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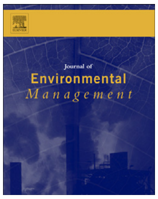

The influence of spatial resolution on human health risk co-benefit estimates for global climate policy assessments

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ABSTRACT

Assessment of the ability of climate policies to produce desired improvements in public health through co-benefits of air pollution reduction can consume resources in both time and research funds. These resources increase significantly as the spatial resolution of models increases. In addition, the level of spatial detail available in macroeconomic models at the heart of climate policy assessments is much lower than that available in traditional human health risk modeling. It is therefore important to determine whether increasing spatial resolution considerably affects risk-based decisions; which kinds of decisions might be affected; and under what conditions they will be affected. Human health risk co-benefits from carbon emissions reductions that bring about concurrent reductions in Particulate Matter (PM_{10}) emissions is therefore examined here at four levels of spatial resolution (Uniform Nation, Uniform Region, Uniform County/city, Health Risk Assessment) in a case study of Taiwan as one of the geographic regions of a global macroeceonomic model, with results that are representative of small, industrialized nations within that global model. A metric of human health risk mortality (YOLL, years of life lost in life expectancy) is compared under assessments ranging from a “uniform simulation” in which there is no spatial resolution of changes in ambient air concentration under a policy to a “highly spatially resolved simulation” (called here Health Risk Assessment). PM_{10} is chosen in this study as the indicator of air pollution for which risks are assessed due to its significance as a co-benefit of carbon emissions reductions within climate mitigation policy. For the policy examined, the four estimates of mortality in the entirety of Taiwan are 747 YOLL, 834 YOLL, 984 YOLL and 916 YOLL, under Uniform Taiwan, Uniform Region, Uniform County and Health Risk Assessment respectively; or differences of 18%, 9%, 7% if the HRA methodology is taken as the baseline. While these differences are small compared to uncertainties in health risk assessment more generally, the ranks of different regions and of emissions categories as the focus of regulatory efforts estimated at these four levels of spatial resolution are quite different. The results suggest that issues of risk equity within a nation might be missed by the lower levels of spatial resolution, suggesting that low resolution models are suited to calculating national cost-benefit ratios but not as suited to assessing co-benefits of climate policies reflecting intersubject variability in risk, or in identifying sub-national regions and emissions sectors on which to focus attention (although even here, the errors introduced by low spatial resolution are generally less than 40%).

1. Introduction

Environmental assessment plays a crucial role in maintaining environmental sustainability, as environmental quality is increasingly affected by human activities such as electricity generation (Finnveden et al., 2003), transport (Granovskii et al., 2006), agriculture (Australian Government, 2009), industrial development (Morra et al., 2006) and water resource management (Mitchell, 2005). In order to quantify and compare the positive and negative effects of economic activities on the environment, and to design appropriate policies for mitigating risk, tools for integrating public health, ecosystem assessment, land use, and material use and flows into Environmental Impact Assessment (EIA) and Strategic

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Environmental Assessment (SEA) have been developed. In both EIA and SEA, significant attention is focused on human health risk as a driver of policy choice (European Parliament and Council of the EU, 2001; UNECE, 2003; WHO, 2004), both as a direct benefit of environmental policies generally and an indirect co-benefit of climate and energy policies specifically.

Climate change has significant implications for many human activities, including economy, energy supply, and transport. Although climate change mitigation policies reduce greenhouse gas (GHG) emissions, there is increasing understanding that such policies can be accompanied by positive and negative ancillary effects on public health, ecosystems, land use, and materials. In these ancillary effects, a potentially significant positive co-benefit of GHG mitigation is reduction in human health risk (Bollen et al., 2009). Since co-benefits of climate change policies in terms of air pollution control accrue, co-benefits provide some incentives to put in place climate change mitigation policies and programmes by offsetting some GHG mitigation costs in the short term and by focusing political attention onto shorter-term, more localized, impacts of climate policy.

For example, in 1999, the near-term human health benefits resulting from avoided mortality and morbidity due to the co-benefits of PM reduction taking place during GHG reduction from the energy sector was assessed in China. The results demonstrate that the near-term health co-benefits from GHG reductions could be substantial but are highly dependent on the technologies and sectors chosen as the focus of mitigation efforts (Wang and Smith, 1999). In 2000, in order to improve the use of estimates of air quality benefits in assessing Canada's GHG reduction options, the co-benefits associated with some of the GHG emission reduction measures were assessed, and shown to produce economic savings of several hundred million dollars per year in 2010 (Caton and Constable, 2000). Cifuentes et al. (2001) assessed near-term public health consequences of reductions in ambient concentrations of particulate matter and ozone associated with policies to reduce GHG emissions, based on existing transportation and energy.

