purchasing power parity rates. The opposite is true for some high-income countries, where local prices are higher than in the United States: in 2009, Switzerland had a gross national income per capita of $65,430 at market exchange rates, but $47,100 at purchasing power parity rates.[8]

International Sources of Macroeconomic Data

Penn World Table, http://pwt.econ.upenn.edu/

UN-DESA Population Division, http://esa.un.org/unpp/

United Nations Development Programme, http://hdr.undp.org/en/statistics/data/

World Bank, http://data.worldbank.org/

[8] Data are from http://siteresources.worldbank.org/DATASTATISTICS/Resources/GNIPC.pdf .

2b. Incorporating national baseline GHG emissions

Most national climate-economic models include estimates of national baseline greenhouse gas emissions. Data for an initial year are taken from national emissions inventories. Future years' baseline emissions may be modeled in one of two ways: Emissions may be modeled endogenously by combining economic projections with information about the emissions intensity of national industries; or emission may be introduced exogenously from projections made by national environmental or energy agencies. In either case, models commonly distinguish between emissions from fossil-fuel combustion, from agriculture and forestry with existing land-use patterns, and from land-use change.

Emissions inventories have traditionally been estimated from a "geographic" standpoint, including all greenhouse-gas emissions released within a nation or regions boundaries. For a few categories, however, it has become a common practice to assign emissions based on use rather than geography.[9] The most prominent example is electricity; many national emissions inventories include emissions from the electricity *used* within the country and not the electricity *generated* within the country (an important distinction when electricity is traded across national boundaries).

In addition to their geographic inventories (with or without use emissions for key sectors) some nations have also created supplemental inventories tracking use emissions. These "consumption-based" inventories trace the emissions caused by all purchases within a nation, including emissions that occur upstream from resource extraction, farming, and industrial production. A consumption-based inventory includes all emissions from a nation's purchases of goods and services (including fuel and electricity) but does not include any emissions from goods and services that are produced for export. While these supplemental consumption-based inventories are becoming more common, they are not a replacement for traditional geographic-based inventories. The assignment of emissions responsibility by consumption is controversial, and consumption-based calculations are very labor and data intensive. (For a consumption-based model with emissions results for 87 countries and regions see (Peters and Hertwich 2008)).

Option 1: Model baseline national emissions endogenously as a function of aggregate projected economic output or projected output in energy intensive sectors.

Option 2: Model baseline national emissions exogenously based on projections provided by national agencies.

Recommendation: Modeling emissions endogenously within the model – Option 1 – allows for the greatest consistency of economic and climate projections. Baseline emissions generated endogenously, however, should be cross-checked for accuracy against projections made by national agencies (Option 2).

[9] See IPCC Guidelines for National Greenhouse Gas Inventories, http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html.

International Sources of Greenhouse Gas Emissions Data

Emission Database for Global Atmospheric Research (EDGAR):
http://edgar.jrc.ec.europa.eu/index.php

International Energy Agency (IEA), CO_2 Emissions from Fuel Combustion 2010:
http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=2143

U.S. Energy Information Administration, International Emissions
http://www.eia.doe.gov/environment/data.cfm

World Resources Institute, Climate Analysis Indicators Tool: http://cait.wri.org/

2c. Number of sectors to analyze

The degree of aggregation or disaggregation is another modeling choice for which there is no single right answer. Many global models are highly aggregated, in order to focus on the big-picture interactions between climate change and long-run economic growth. On the other hand, some national economic models, such as input-output models, may represent the short-run behavior and interactions of hundreds of economic sectors. Between these extremes, there are many useful models with a moderate number of separate economic sectors. More sectors allow more precision and detail; more aggregation (i.e., fewer sectors) clarifies the understanding of the problem as a whole.

Option 1: Use a highly aggregated macroeconomic model with 1 to 3 economic sectors.

Option 2: Model the economic behavior and growth of an intermediate number of economic sectors (perhaps 10 to 30).

Option 3: Apply a highly disaggregated model, representing as many separate sectors as possible.

