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Project Summary

Evaluation of Significant Anthropogenic Sources of Radiatively Important Trace Gases

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Emissions of greenhouse gases from human activities, including fossil fuel combustion, industrial/agricultural activities, and transportation, contribute to the increasing concentrations of radiatively important trace gases (RITGs) in Earth's atmosphere. In order to evaluate the extent to which these anthropogenic (human) activities will influence future atmospheric composition and climate, it is necessary to identify all significant global sources and sinks, and to characterize the strengths of these sources. Trace gases of concern include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), chlorofluorocarbons (CFCs) and ozone (O_3). Several gases which are not themselves radiatively active, but which can contribute to the buildup of a radiatively active trace gas, include oxides of nitrogen (NO_x) and nonmethane hydrocarbons (NMHCs). These compounds play a key role in the formation of ozone in the troposphere.

The U.S. EPA has conducted several emissions research projects to evaluate and better characterize emissions from specific sources of RITGs. The purpose of these emissions research projects was to rank sources of RITGs in terms of their potential impacts on radiative forcing and to develop country- and source-specific emission factors where data were adequate to warrant emission factor development. In addition, for some source categories, preliminary country-specific information was collected which could be of use in future emission factor research. One of the objectives of this document is to integrate the results of these research projects and to identify areas where further research is needed.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Approach

The methodology used in this study involved two levels of screening: a preliminary source assessment, followed by a detailed source characterization. The preliminary source assessment evaluated a source's contribution to estimated global radiative forcing, evaluated the potential for emissions from that source to vary from country to country, and assessed potential data weaknesses. Based on the results of the preliminary source assessment, the detailed source characterization involved development of improved emissions data, and where data were adequate, country-specific emission factors.

Table 1 identifies RITG sources that were assessed and those chosen for further evaluation by source characterization. In some cases, available country-specific data were inadequate to support emission factor development. In these cases, data availability as well as data needs were documented. As follow-on research to this study, several sources were

Table 1. Summary of Source-Specific Studies Conducted

Source	Associated Gases	Preliminary Assessment	Country-Specific Emission Factor Development [a]	Further Research [b]
Utility Coal-fired Boilers [c]	CO_2, NO_x	x	x	
Utility Oil/Gas-fired Boilers	CO_2, NO_x	x		
Industrial Boilers [c]	CO_2, NO_x	x		
Coal Mines	CH_4	x		x
Natural Gas Transmission/ Distribution	CH_4	x	x	x
Transportation	NO_x, VOC, CO, CO_2, N_2O	x	x	
Rice Cultivation	CH_4	x	x	
Crop Fertilization	N_2O	x		
Municipal Solid Waste Landfills	CH_4	x	x	x
Deforestation	CO_2, CH_4	x		
Misc./Industrial/Other Sources [d]	CH_4	x		
Res/Ind CFC Use	CFC	x		
Residential Wood Combustion	CO_2, NO_x	x		
Residential/Commercial Fossil Fuel	CO_2, NO_x	x		

[a] *Detailed assessments were conducted for some sources with the initial intent of developing country-specific emission factors. However, emission factors could not be developed for all sources because of limitations in readily available data.*

[b] *Note: Sources evaluated in the Further Research stage are not within the scope of this project.*

[c] *Country-specific data developed for utility coal-fired boilers are also applicable to industrial coal-fired boilers.*

[d] *These sources include transportation, solvent use, coke production, chemical manufacturing and all other sources included in a global VOC inventory model developed by EPA.*

chosen for a third stage of research in other projects. These are identified in Table 1. A more detailed discussion of these evaluations follows.

Preliminary Source Assessments

Overview of Assessments

Preliminary source assessments were conducted as a first step in the process of developing improved emissions estimates. The objectives of the preliminary source assessments were to (1) assemble and evaluate current global emissions estimates, determine the weaknesses in those estimates, and identify sources whose emissions characteristics are most uncertain on global scales and are thus in need of improvement; (2) estimate and evaluate the significance of the contribution of individual sources of RITGs to global emissions and potential global warming; and (3) assess the potential for emissions from key sources to vary from country to country based on technological or other differences which may exist between countries.

