State Greenhouse Gas Inventories – Tools for Streamlining the Process

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ABSTRACT

In 1999, under the auspices of the Emission Inventory Improvement Program (EIIP), the U.S. Environmental Protection Agency's State and Local Climate Change Program (SLCCP) and a group of state experts revised the guidance on preparation of state-level greenhouse gas (GHG) inventories. Although the revised methods are consistent with methods used in the U.S. GHG inventory and international guidance, the approach is resource-intensive, representing a barrier to states preparing an inventory.

To improve the inventory process, the SLCCP implemented a pilot streamlining project to support development of the Florida Greenhouse Gas Inventory. The approach identifies three "key" emissions sources to be estimated for all state inventories: carbon dioxide from fossil fuel combustion , methane from landfills, and carbon flux from land use change and forestry. Additional sources are then identified by applying selection criteria based on potential significance of the sector in the state; interest in the sector on the part of state staff; availability of data; quality of data and certainty of the method; cost of developing an estimate; and availability of cost-effective mitigation options.

The streamlined approach was successful on several fronts. First, it provided estimates of GHG emissions from eight source categories, encompassing the majority of total emissions and sinks. Second, the framework employed methods that are consistent with current international, national, and state guidance on GHG inventory preparation. Third, the streamlined inventory framework reduced the cost of inventory preparation, making it possible for Florida to quickly develop an inventory and to begin considering mitigation strategies.

INTRODUCTION

The U.S. Environmental Protection Agency's State and Local Climate Change Program (SLCCP) began in 1992 with a goal of building climate change capacity in state and local governments and encouraging states to take actions to reduce greenhouse gas (GHG) emissions. In pursuit of these goals, EPA encouraged states to prepare GHG emission inventories. In addition to building technical and institutional capacity in the states on the climate change issue, GHG inventories provide a baseline to measure future changes in state emissions and represent a critical step toward developing comprehensive climate change policies and strategies. State inventories also help states identify opportunities to reduce emissions.

Among the products of the State and Local Climate Change Program has been guidance on the methods for developing GHG emission inventories. The guidance mirrored the approach used in the U.S. Inventory, which was in turn based on international guidance.

International inventory guidance, combined with lessons learned through preparation of the U.S. inventory, were the basis of the step-by-step inventory guidance EPA's State and Local Climate Change Program developed for the states. EPA has revised guidance on state-level inventories three times since publishing the first State Workbook in 1992. The workbook was revised in 1995 and 1998 to reflect changes in the IPCC methods. In 1999, the workbook was thoroughly reviewed, revised, and updated under the auspices of the Emission Inventory Improvement Program (EIIP). The resulting document, EIIP *Volume VIII: Estimating Greenhouse Gas Emissions*, reflected experience of state officials, use of the Data Attribute Ranking System (DARS) to systematically rate uncertainty in the methods and data, and some updates to the methods. *Volume VIII: Estimating Greenhouse Gas Emissions* provides methods to estimate GHG emissions and sinks from 14 sectors:

- Combustion of fossil fuels;
- Industrial processes;
- Natural gas and oil systems;
- Coal mining;
- Municipal waste disposal;
- Domesticated animals;
- Manure management;
- Flooded rice fields;
- Agricultural soils;
- Forest management;
- Burning of agricultural crop wastes;
- Municipal wastewater;
- Methane and N_2O emissions from mobile source combustion; and
- Methane and N_2O emissions from stationary source combustion.

For each sector, the guidelines describe sources of data, emission factors, calculation methods, sources of uncertainty, and suggestions on reporting. In the years since the first guidance was published, 34 states plus Puerto Rico have developed GHG inventories. Of these, 17 states have completed state action plans for reducing GHG emissions.

STREAMLINING THE STATE GHG INVENTORY PROCESS

Since the first EPA guidance on developing state emission inventories was published, the number of sources and the complexity of the estimation methods have reflected the comprehensive approach initially set forth by Intergovernmental Panel on Climate Change (IPCC). The most recent guidance for states (EIIP *Volume VIII*) includes the 14 source categories listed above, comprising over 50 source- and GHG-specific methods for estimating emissions. The number of sources, complexity of the

methods, data-intensity, and the sheer length of the guidance document indicate the time and resource-intensive nature of state GHG inventory preparation.