Recommendation: Option 1 is useful primarily for initial explorations; while it may provide a starting point, it will not generally produce adequate analyses of the interactions of climate and the national economy. Option 3 is prohibitively expensive, in time and money, if a new model has to be created. It is appropriate only when a detailed economic model, such as a national input-output model, is already available for use. In most cases, Option 2 is the preferred alternative, representing a middle ground between comprehensive overview and disaggregated detail.

When a moderate degree of disaggregation is desired, as with Option 2, it may be important to distinguish some or all of the following:

- The sectors most vulnerable to climate change, such as agriculture, fishing, forestry, tourism, and construction;
- The most emissions-intensive sectors, such as transportation, electricity generation, mining, oil refining, agriculture (especially livestock), and basic materials industries such as cement, iron and steel, other metals, paper, basic chemicals, and plastics; and
- The most trade-affected sectors (top export and import industries).

Simple climate-economics models can be designed to highlight critical climate damages, establishing a lower bound for likely economic costs under business-as-usual emissions, rather than give a comprehensive accounting of future costs.[10]

International Sources of Data Disaggregated by Economic Sector

Food and Agriculture Organization, http://www.fao.org/corp/statistics/en/

United Nations Development Programme, http://hdr.undp.org/en/statistics/data/

World Bank, http://data.worldbank.org/

World Tourism Organization's *Compendium of Tourism Statistics*, http://pub.unwto.org/

[10] Examples include: Ackerman, F. and Stanton, E.A. (2008). *The Cost of Climate Change: What We'll Pay If Global Warming Continues Unchecked*. New York: Natural Resources Defense Council. Available at http://www.nrdc.org/globalwarming/cost/contents.asp
Bueno, R., Herzfeld, C., Stanton, E.A. and Ackerman, F. (2008). *The Caribbean and Climate Change: The Costs of Inaction*. Report commissioned by the Environmental Defense Fund. Somerville, MA: Stockholm Environment Institute-U.S. Center. Available at http://sei-us.org/publications/id/86
Stanton, E.A. and Ackerman, F. (2007). *Florida and Climate Change: The Costs of Inaction*. Report commissioned by the Environmental Defense Fund. Medford, MA: Global Development and Environment Institute, Tufts University. Available at http://sei-us.org/publications/id/47
Stanton, E.A., Davis, M. and Fencl, A. (2011). *Costing Climate Impacts and Adaptation: A Canadian Study on Coastal Zones*. National Round Table on the Environment and the Economy Economic Risks and Opportunities of Climate Change Program (forthcoming). Stockholm Environment Institute-U.S. Center.

3. Macroeconomic issues: Public sector and financial markets

While the public sector and financial markets are key components of national macroeconomic models, they are less central to models focused on climate and the economy. The effects of government fiscal and monetary policies and the operations of private financial markets can often be subsumed into GDP projections, except where important targeted investments in emission-intensive sectors are expected.

3a. Government budgets

Government spending and taxes, and the operations of government enterprises, may or may not be central to a national economic assessment of climate change. Depending on the areas in which the public sector is active, it may be important to examine government spending on transportation, electricity, and other infrastructure; management of public oil and gas deposits, forests, and other natural resources; and energy efficiency initiatives, emissions taxes, and other climate and energy policies. In general terms, government spending can influence the level of employment, the rate of economic growth, and the balance of trade. Changes in tax and subsidy incentives can play a part in climate policy, through such measures as removal of fossil-fuel subsidies, introduction of subsidies for renewable energy, or tax incentives for low-emission vehicles.

The structure of the available economic models will probably dictate the treatment of the public sector. Some government activity is directly tied to economic growth or stagnation: taxes will normally increase when the economy expands; payments to people who are unemployed or below a certain income level will normally increase during economic downturns. These components of the public sector should be endogenous in an economic model. Other government activity, such as expenditure on infrastructure or exploitation of natural resources, is more likely to be exogenous, based on policy choices.