A major objective of this project was to develop a relative ranking of the significance of major sources of RITGs, or greenhouse gases. The first step was to develop a set of greenhouse gas significance (GGS) factors for CO_2, CH_4, N_2O, CFCs, and NO_x emitted by anthropogenic sources; these factors equal the percentage of total estimated global warming, o total "radiative forcing potential" (RFP), at tributable to these emissions between 198 and 1990 (the period selected for thi analysis). Once these factors were devel oped, they were multiplied by the fractio of total global emissions of each gas at tributable to a specific source—the globa emissions significance (GES) factor. Th result of this second step was the RFP c a specific gas from a specific source, o the percentage of total estimated globa warming attributable to emissions of tha gas from that source. The gas-specifi RFPs for each source were then summe to obtain the *total* RFP for each majo source of RITGs.

Between 1985 and 1990, the estimate percentage contributions to potential globa warming, or GGS factors, or the RITG evaluated in this study are: CO_2, 54; CH 20; N_2O, 8; and tropospheric O_3, 7. De tails of the development of these factor and their use in determining the total RFP for each major source of RITGs are pr vided in the full report. The assessment c results from that effort are given below.

Results of Assessments

The most significant source of RIT emissions is industrial and utility coal us (this group includes coal combustion an coal mining), which is estimated to have total RFP of 17; i.e., 17% of total glob radiative forcing. Emissions of CO_2 accou for over 14% of the estimated forcin while CH_4 and NO_x emissions account f about 3%. If residential and commerci coal use is also considered, the radiati forcing associated with the global uses coal (burning and mining) is estimated be about 20%.

Several other source categories co tribute significantly to radiative forcing (s Table 2). These categories include ag cultural activities (e.g., CH_4 emissions fro rice cultivation, and N_2O emissions fro general tilling and fertilizing), industrial a residential CFC use, and CO_2 and N from transportation sector oil consumptic Each is estimated to have a total RFP 11. Deforestation from forest burning a tivities contributes significant quantities CO_2 and is estimated to have a total R of 9. The loss of forests results in the lo of a sink for CO_2 emissions which is negative feedback not included in the f tors above.

Industrial and residential CFC use estimated to have a total RFP of Transportation sector fuel consumpt contributes significant emissions of C and NO_x. In addition, the transportat sector is one of the most potentially s nificant sources contributing to troposph

Table 2. Estimated Total Radiative Forcing Potential Associated with Major Source Groups [a]

General Source Group Description	Estimated Contribution to Radiative Forcing (%)	Key Greenhouse Gases	
		Primary	Secondary
Utility and Industrial Coal Use (includes mining)	17	CO_2	CH_4, NO_x
Rice Cultivation and General Tilling and Fertilizing	11	CH_4, N_2O	--
Industrial and Residential CFC Use (includes automobile air conditioning units)	11	CFCs	--
Transportation Sector Oil Consumption	11	CO_2	NO_x
Deforestation	9[a]	CO_2	CH_4, N_2O
Residential Wood Combustion	9[a]	CO_2	CH_4, N_2O
Residential and Commercial Fossil Fuel Combustion (coal, oil, gas)	7	CO_2	CH_4
Industrial Oil Combustion	6	CO_2	NO_x
Utility and Industrial Gas Consumption, Industrial Process Emissions, Cement Manufacturing, Waste Disposal Sources, Fuel Production, and Ruminants	19	CO_2, NO_x	
Total	100		

[a] *The total forcing associated with deforestation is actually about 20%. However, the CO_2, N_2O, and CH_4 emissions and the loss of CO_2 sink activity are split between the agricultural and residential sectors since an estimated 50% of the wood cut in deforestation is burned for residential heating and cooking. This analysis does not take into account that the combustion processes between field and residential appliance combustion may differ and ,thus, the emissions may also differ.*

ozone because of the high NO_x, VOC and CO emissions associated with automobile use in urban areas. Table 2 shows that several other fuel combustion groups contribute significantly to radiative forcing. These include residential wood combustion, estimated to have a total RFP of 9; residential and commercial fossil fuel use, estimated to have a total RFP of 7; and industrial oil combustion, estimated to have a total RFP of 6. As with utility and industrial coal use, CO_2 emissions account for most of this forcing, while NO_x, N_2O, and CH_4 are estimated to contribute the rest.