A significant challenge in linking climate policy and human health analyses through co-benefits is that macroeconomic models (often as input–output or I–O models) are at significantly lower spatial resolution than is common in human health risk assessment. Human health impacts in global analyses of climate policies are therefore simulated by less spatially detailed models that scale ambient concentration changes to emissions changes in each of the modeled economic regions. The decision to use such approximations is driven in part by the infeasibility of conducting full HRA for the millions of sources of emissions in the almost 200 nations involved in climate negotiations, and in part by the lack of economic data at small spatial scales. In some cases, this initial simplification may be followed by detailed application of other aspects of HRA and Life Cycle Assessment (LCA) to improve the accuracy and detail of localized human health risk estimates (Matthews et al., 2002; Flemström et al., 2004; Udo de Haes et al., 2007); for instance, potential human exposure to a toxic pollutant is calculated with CalTOX and the exposure and risk estimates adapted for LCA evaluation (Huijbregts et al., 2005). In other cases, empirical factors have been used to convert fractional changes in emissions within an economic region into fractional changes in ambient air concentration, and then to estimate health co-benefits of climate change mitigation in regard to particulate matter and ozone based on these less spatially detailed analyses (Crawford-Brown et al., 2012, 2013).

By contrast, Health Risk Assessment (HRA) quantifies the effect of a policy on the health of populations using significantly more detailed spatial resolution than economic models, with a concern for both the over all incidence of effects and any disparities in effects across geographic regions or social groups that might raise concerns over equity. Geographically explicit source-oriented thinking is commonplace in HRA, which helps analysts identify the points of most effective intervention within the risk chain starting from particular sources of pollutant releases and ending with the health consequences to receptors. The locations of emission sources with respect to receptors are emphasized in HRA, since this spatial relationship can observably influence exposures and hence risks at highly local levels. For example, spatially-resolved HRA for long-term emissions has been carried out for a municipal solid waste incinerator in Italy, and the harms to receptor populations assessed in regard to dioxins/furans, Cd, Pb and Hg through air inhalation, dermal contact, soil and food ingestion (Cangialosi et al., 2008). In addition, HRA may be integrated with GIS to yield an HRA-GIS tool which can help local authorities and policy makers in managing risks and planning remedial and reduction actions for industrial sources (Morra et al., 2006). Recently, HRA of major sources releasing arsenic was converted into sector-based risk coefficients (where a sector can refer to either a component of infrastructure or an economic sector), and then used with an I–O table to analyze the association between economic sector activities and health risks (Ma et al., 2012).

The replacement of highly spatially resolved HRA with analyses at the lower levels of spatial resolution common in economics is particularly noted when environmental and health risk models are coupled to global macroeconomic models to study the influence of broad climate policies such as carbon taxes that drive general economic shifts across many sectors of the economy simultaneously and can result in leakage both between economic sectors and between national economies (Crawford-Brown et al., 2013). This reduction in spatial resolution arises because the underlying I–O information used in macroeconomic models generally is aggregated across each economic sector (such as manufacturing), reducing the ability to specify where particular instances of the economic activity are located spatially. If macroeconomic models are to be used in integrated assessments of climate policy, or in assessment of global policies that rely on national or even regional I–O tables, there will be an inevitable reduction in the spatial resolution of emissions sources and hence of ambient concentrations, exposures and risks that underlie HRA.

If greater spatial resolution were required to produce reasonably accurate estimates of environmental and health indicators in global climate policy assessments, there would be a need to produce I–O tables at smaller geographic units, greatly increasing the cost of the macroeconomic analyses and introducing considerable uncertainties into those analyses. It is necessary to understand, therefore, the influence of greater spatial resolution on calculation of the health co-benefits from policies and programmes of GHG reduction. The degree of spatial resolution ranges from a “uniform simulation” in which there is no spatial resolution of changes in ambient air concentration across a defined area of the macroeconomic model, up to a “highly spatially resolved simulation” common in HRA. These two extremes of spatial detail in human health risk assessment are methodologically and also normatively different with respect to the manner in which they identify the points of intervention within the risk chain for a policy or programme. For example, highly spatially resolved analyses allow focus on particular instances of an economic sector (eg. on specific factories in the manufacturing sector) in a specific location, while less spatially resolved analyses must necessarily examine policies or programmes applied uniformly across an entire economic sector and region reflected in a macroeconomic model. The differing levels of spatial resolution can therefore (under conditions to be explored in this paper) lead to different conclusions as to where an intervention can be made most effectively in reducing risk both