Option 1: Include government activities only as a source of emissions.

Option 2: Include government emissions as well as the likely effects of key policy initiatives related to climate and energy.

Option 3: Model government activities fully, including investment in infrastructure and endogenous economic effects related to taxes and transfer payments (such as unemployment or welfare support).

Recommendation: The best choice will depend on the overall complexity of the modeling effort. Option 1 is most appropriate to a very simple climate-economics model. The most complex models will require Option 3. For most modeling efforts, Option 2 will be preferred, so that the main effects of government on emissions are included without making it necessary to incorporate a level of detail that would be inconsistent with other parts of the model.

While the most complete data on government activities is generally national, some data are provided, in terms that are comparable across countries, by the United Nations and World Bank.

International Sources of Data on Government Budgets

United Nations Development Programme, http://hdr.undp.org/en/statistics/data/

World Bank, http://data.worldbank.org/

3b. Financial and monetary sectors

The financial sector, along with monetary policy, plays a central role in determining interest rates and exchange rates, which affect economic growth and trade. The importance of the financial sector for economic growth became unfortunately clear in 2008, when a financial crisis had rapidly spreading economic impacts, causing a sustained worldwide slump in growth (and hence a slowdown in carbon emissions). In a detailed economic model, financial institutions and monetary policies play an important part in determining the pace of growth.

In a model focused more specifically on climate finance and investments, the policies of lending institutions toward energy efficiency and renewable energy may be important; the transition to a more sustainable economy could be eased by "green finance," or blocked by its absence. Many economics models, however, do not include specific financial data or a separate representation of the financial sector. Instead, these models use projections of GDP and its components that take into account the likely future impacts of financial and monetary policies.

Option 1: Use the standard projection of GDP and its components made available by the national economic bureau.

Option 2: Begin with the standard projection of GDP and its components, but consider revisions to these data based on assumptions about financial and monetary policy that enhance consistency with other projections used in the climate-economics model.

Option 3: Fully incorporate a financial sector and government fiscal and monetary policy into the model, including public investments in energy efficiency and renewable energy.

Recommendation: Most national climate-economics models will use Option 1, relying on the detailed modeling efforts of their national economic bureaus. A few models will make strategic corrections to standard GDP projections, following Option 2. Only the most complex models will attempt Option 3.

International Sources of Data on Financial and Monetary Sectors

World Bank, http://data.worldbank.org/

4. Environmental issues: Climate damages and forest impacts

Climate damages will include reductions to the annual output of many vulnerable sectors and large-scale replacement costs for infrastructure damaged by flooding and other serious climatic effects. Forests have an important role in several aspects of climate modeling: changes in forest coverage due to climatic factors or land use changes will impact on emission sequestration, while investment in afforestation is expected to be a critical component of global mitigation policy.

4a. Incorporating climate damages

Economic models of climate change often calculate damages as a fraction of output, either for the economy as a whole or for vulnerable sectors such as agriculture. Based on primary research on climate damages, these models often specify a relationship between output losses and changes in temperature (or in some cases, changes in precipitation or sea level).[11] Thus a scenario with greater climate impacts would be projected to cause greater economic losses. Damages calculated in this manner result in an *underestimate* of the welfare cost of climate change because they fail to account for the disutility of having to bear the risks of climate change. This source of disutility would be real even if the potential damages never take place.[12]

Unfortunately, the expected magnitude of damages and their relationship to climate change are still being debated; there is nothing like a consensus about the appropriate estimates to use in economic modeling. Some models have even estimated net benefits to agriculture from the first few decades of climate change, either for the world as a whole or for high-latitude regions; newer research on agricultural damages has led many, but not all, economists to reject this view. (There is virtual unanimity that agriculture, like other sectors, will suffer from climate change in the long run.)