Based on the experience of the states that have completed comprehensive inventories, it is clear that most of the emissions and sinks, and most of the best mitigation opportunities, are associated with a relative handful of sources. Moreover, the effort involved in characterizing some of the less important sources can be as intensive as the effort to analyze those representing the best opportunities.

Strategically, the principal objective of the State and Local Climate Change Program is to encourage state and local governments to take actions that mitigate GHG emissions. To the extent that the state inventory process was so resource-intensive that it acted as a barrier impeding states from getting involved in climate change planning and actions, it was important to streamline the process.

In the past, the Program had been reluctant to embark on this streamlining, in part because of the desire to maintain consistency with the national inventory and international guidance. The IPCC has embarked on an effort to encourage streamlining, through its efforts to develop "Good Practice" guidelines for inventories.

The IPCC *Good Practice* report provides guidance on the following elements:

- Choice of estimation method within the context of the *IPCC Guidelines*;
- Quality assurance and quality control procedures to provide cross-checks during inventory compilation;
- Data and information to be documented, archived, and reported to facilitate review and assessment of emission estimates; and
- Quantification of uncertainties at the source category level and for the inventory as a whole, so that the resources available for research can be directed toward reducing uncertainties over time, and the improvement can be tracked.[1]

The methodological choice guidance in the *Good Practice* report is achieved through the identification of "key source categories." These key source categories are determined through both quantitative factors—in terms of their fraction of total emissions and effect upon aggregate emission trends or uncertainties—and qualitative factors—such as an expectation of significant future growth in emissions. The purpose of this determination is that resources should be focused on improving the estimates (i.e., reducing the uncertainty) for these source categories.

So conditions were ripe for streamlining the state GHG inventory process by focussing efforts on a set of key sources, based on experience gained in other states that had conducted inventories and from preparing the national inventory. The impetus for the effort came when Florida Department of Environmental Protection (FDEP) officials indicated their interest in completing an inventory, but expressed concerns about the ability of state staff to participate due to resource constraints. The State and Local Climate Change Program offered to assist Florida in the development of a streamlined inventory. EPA felt that, if successful, this effort would serve to lower the barrier for preparation of state GHG inventories and lead to inventory development in other states.

The general framework we developed involves four steps:

- Characterize key sources and sinks
- Set priorities for additional sources
- Characterize additional sources
- Report results and implications for mitigation.

For any state, three GHG sectors are considered key sources: carbon dioxide (CO_2) fossil fuel combustion, methane (CH_4) from landfills, and carbon flux from land use change and forestry. These sources are the main drivers of total emissions on a national basis, as shown in Figure 1. Fossil fuel CO_2 and landfill CH_4 comprise 80 percent and 3 percent of total U.S. emissions, respectively, while land use change and forestry is the largest sink, comprising about 99 percent of U.S. carbon storage. (This percentage includes storage in paper and wood products and storage of landfilled products, both of which are usually included in the overall estimate of sequestration.) Moreover, completed state inventories are generally consistent with this skewed distribution, following from the fact that energy consumption, disposal of waste, and land use changes are ubiquitous and economically important practices. Lastly, for fossil fuel combustion and land use change and forestry, federal agencies maintain emissions estimates apportioned on the state level. The Energy Information Administration has compiled data on state energy use and the SLCCP has converted this to estimates of CO_2 emissions for each state, and the United States Forestry Service operates a forest carbon model that provides carbon flux data for each state.

The priority-setting step involves a screening analysis to choose additional sources where analysis would be most fruitful. The remaining sectors and gases (industrial processes, natural gas systems, enteric fermentation, etc.) generally contribute far less to overall emissions and sinks, and are much more difficult to estimate, due to more complex methods, less available data, or both. Also, many emission source activities have varying importance among the states. For example, rice cultivation and coal mining are concentrated in a few regions of the U.S. and are a negligible source of emissions for many states.

