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# Primary Sources of Greenhouse Gases: A Cross-Scale Comparison

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## Introduction[1]

Until the 1990s, most efforts to identify the human activities producing greenhouse gases (GHGs) and to measure their emissions focused on the global level. At the global scale, GHGs diffuse and mix regardless of their points of origin. This universal mixing, however, makes it difficult to use instruments for measuring GHG emissions at sub-global scales. Instead, analysts must infer GHG emissions from the human activities responsible for the emissions. Most countries keep broad records of production and consumption of fossil fuels, chemical manufacture and use, land in forestry and agriculture, waste disposal, and other major human activities within their boundaries. It is relatively straightforward, therefore, to construct national inventories of GHG emissions from general human activity data. The United States, for example, has compiled GHG emissions inventories from such data since before 1990.[2]

Still, in a large, diverse country like the United States, the mix of human activities and resulting GHG emissions varies from region to region and state to state. For instance, states dominated by agriculture

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1. The first two sections of this paper are modified from ADAM ROSE ET AL., REPORT TO THE PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION, GREENHOUSE GAS EMISSION INVENTORY FOR PENNSYLVANIA PHASE I REPORT (2003).

2. *See* Energy Information Administration, U.S. Dep't of Energy, Emissions of Greenhouse Gases in the United States 2000, (2001), *available at* http://www.eia.doe.gov/oiaf/1605/1605a.html#links (last modified Apr. 7, 2003); Environmental Protection Agency, U.S. Inventory of Greenhouse Gas Emissions and Sinks, 1990-1999, (2001), *available at* http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2001.html (last modified Jan. 10, 2001).

like Kansas, heavy manufacturing like Ohio, or coal mining like West Virginia emit markedly different bundles of GHGs. If the United States were to develop a national mitigation plan to reduce emissions, but failed to account for state-by-state differences, it is unlikely that the plan would succeed because it would lack the detail to be cost-effective and equitable. On the one hand, a "one size fits all" national policy skewed toward reducing emissions from the largest source categories, says coal-fired electric utilities, would place a crippling social and economic burden on regions or states dependent on coal. On the other hand, parts of the country dominated by emissions source categories making up a small part of the national mix, such as agriculture-related methane and nitrous oxide emissions in grain belt states, may be called upon to reduce emissions less than their fair share.[3] Therefore, as a first step towards developing an effective plan for greenhouse gas abatement, states must compile emissions inventories.

Recognizing the need for state-level action, the United States Environmental Protection Agency (EPA) has encouraged states to compile emissions inventories for more than a decade. The GHGs cataloged by United States emissions inventories at both national and state levels include carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and certain manufactured fluorinated gases commonly known as ozone depleting compounds (ODCs) and their substitutes (ODSs). ODCs include chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which were banned under the Montreal Protocol and are no longer, included in GHG emissions inventories. ODSs include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sodium hexafluoride ($SF_6$). The sectors tracked by the greenhouse gas emission inventories include activities associated with energy production and consumption, other industrial processes, agricultural production, forestry, and waste disposal. The state-level emissions inventory protocols use the international reporting standard established by the Intergovernmental Panel on Climate Change (IPCC) and expanded by EPA.[4] Rose et al. assembled the most recent Pennsylvania emissions inventory in which

3. William E. Easterling, III, et al., Changing Places, Changing Emissions: The Cross-scale Reliability of Greenhouse Gas Emissions in the U.S., 3 LOC. ENV'T 249, 249-64 (1998).

4. EMISSION INVENTORY IMPROVEMENT PROGRAM, ESTIMATING GREENHOUSE GAS EMISSIONS, (1999), *available at* http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html (last modified June 19, 2003); INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, REVISED 1996 IPCC GUIDELINES FOR NATIONAL GREENHOUSE GAS INVENTORIES, (1997), *available at* http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm (last visited Sept. 22, 2003); ENVIRONMENTAL PROTECTION AGENCY, *supra* note 2.

they compared 1990 and 1999 emissions.[5]