Inclusion of climate damages in an economic model requires that they be assigned prices. Some climate damages are naturally expressed in economic terms, but others, such as damages to human health and the natural environment, do not have prices.[13]

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[11] For a discussion on climate-economics models success in simulative the science of climate change, see van Vuuren, D.P., Lowe, J., Stehfest, E., et al. (2009). “How well do integrated assessment models simulate climate change?” *Climatic Change* 104(2), 255–85. DOI:10.1007/s10584-009-9764-2.

[12] There is no agreed-upon way of measuring this disutility. William Nordhaus’ early attempt to calculate willingness to pay to avoid catastrophic risk is described in Nordhaus, W. and Boyer, J. (2000), *Warming the World: Economic Models of Global Warming* (Cambridge, MA: MIT Press); for a critical reanalysis of the Nordhaus estimate, see Roughgarden, T. and Schneider, S. (1999), “Climate change policy: Quantifying uncertainties for damages and optimal carbon taxes,” *Energy Policy* 27(7), 415-29, DOI: 10.1016/S0301-4215(99)00030-0. More recent discussion has placed greater importance on reducing the possibility of catastrophic outcomes; see, in particular, Weitzman, M. (2009), “On modeling and interpreting the economics of catastrophic climate change,” *Review of Economics and Statistics* 91(1), 1-19, DOI: 10.1162/rest.91.1.1.

[13] For a discussion of monetizing non-market damages, see Ackerman, F. and Scrieciu, S. (2010). *Critical issues for climate policy analysis (or “boundary conditions”)*. Multi-Criteria Analysis for climate change: Developing guidance for sound climate policy planning (MCA4climate). Paris: United Nations Environment Programme. Available at http://www.mca4climate.info/medias/file/Critical_issues_for_climate_policy_analysis(1).pdf
Also, see Ackerman, F. and Heinzerling, L. (2004). *Priceless: On Knowing the Price of Everything and the Value of Nothing*. New York: The New Press.

Option 1: Measure climate damages as the expected reduction in vulnerable sectors' contribution to GDP, especially agriculture, fisheries, forestry, and tourism.

Option 2: Include both expected GDP losses in key sectors and the expected replacement cost of buildings and other infrastructure damaged by climate change.

Option 3: To these estimates of economic losses and replacements costs for damaged infrastructure, add a monetary value for damages to human health and the natural environment.

Recommendation: Option 1 leaves out what are expected to be some of the most serious economic costs of climate change: Damages to infrastructure from coastal flooding are likely to be extensive, and higher temperatures will have grave consequences for a wide range of infrastructure (roads, pipelines, ports, buildings), especially in the high latitudes.[14] For example, many buildings, underground train systems, and electrical distribution systems have been constructed with narrow heat tolerances, appropriate to the current climate. Option 2, which includes both economic losses and infrastructure costs, will provide the best climate damage estimates for most models. It will be important, however, to report model results along with a clear discussion of what is and is not included. While Option 2 includes only market damages, Option 3 has the added category of monetary values for non-market damages. This is a complicated area of modeling, where errors, conjecture, and implicit normative choices can easily dominate results. Often, a separate discussion of expected impacts to health and environment will be of more use to decision-makers than model results that lump together market and non-market effects.

4b. Forestry and deforestation

Forests sequester large amounts of carbon, which is removed from the atmosphere as trees grow, and "stored" in living trees for decades. Additional sequestration occurs in the carbon-rich soil of forests. Deforestation releases much of this sequestered carbon when trees are cut down; deforested soil also loses carbon over time. The *Stern Review*,[15] abatement cost studies by McKinsey & Company,[16] and other analyses have concluded that reductions in deforestation, or increases in afforestation, are among the world's lowest-cost options for greenhouse gas mitigation. This is of particular importance in countries with large tropical forests.

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[14] See National Round Table on the Environment and the Economy (forthcoming 2011). *Climate Prosperity: Economic Risks and Opportunities of Climate Change for Canada*.

[15] Stern, N. (2006). *The Stern Review: The Economics of Climate Change*. London: HM Treasury. Available at http://www.hm-treasury.gov.uk/stern_review_report.htm.