Criteria for setting priorities among the remaining sectors include the following:

- Significance of the sector (in terms of contribution to total emissions and sinks)
- Interest in the sector on the part of state staff
- Availability of data
- Quality of data and certainty of the method (based on Data Attribute Ranking System [DARS] scores as rated in the EIIP guidance)
- Cost of developing an estimate
- Availability of cost-effective mitigation options.

The characteristics of other sources vis-à-vis the criteria are evaluated based on readily available information and discussions with state personnel. After completing the screening step, the general approach continues with the estimation of emissions and sinks for the selected sectors. Finally, the results are summarized, with emphasis on the sectors where mitigation opportunities are likely to be present. The availability of these opportunities is based, in part, on the frequency with which they are recommended by other states that have developed complete Action Plans for mitigating emissions. (See

http://yosemite.epa.gov/globalwarming/ghg.nsf/StatePolicyOptionsSearch?OpenForm for a searchable data base with this information.)

THE FLORIDA GHG PILOT INVENTORY

Having developed a general framework for streamlining state inventories, the next step was to test it by applying it for estimating Florida's emissions and sinks. Below is a discussion of the methods used to estimate emissions from the key sources; a summary of how the criteria were used to select additional sources; and the methods used to estimate emissions from the additional sources.

Estimating Key Sources

Fossil Fuel Combustion CO_2

To estimate the CO_2 emissions resulting from energy use, the method outlined in the EIIP Workbook was followed. Emissions are calculated on a fuel-by-fuel basis, and are equal to the product of a fuel's consumption, its carbon content, and its oxidation efficiency. Appropriate adjustments are made to account for the carbon stored via non-energy fuel uses, i.e., fuels that are transformed into products, such as asphalt, lubricants, or plastics, rather than combusted for energy. Data on fuel consumption is provided for each of the 50 states by the Energy Information Administration of the Department of Energy in its *State Energy Data Report.* Carbon content values can be found in the EIIP Workbook. (The individual state summaries and spreadsheet files associated with the *State Energy Data Report* are available for viewing and downloading at http://www.eia.doe.gov/emeu/sedr/contents.html.)

Landfill CH_4

Like the fossil fuel combustion CO_2 emissions, CH_4 emissions from landfills are estimated using the method found in the EIIP Workbook. This method describes net CH_4 emissions as the amount of CH_4 generated by landfills, less the amount of CH_4 collected by flaring or utilization systems and less the amount of CH_4 oxidized by soil (typically 10 percent of generation). Methane generation is a function the size of each of the state's landfills (large landfills exhibit different emissions patterns than small landfills), the average rainfall, and the total waste-in-place (WIP) deposited in the state's landfills over the last 30 years (waste has a CH_4 generating capacity for approximately 30 years). Hence, two sets of data are necessary to calculate emissions using this method: a state-level estimate for the total WIP, and landfill-level information which characterizes the size, number, and CH_4-flaring or -collecting capacity of the state's landfills.

The state-level value for total WIP was estimated by adding historical annual waste generation data, found in the FDEP's *1999 Solid Waste Management in Florida Annual Report.* The landfill information was assembled from communications with the FDEP and from *Landfill Gas-To-Energy Project Opportunities: Landfill Profiles for the State of Florida*, developed by the EPA's Landfill Methane Outreach Program (LMOP). In general, a state's environmental or solid waste department tracks characteristics of individual landfills such as size, acceptance rate, and CH_4 flaring/collection equipment. The Landfill Profiles, available for thirty-one states, also present this information and are accessible on-line.