Not only is there great diversity from state to state, but also there is tremendous variation within most states. In Pennsylvania, various cities, counties, and regions are known for their coal mining, transportation systems, manufacturing, agriculture, forestry, or refuse disposal. Even in one place, Centre County for example, all of these activities are important. Ultimately, sub-state entities, such as metropolitan regions, counties, and even universities, will need to compile inventories and formulate mitigation action plans.[6] Recent efforts have recognized that need. For instance, the Global Change in Local Places project adapted the EPA state-level methodology to conduct GHG inventories for select counties in North Carolina, Kansas, Ohio, and central Pennsylvania.[7] The International Council for Local Environmental Initiatives-Cities for Climate Protection (ICLEI-CCP) campaign independently developed tools to inventory GHGs from communities and institutions.[8] Lachman used this instrument to compile a GHG emissions inventory for The Pennsylvania State University.[9]

The following discussion will demonstrate how GHG emissions vary across scales by comparing emissions of the United States, Pennsylvania, and central Pennsylvania for 1990.[10] The emissions of central Pennsylvania represent the five-county study area—Clearfield, Centre, Clinton, Union, and Snyder counties—investigated for the Global Change in Local Places project.[11] First, however, it is important to review methods used to compile GHG emissions inventories.

## GHG Emissions Methodology

GHG emission figures are estimates of emissions based on socioeconomic activity data. They are only as accurate as the underlying socioeconomic data and the accounting practices, transformations, and emissions and conversion factors applied to those data. Experts are

5. ROSE, *supra* note 1.

6. Thomas J. Wilbanks & Robert W. Kates, *Global Change in Local Places: How Scale Matters*, 43 CLIMATIC CHANGE 601 (1999).

7. Robert W. Kates & Ralph Torrie, *Global Change in Local Places*, 40(2) ENV'T 5, 39-41 (1998); Robert W. Kates et al., *Methods for Estimating Greenhouse Gases From Local Places*, 3 LOC. ENV'T 279-97 (1998); Easterling, III et el., *supra* note 3.

8. Kates et al., *supra* note 7.

9. Steven F. Lachman, A greenhouse gas inventory of the University Park campus of the Pennsylvania State University (1999) (unpublished M.S. thesis, The Pennsylvania State University).

10. *See also* Easterling, III et al., *supra* note 3.

11. Andrea Denny et al., Global Change and Central Pennsylvania: Local Resources and Impacts of Mitigation, *in* Global Change in Local Places: Estimating, Understanding, and Reducing Greenhouse Gases, (Association of American Geographers Global Change in Local Places Research Team, eds.) (Cambridge University Press) 122-140 (2003).

constantly improving the techniques used to convert socioeconomic data to GHG emissions.

Municipal waste management can be used to demonstrate the process of estimating emissions from socioeconomic data. In this case, GHG emissions and sequestration have three sources: $CH_4$ emitted from waste at each landfill, $CO_2$ and $N_2O$ emitted from the annual combustion of municipal solid waste, and carbon sequestered by the annual addition of waste to landfills. There are no direct measurements of these GHG sources or sinks by instruments, so they must be estimated from socioeconomic data. Calculation of emissions from combustion of municipal solid waste and carbon sequestration from land filling are relatively simple because annual data on waste combustion and land filling are available. Multiplying these quantities by coefficients that reflect the average emissions and sequestration per ton of waste provides reliable estimates of the emissions and sequestration resulting from each activity.

$CH_4$ emissions from municipal solid waste are less straightforward, however. Once placed in a landfill, municipal solid waste can emit $CH_4$ for as long as thirty years. Thus, to calculate $CH_4$ emissions, it is necessary to know how much waste is in place at each landfill and the age of that waste. These data are not always readily available, so the EPA methodology provides a formula for estimating waste in place using gross population data, the average waste disposal per capita, and a thirty-year multiplier. Although this methodology is imprecise, the resulting figure provides a reasonable approximation of $CH_4$ emissions that does not require costly new data collection from each landfill for the last few decades.