The analysis to rank source categories of greenhouse gases by their radiative forcing potential was not the only factor considered in choosing the sources to be evaluated in greater detail. Since one objective of this research was to develop country-specific emission factors where possible, a preliminary evaluation was conducted to identify sources which have a potential to vary significantly from country to country. Each of the sources evaluated was assessed for this variation potential. Oil combustion in industrial and utility boilers is a source of greenhouse gases, but these emissions do not vary significantly from country to country because fuel quality and combustion efficiency are relatively consistent. However, transportation sector fuel consumption is a major source of NO_x emissions, and these emissions vary significantly from country to country due to differences in fuel efficiency and applied emissions controls. CH_4 emissions from rice cultivation vary due to differences in climate, number and length of growing season(s), and the average soil temperature of the rice growing region. CH_4 emissions from municipal solid waste (MSW) landfills vary according to waste composition, waste disposal method, climate, and design characteristics of the landfill. Natural gas transmission and distribution systems emit CH_4 as a function of throughput, system design and maintenance, and pipeline construction materials.

A great deal of uncertainty surrounds existing emissions estimates for many source types. One objective of EPA's global climate research is to identify areas where uncertainty can be reduced. In general, emissions estimates for most CH_4 sources are the least certain; because of this, significant emphasis was placed on evaluating several key CH_4 sources in more detail. EPA is currently conducting measurements research programs to improve the understanding of coal mine CH_4 emissions as well as emissions from MSW landfills and natural gas production and distribution facilities.

Detailed Source Characterizations

Overview of Characterizations

The objectives of the detailed source characterizations were to develop improved emissions data and, where data were adequate, to develop country-specific emission factors for key sources. Another objective was to identify the additional data and analysis needed to make further improvements in the emission factors for key sources. Under the source characterizations, country-specific fuel, technology, and other data were obtained in an effort to develop more representative emission factors for the key sources of RITGs identified in the preliminary assessments. Where adequate supporting data were available, country-specific emission factors were developed.

Results of Characterizations

Based on the results from the preliminary source assessments, country-specific emission factors were developed for coal-fired utility boilers, natural gas production/distribution sources, transportation sources, MSW landfills and rice cultivation. Improved country-specific data were developed for coal mining operations, but these data were insufficient for developing

country-specific emission factors. Ongoing research is being conducted by EPA to support the development of coal mine emission factors and improved global emissions estimates from coal mine ventilation (see discussion below). Brief descriptions of the sources evaluated are provided below, along with tables of emission factors developed in this study.

Utility Coal-Fired Boilers

Coal combustion technologies are significant sources of CO_2 and to a lesser extent, ozone precursors such as NO_x and VOC. Based on calculations performed for this study, coal-fired utility boilers are estimated to account for approximately 10% of total global radiative forcing due to emissions of CO_2 and NO_x. Factors which can significantly affect emissions from utility boilers include overall generating station efficiency, the extent of electricity use within the plant (partially driven by the use of emissions controls), fuel quality parameters such as coal heat content and carbon content, electrical transmission system and distribution system efficiency, type of controls used (if any), and the general boiler design. Because these factors can vary significantly from country to country, country-specific information was obtained for these factors so representative emission factors could be developed. The factors taken into account in developing CO_2 emission factors for this study include fuel quality (heat content and carbon content) and generation station efficiency (busbar efficiency). Transmission line loss data are also presented because these data are needed for emissions modeling and other RITG research. Emission factors range from 44,620 g CO_2-C/GJ in Finland to 159,003 g CO_2-C/GJ in Pakistan (as a point of reference, the U.S. is 74,767 g CO_2-C/GJ). The countries for which emission factors were developed account for more than 99% of coal combustion in utility boilers.

Some initial data on the types of NO_x controls used in some Organization for Economic Cooperation and Development (OECD) countries and the NO_x emissions standards used in several countries were also identified. However, these data were not sufficient to warrant the development of country-specific NO_x emission factors for coal-fired boilers.

Natural Gas Production/ Distribution Systems

Natural gas consists of 89 to 93% CH_4, and losses of natural gas through gas production and distribution systems have been estimated to account for 9 to 12% of total annual global CH_4 emissions from anthropogenic sources. Factors which may affect CH_4 emissions from production and distribution systems include the age and condition of the system, the construction materials, the total length of pipeline and the number and type of fittings, the system throughput, and perhaps climate and soil conditions. Country-specific emission factors developed in this study range from 0.2% loss (percent of natural gas throughput) in Tunisia to 5.5% in Argentina (as a point of reference, the U.S. is 1.3%). The countries evaluated for emission factor development account for about 75 percent of global natural gas production in 1985. These factors can be multiplied by a country's pipeline system throughput to estimate CH_4 emissions for each country. For this study, throughput was defined as the sum of indigenous production (minus exports) plus any imports. These emission factors attempt to account for gas lost to the atmosphere after the first metering point in the natural gas production and distribution system. As a consequence, they may not take into account gas lost at the well head itself. EPA is currently conducting research to characterize CH_4 emissions from natural gas operations.