[16] See, for example, McKinsey & Company (2009). *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*. Available at http://www.mckinsey.com/clientservice/ccsi/pathways_low_carbon_economy.asp. McKinsey has also done country studies, available at http://www.mckinsey.com.

For countries with substantial forest sectors, it is important to include forest sequestration and deforestation emissions in any national accounting of emissions. The economics of forest protection and forest-based industries can be included in an economic model; these activities are generally quite separate from the principal sources of fossil-fuel emissions. Under some proposals that have been raised in global climate negotiations, there could also be significant international flows of resources related to forest protection in the future.

There are a number of unique issues that arise in accounting for forest sequestration of carbon. What is the baseline or business-as-usual level of growth or decline in forests, and forest carbon, which would have occurred in the absence of climate initiatives? Should that baseline level be counted as a change in emissions? How does an emissions inventory account for cases of accidental release of carbon dioxide, when trees are killed by wildfires, pests, or disease?

There is also a potential issue of double counting in the treatment of forest sequestration. In analyses of waste management, it is common to ignore carbon dioxide emissions from incineration or land disposal of paper, on the grounds that this is biogenic carbon, and will be reabsorbed when new trees are grown to produce an equivalent amount of paper for future use.[17] If the carbon dioxide removed from the atmosphere by tree growth has already been counted once, to offset paper disposal emissions, it should not be counted again as new carbon sequestration.

Option 1: Ignore emissions sequestered in forests, or include them only as a part of exogenous net emission projections already modeled by the national environment or natural resources bureau.

Option 2: Incorporate a simple forestry module into the main climate-economics model. In this module, forest sequestration projections would be driven by assumptions about future land use changes, including deforestation and afforestation, which in turn would be a function of exogenous policy choices and the economic growth in the main model.

Option 3: Link together a detailed forestry model – most likely an existing national forestry model – and the main climate-economics model.

Recommendation: For many nations, forest sequestration is not an important contributor to net emissions and is not likely to be an important contributor to future mitigation efforts; where this is the case, Option 1 will be sufficient. For nations with significant current-day forest sequestration and future afforestation potential, the choice between Option 2 and Option 3 will likely depend on the availability of an existing national forestry model that can be adapted to use in climate-economics modeling.

International Sources of Data on Forestry

Food and Agriculture Organization, http://www.fao.org/corp/statistics/en/

[17] This biogenic assumption refers only to carbon dioxide emissions. Methane emissions from land disposal of paper are a different matter; conversion of the carbon from wood and paper waste into methane in landfills greatly increases its global warming potential, well beyond the level that is offset by replacement growth in forests.

5. Model boundaries: interactions with other systems

For nations with larger economies and larger contributions to global emissions, it is essential to model the two-way interactions between the world economy and climate system on the one hand, and domestic economic output and emissions on the other hand. Changes to economic growth or emissions in smaller countries have correspondingly smaller impact on global trends; in such cases, the interaction effects are less important to accurate modeling. The energy system, both global and national, also has important interactions with national economic growth and greenhouse gas emissions. Including one or more separate energy sectors[18] in climate-economic models is essential for comprehensive representation of the consequences of national policies choices.

5a. Interactions with the world economy and climate system

For a small country or region, a model will often treat the key parameters of the world economy as exogenous, and unchanged by events within the national economy. World GDP, international demand for the country's exports, prices for oil, and for other imports and exports, and other factors are often assumed to be fixed, regardless of national decisions.

For a larger country, or for a major exporter of oil or other important commodities, it may be appropriate to model more complex interactions with the world economy. The largest developing countries and emerging industrial economies may be big enough to influence world markets and prices. In such cases, the model will need to be sufficiently complex to represent the two-way interactions.

At a global level, there are two major interactions between economic activity and the climate system. First, greenhouse gas emissions from production and consumption lead to climate change, which causes economic damages; second, investment in abatement reduces emissions, and therefore slows climate change, but also slows the rate of growth of consumption. (Investment in adaptation can also reduce climate damages, but does not affect the pace of climate change, as discussed above.) In a global climate-economics model, the interplay between these forces is at the core of the model's dynamics: economic growth makes climate change worse; abatement reduces climate damages but also dampens growth.