Cross-Scale Comparison

Comparing percentage radiative forcing by GHGs emitted by the United States, Pennsylvania, and central Pennsylvania during 1990 shows little difference between the nation and state.[12] The United States and Pennsylvania have virtually the same contributions from $CO_2$ (89% and 90%, respectively) and from $N_20$, (2% and 3 %), while the largest difference exists in contributions from $CH_4$ (12% and 9%), which is only 3%. However, Central Pennsylvania contrasts significantly with both the nation and the Commonwealth. Radiative forcing from $CO_2$ emitted

12. *See infra* Figure 1, app. The updated 1990 GHG emissions estimates for Pennsylvania by Rose et al. were under embargo at the time of this writing. Thus, older figures from California University of Pennsylvania, *Greenhouse Gas Emissions in Pennsylvania: An Inventory* (Earth Systems Laboratory, California University of Pennsylvania 1993) are used here for comparison, not for precision.

from this area is 8% higher than Pennsylvania as a whole, while $CH_4$ and $N_20$ are roughly half the state averages.

A similar comparison of radiative forcing by GHGs emitted by five important socioeconomic sectors provides comparable results.[13] Fossil fuel combustion contributes approximately the same proportion of radiative forcing for the United States (89%) and Pennsylvania (90%). The agricultural and waste management sectors add 4% to 5% for both the nation and the state; production processes and biomass burning supply 1% at both levels. In contrast, 96% of the contribution to radiative forcing from central Pennsylvania comes from burning fossil fuel, while the other four sectors contribute 1% each.

Why does central Pennsylvania differ so dramatically from the rest of the nation? The answer is coal. Central Pennsylvania derives 77% of its radiative forcing from coal combustion, which is nearly two times the coal-based radiative forcing from Pennsylvania and two and a half times that from the United States.[14] When split between coal used to generate electricity and coal used for all other purposes in central Pennsylvania, 35% of all radiative forcing from the state comes from $CO_2$ emitted by electric utilities using coal and 42% comes from all other reasons to burn coal (e.g., running manufacturing plants or heating homes).[15] In distinction, both the United States and Pennsylvania generate 26% of their total radiative forcing from coal-fired electricity production and only 5% and 13%, respectively, from all other coal burning.

## Conclusions

The results of the cross-scale comparison demonstrate that Pennsylvania does not appear to be significantly different in its GHG emissions profile from the United States. In the absence of other data, one could assume that a mitigation strategy aimed at reducing the nation's GHG emissions would work equally well for Pennsylvania. Easterling et al. suggest that such an assumption would mean that the mitigation plan might not be effective in other states with radically different profiles of GHG sources, such as Kansas.[16]

The results also show that—because of its dependence on coal as an energy source—central Pennsylvania varies considerably from national emissions patterns and even from Pennsylvania as a whole. If a national emissions reduction strategy targeted coal, then this area would suffer disproportionately as it restructured its economy to meet national

13. *See infra* Figure 2, app.
14. *See infra* Figure 3a, app.
15. *See infra* Figure 3b and Figure 3c app.
16. Easterling, III et. al. *supra* note 3.

mandates.[17]

The implications of these results are that a United States GHG mitigation strategy must take into account regional and local differences in emissions. A "one size fits all" plan to reduce GHG emissions would produce gross inequities, with some places shouldering more than their fair share of the burden and others making few sacrifices in the drive to stem climate change. Mitigation plans that do not account for spatial unevenness in emissions not only will be unfair, but also will be much less effective than schemes that help each area address the problem in ways that put this global problem into regional and local context.