Land Use Change and Forestry

Land Use Change and Forestry are characterized through application of a U.S. Forest Service model that has been used for the U.S. GHG inventory.[2] The model partitions ecosystem carbon (C) into three separate components – biomass, forest floor, and soil – and estimates the stock of carbon in each component, based on extensive sampling of forest plots for forest inventories and ecosystem studies. The model estimates average C storage for forest stands based on their age, forest type, productivity class, and land use history. Estimates of carbon stocks are available for 1987, 1992, and 1997. For any year bracketed by these dates, the change in carbon stored over the interval, divided by five years, is the annual flux. The net change through the period was toward more carbon storage (i.e., removals from the atmosphere); thus, the results for this sector are expressed as a negative emission (that is, an offset to emissions).

Identifying Additional Sources

To select additional sources, the first criterion applied was potential source significance. We used the results of the 1998 U.S. GHG Inventory (the most recent U.S. GHG Inventory estimates are available on the Internet at http://www.epa.gov/globalwarming/emissions/national/download.html) as an indicator, assuming that Florida's emissions are distributed in rough proportion to the national distribution. Table 1 shows that, outside of the three core sources, fossil fuel combustion CO_2, landfill CH_4, and land use change and forestry, there are only nine other sources that, taken individually, account for greater than 0.5 percent of gross emissions. After performing this first cut, the field of other sources was narrowed based upon a combination of data availability, state interest, and cost of developing an estimate. The project group made decisions on the nine candidate sources:

- Coal Mining and HFC-22 Production were excluded since these activities either do not occur or do not occur to any great extent in Florida.
- Due to the importance of agricultural activities to Florida's economy, Agricultural Soils, Enteric Fermentation, Manure Management were of particular interest to the FDEP officials. Data for these sources are readily available from the U.S. Department of Agriculture (USDA) and the American Association of Plant Food Control Officials (AAPFCO) on an annual, state-by-state basis.
- Due to the widespread and frequent use of air conditioners and refrigerants, FDEP was also interested in emissions from the Substitution of Ozone Substances. Although the data for developing these estimates is not available on a state-by-state basis, it was decided that apportioning national emissions on a population basis would provide a quick, low-cost, and reasonably accurate approximation.
- Natural Gas Systems and Mobile Sources were excluded because the estimation methodologies for both sources require large sets of activity data and neither suggest obvious mitigation opportunities.
- Emissions from Cement Manufacture were excluded due to their small relative significance. Cement is produced throughout the country, and although Florida's cement production is high relative to other states, it accounts for less than 4 percent of national cement clinker production.

Table 1. Top emissions sources, 1998 U.S. greenhouse gas emissions

Emissions Source	1998 Emissions (MMTCE)	Percentage of Gross Emissions
Fossil Fuel Combustion	1,468	80%
Land-Use Change and Forestry	-211	-11%
Landfills	59	3%
Agricultural Soil Management	84	5%
Natural Gas Systems	34	2%
Enteric Fermentation	34	2%
Manure Management	23	1%
Coal Mining	18	1%
Mobile Sources	17	1%
Substitution of Ozone Depleting Substances	14	1%
HFC-22 Production	11	1%
Cement Manufacture	11	1%

Note: Grey shading indicates "Key Source."

Estimating Additional Sources

Agricultural Soils

Nitrous oxide emissions from Agricultural Soils were estimated using methods proscribed by the EIIP Workbook. Emissions come in two forms: direct emissions, where N_2O is released directly to the atmosphere, and indirect emissions, where ammonia (NH_3) and oxides of nitrogen (NO_x) are emitted to the atmosphere and subsequently deposited into soil, ultimately increasing atmospheric N_2O releases that occur within the nitrogen cycle.

Cropping practices, such as cultivation of nitrogen-fixing crops and histosols (high organic content soils), incorporation of crop residues to soils, or application of fertilizers and animal waste to fields are all sources of direct N_2O emissions. Indirect N_2O emissions result from the application of fertilizers and animal waste applied to fields and from the associated nitrogenous leaching and runoff.

In order to calculate emissions, nitrogen content/generation and volatilization factors from the EIIP guidance are applied to data on livestock populations, crop production, cropping practices, and fertilizer use. This data is gathered from the U.S. Department of Agriculture (USDA), which provides all data on a state-by-state basis, and from the Association of American Plant Food Control Officials (AAPFCO), which provides data on state or regional levels.