In a national or regional model, it is difficult to represent the full chain of two-way causation between climate and economy. On the one hand, the rest of the world's emissions will be exogenous to the model; local emissions are only a fraction of the global total. On the other hand, local abatement is only a fraction of the total global effort; it may be helpful to model local abatement as a specified share of worldwide effort, treating everyone else's abatement spending as exogenous to the national model.

[18]Multiple energy sectors make it possible to capture the possibility of substituting zero-carbon primary energy sources for fossil fuels.

Option 1: Model the world economy, global emissions, and the atmospheric concentrations of greenhouse gases as exogenous to national economic growth, baseline emissions, and mitigation efforts. A variation on this option would model small changes in global emissions consistent with national changes in emissions and the nation's share of global emissions.

Option 2: Model the world economy exogenously, but model changes to global emissions (and the resultant atmospheric concentrations) either as proportional to national mitigation efforts (in other words, assume that other nations will carry out the same level of emission reductions as the nation under study) or in accordance with Kyoto or another common schedule of reductions.

Option 3: Model the world economy and global emissions as function of national economic growth and emissions, and other global variables.

Recommendation: Many nations' economic output and emissions are so small in relation to the global total that Option 1 will be the most appropriate choice. Option 3, a central concern of global integrated assessment models, is the most costly in terms of modeling effort and data requirements. Only the nations with the largest economies need attempt this level of complexity in climate-economics modeling. For most nations with significant emissions, Option 2 will provide the correct level of detail for an accurate representation of global impacts on national damages and economic growth.

5b. Interactions with the energy system

Energy use is crucial to modern life, and is the source of the great majority of greenhouse gas emissions. Depending on the level of detail in the model, the energy sector may be treated separately, including electricity, heating fuel, and energy used in transportation and industry. Energy prices, taxes, and subsidies will influence energy use. Total energy demand and the composition of energy sources used are likely to change as temperatures rise, reducing the need for heating fuels and increasing the need for electricity to run refrigeration and air conditioning systems.

In the short run, the key variables to model are often the use of different modes of transportation and the energy efficiency of each mode, and the demand for electricity and mix of fuels used to generate it.[19] For later years, in a model with a longer time horizon, technological development will determine the rate at which new energy options become available, and the projected prices for various energy sources. Much will depend on the model's assumptions about oil supplies, market power of oil producers, and the availability of unconventional, environmentally damaging sources of oil such as shale and tar sands.

[19] See Fisher, J. and Ackerman, F. (2011). *The Water-Energy Nexus in the Western States: Projections to 2100*. Somerville, MA: Stockholm Environment Institute-U.S. Center and Synapse Energy Economics Inc. Available at http://sei-us.org/publications/id/370

Option 1: Model energy use as proportional to economic growth, and assume an exogenous decrease in carbon intensity over time (that is, assume installation of improved technology that increases energy efficiency and decreases greenhouse gas emissions per unit GDP).

Option 2: Model energy use separately from other economic activity, assuming an exogenous decrease in carbon intensity over time and a simple relationship between temperature change and energy use.

Option 3: Model both carbon-based and zero-carbon energy sources separately from other economic activity, and introduce endogenous technological improvements, so that greater investment in alternative energy reduces the relative cost of similar future investments. This option should also include the expected relationship between temperature change and energy use.

Recommendation: Option 1 oversimplifies many of the key relationships between energy use, economic growth, and climate change. Option 3 represents the cutting edge of current climate economics modeling, an area that is still undergoing significant development and that is only attempted in the most complex (usually global) models. For most national models, Option 2 offers an appropriate level of detail while avoiding undue model development costs.

International Sources of Data on Energy

International Energy Agency, http://www.iea.org/

U.S. Energy Information Agency, http://www.eia.doe.gov/countries/

World Bank, http://data.worldbank.org/