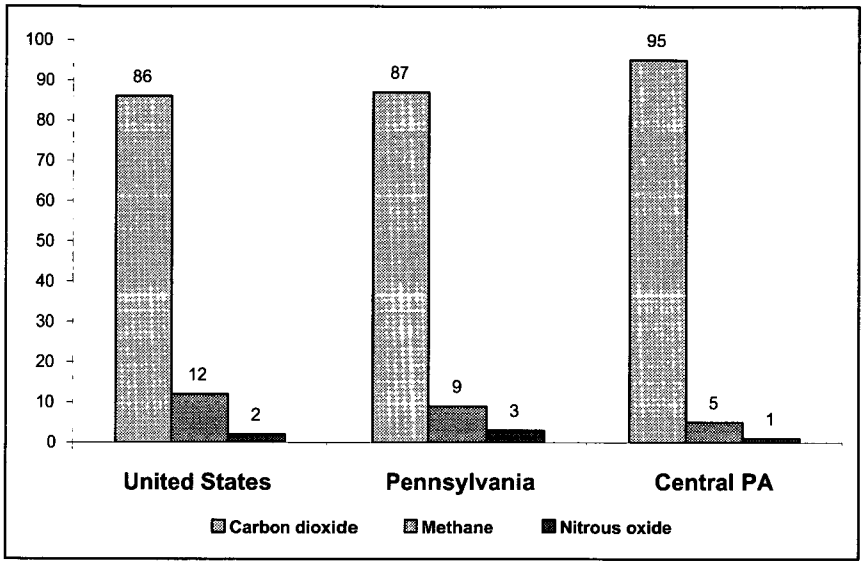


Figure 1. Percent radiative forcing by GHG, 1990, from the United States, Pennsylvania, and central Pennsylvania.

17. Denny, *supra* note 11.

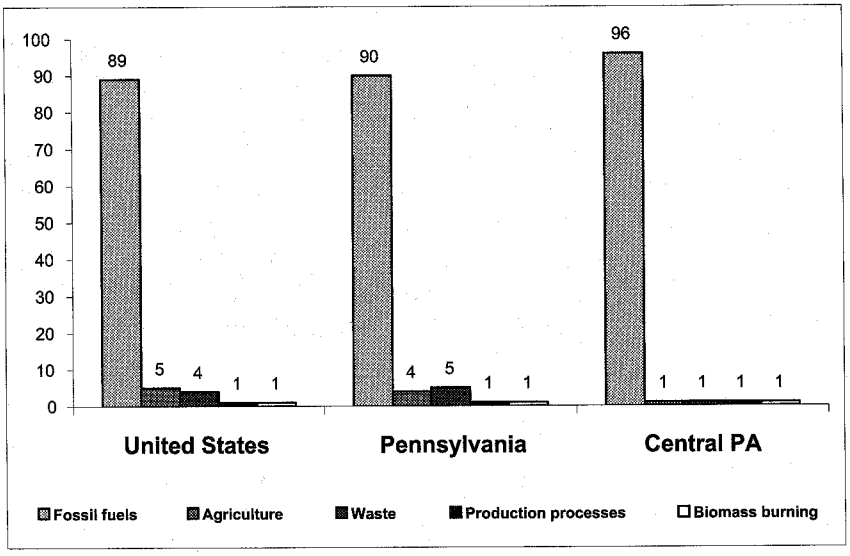


Figure 2. As in Figure 1, but for percent radiative forcing by socioeconomic sector.

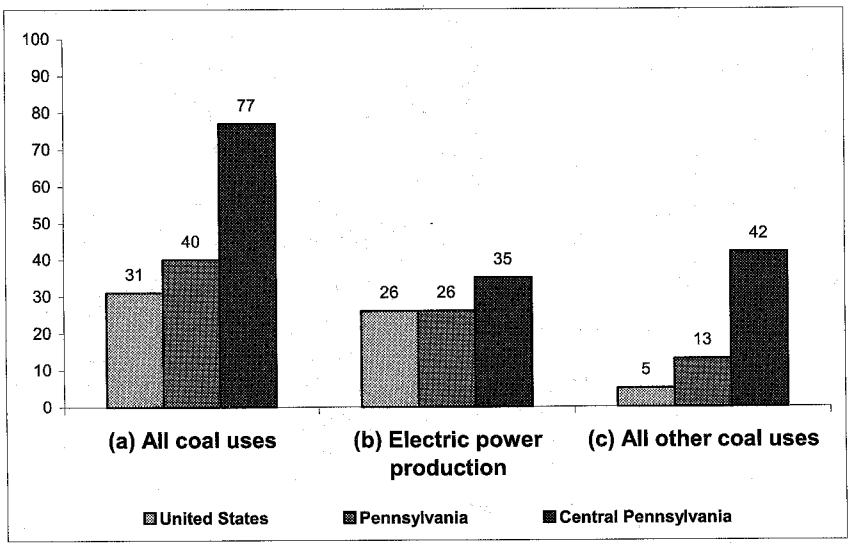


Figure 3. As in Figure 1, but for percent radiative forcing from (a) all sources of coal combustion, (b) coal combustion by electric utilities, and (c) coal combustion by all sources except electric utilities.