Enteric Fermentation and Manure Management

For both sources, the methodology found in the EIIP Workbook was used. The methods have been treated together since both are functions of livestock population, taken from USDA data. Enteric fermentation is estimated by multiplying animal populations by their respective animal-specific, region-specific CH_4 generation factors. The manure management emissions estimation method is very similar, using state-specific factors describing manure management systems and animal-specific nitrogen and CH_4 generation factors.

Substitution of Ozone Depleting Substances

Because data on emissions are not available on a state-by-state basis, national emissions were simply apportioned based on population. Data for U.S. and Florida population was taken from the U.S. Census Bureau.

RESULTS OF THE INVENTORY

We estimated Florida's gross emissions (excluding offsets from land use change and forestry) from the seven source categories included in our streamlined inventory to be 55.9 MMTCE in 1990. Since 1990, emissions from these sources have increased 14 percent to 63.3 MMTCE in 1997. Carbon sequestration associated with land use change and forestry was responsible for offsetting 2.5 MMTCE of emissions in 1990 and 2.3 MMTCE of emissions in 1997, or 4.5 and 3.6 percent of gross emissions, respectively. Net emissions in Florida, calculated as emissions minus sinks, ranged from 53.4 MMTCE in 1990 to 61.0 MMTCE in 1997.

The most prevalent GHG was CO_2, with emissions comprising 50.7 to 57.6 MMTCE/year (approximately 90 percent of gross emissions) during the period from 1990 through 1997, as shown inTable 2. Annual CH_4 emissions ranged from 3.5 to 3.9 MMTCE, representing between 5.5 and 6.7 percent of gross emissions. Nitrous oxide emissions were relatively consistent from 1990-1997, comprising approximately 1.6 MMTCE (2.4 to 2.8 percent of gross emissions). Emissions of HFCs and PFCs, negligible in 1990, increased to 0.7 MMTCE in 1997 as the demand for substitutes for ozone depleting substances increased.

Table 2. GHG emissions by sector and gas (MMTCE)

	1990	1991	1992	1993	1994	1995	1996	1997
Carbon Dioxide (CO_2)	**48.15**	**48.35**	**49.45**	**50.23**	**51.67**	**52.52**	**53.53**	**55.26**
Fossil Fuel Combustion	50.68	50.88	51.77	52.55	53.99	54.84	55.85	57.58
Land-Use Change and Forestry (Sink)[a]	-2.53	-2.53	-2.32	-2.32	-2.32	-2.32	-2.32	-2.32
Methane (CH_4)	**3.64**	**3.75**	**3.83**	**3.79**	**3.85**	**3.91**	**3.51**	**3.50**
Landfills	2.71	2.82	2.90	2.85	2.89	2.94	2.59	2.60
Enteric Fermentation	0.71	0.72	0.73	0.74	0.75	0.76	0.73	0.72
Manure Management	0.21	0.21	0.20	0.21	0.20	0.20	0.19	0.19
Nitrous Oxide (N_2O)	**1.58**	**1.58**	**1.60**	**1.59**	**1.57**	**1.58**	**1.59**	**1.54**
Agricultural Soils	1.27	1.28	1.30	1.28	1.27	1.28	1.28	1.24
Manure Management	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Consumption HFCs and PFCs	**0.01**	**0.01**	**0.02**	**0.08**	**0.15**	**0.38**	**0.54**	**0.67**
Total Emissions	**55.90**	**56.22**	**57.22**	**58.01**	**59.56**	**60.71**	**61.49**	**63.30**
Total Sinks	**-2.53**	**-2.53**	**-2.32**	**-2.32**	**-2.32**	**-2.32**	**-2.32**	**-2.32**
Net Emissions	**53.37**	**53.69**	**54.90**	**55.69**	**57.24**	**58.39**	**59.17**	**60.98**

Emissions in Florida in 1990 represent 4 percent of U.S. emissions from the seven source categories included in the streamlined GHG inventory for Florida. On a per capita basis, emissions in Florida – approximately 4.3 MTCE for both 1990 and 1997 – were slightly below the national average for the eight streamlined sources in the U.S. as a whole, which increased from 4.8 MTCE in 1990 to 5.5 MTCE in 1997.

Table 3 presents a comparison of sectoral emissions in the U.S. and Florida for the sources included in Florida's streamlined inventory. Fossil fuel combustion was responsible for the majority of emissions in Florida, as it is been in other states and in the U.S. In Florida, emissions from fossil fuel combustion represented 90 percent of total gross emissions. Landfills and agricultural soils were the next largest sources of emissions; on average, they represented 5 percent and 2 percent of total gross emissions, respectively.

Table 3. Percentage of gross GHG emissions by sector and gas for sources included in Florida's Streamlined GHG Inventory.

	Florida	U.S.
CO_2	**90.6%**	**87.4%**
Fossil Fuel Combustion	90.6%	87.4%
Land-Use Change and Forestry (Sink)	-4.0%	-16.8%
CH_4	**6.3%**	**7.0%**
Landfills	4.7%	3.7%
Enteric Fermentation	1.2%	2.1%
Manure Management	0.3%	1.2%
N_2O	**2.7%**	**5.2%**
Agricultural Soil Management	2.2%	5.0%
Manure Management	0.5%	0.2%
HFCs, PFCs, and SF_6	**0.4%**	**0.4%**
Total Emissions	**100.0%**	**100.0%**

According to the *U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-1999*, sources included in Florida's streamlined inventory comprise 91 to 92 percent of total gross emissions in the U.S. during the period from 1990 through 1997 (Table 4).

Table 4. Comparison of U.S. emissions from sources included in Florida's Inventory to total U.S. emissions (MMTCE).

	1990	1991	1992	1993	1994	1995	1996	1997
Gross Emissions from "Streamlined" Sources	1,505	1,492	1,521	1,554	1,585	1,598	1,653	1,678
Gross Emissions from All Sources	1,650	1,636	1,667	1,700	1,733	1,748	1,804	1,828
Fraction of Gross Emissions Represented by "Streamlined" Source Emissions	**91%**	**91%**	**91%**	**91%**	**91%**	**91%**	**92%**	**92%**

CONCLUSIONS

The framework used to streamline Florida's inventory, although not as comprehensive as the EIIP guidance or the national inventory, was successful on several fronts. First, the inventory resulted in reliable estimates of GHG emissions from eight source categories that represent over 90 percent of national emissions. Second, this framework employed methods that are consistent with the IPCC Good Practices framework and with the most current international, national, and state guidance on GHG inventory preparation. Third, the streamlined inventory framework reduced the cost of inventory preparation, making it possible for Florida to develop an inventory and to begin considering mitigation strategies.

We learned several important lessons through demonstration of the streamlined process in Florida. The source selection process is an effective one, and is likely to lead

to capture of a majority of important sources. In the process, the criterion addressing uncertainty is not one of the chief discriminating factors – most of the sources outside of the "key" set have similar uncertainty. Probably the most important methodological lesson is that enteric fermentation, manure management, and agricultural soils should be added to the list of key sources. All rely on readily available data assembled at the state level, and all are generally significant insofar as they comprise 8 percent of national gross emissions.

The streamlined inventory process "lowers the bar" for inventory preparation at the state level. This is particularly important from the perspective of the State and Local Climate Change Program, whose mission is to encourage states to evaluate sources of GHG emissions and take actions to reduce emissions within state boundaries. Without some indication of baseline emissions, it would be difficult for state officials to identify and implement cost-effective GHG mitigation strategies. For these reasons, we feel that the streamlined GHG inventory approach may be useful for other states interested in quantifying GHG emissions and identifying strategies to reduce state emissions.

REFERENCES

1. IPCC. *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventory Programme. 1999.

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Figure 1. Distribution of U.S. 1997 Gross GHG Emissions*
(Key sources appear in **Bold**)