Municipal Solid Waste Landfills

Municipal solid waste landfills have been estimated to account for between 4 and 15 percent of global CH_4 emissions from anthropogenic sources. Country-specific parameters affecting emissions include per capita waste generation rate, waste composition, fraction of waste landfilled, and any CH_4 recovery practices employed. Emission factors developed for countries where sufficient data were available to support emission factor development take into account the percent of waste landfilled, percent degradable organic content, and waste generation rates. Country-specific data from 31 countries representing approximately 67% of the global population were collected in developing these emission factors. The emission factors range from 1.6 kg CH_4/capita/yr in Switzerland to 42 kg/capita/yr in Canada (as a point of reference, the U.S. is 36 kg/capita/yr).

Transportation Sources

Motor vehicles emit many pollutants including hydrocarbons, CO, NO_x and CO_2, all of which contribute to global climate change. Based on research conducted in this study, transportation sector fuel consumption is estimated to account for about 11% of the radiative forcing potential associated with anthropogenic sources. Factors affecting emissions from motor vehicles within a specific country include fleet average fuel efficiency (a function of automobile efficiency and fleet retireme rate) and the level of emissions cont achieved by each country (i.e., the degr to which crankcase ventilation, exhau controls, engine modifications, and tw or three-way catalysts are applied). The factors must be characterized to devel country-specific emission factors. Count specific CO_2, CO, and NO_x emission fa tors developed for light duty gasolir powered vehicles for 37 countries whe data were available represent 88% of t world vehicle fleet. The emission fact range: from 6752.7 g CO_2/gal.* in m developing countries to 7977.6 g CO_2/g in Japan (with 7892.6 in the U.S.); fr 39.2 g NO_x/gal. in Japan to 55 g NO_x/gal most developing countries (with 41.6 the U.S.); and from 339.8 g CO/gal. Japan to 871 g CO/gal. in most develop countries (with 378.2 in the U.S). M general uncontrolled global emission f tors for light duty diesel vehicles are e mated to be 7675 g CO_2/gal., 23 g CO/g and 24 g NO_x/gal. Given that assumptic are made for future fuel efficiency a control levels, the country-specific d developed for transportation sources c be used to estimate emission factors wh are representative of the future fleet automobiles.

Rice Cultivation

CH_4 emissions from wet rice cultivat are estimated to account for about 30% total global emissions of CH_4. Given approximate radiative forcing potentia CH_4, wet rice cultivation therefore is e mated to account for about 6% of t global radiative forcing. The factors aff ing CH_4 emissions from rice cultivation clude the total land area under rice c vation in a country, the number of grow days per year (a function of the num and length of the growing seasons), the release rate of CH_4 per hectare year. The release rate is strongly correl with average soil temperature, whicl turn is a function of the type of sea (wet or dry). These factors were all c sidered in developing country-spe emission factors. The countries for w emission factors were developed acc for more than 90 percent of world production. Except for emission fac developed for low temperatures (19-2C the difference between the two set emission factors is fairly consistent. wet season emission factors develc from Italian data tend to be about t times higher than those developed the Spanish data, while the dry se

*1 gal. = 3.8 L.

emission factors are about four times higher. The wet season emission factors range from 1.9 mg/m²/hr in Japan (Spanish data) to 41.7 mg/m²/hr in Bangladesh (Italian data). The dry season emission factors range from 1.8 mg/m²/hr in India (Spanish data) to 28.3 mg/m²/hr in Indonesia (Italian data)

A number of other factors affect CH_4 emissions but insufficient data exist to incorporate these factors into current emission factor estimates. These factors include the effects of fertilizer use, the presence of salts in the paddy water, the effect of the organic composition of the paddy soil, and the effects of plant density on CH_4 emissions. These additional factors should be explored if future research is conducted to characterize CH_4 emissions from rice cultivation.

Coal Mining

CH_4 emissions from coal mines are estimated to contribute approximately 10% of total global CH_4 emissions. The maturation of a coal seam produces CH_4 by biogenic and thermogenic processes. CH_4 release from a coal mine depends on many factors, including the amount and rank of coal obtained from underground and surface mines, the underground mining technique used, underground and surface mine depth, coal rank and characteristics, coal-bed CH_4 content, gob gas quantities and characteristics, and current CH_4 recovery and use practices. Improved country-specific data were developed for coal mining operations, but these data were not complete enough to warrant country-specific emission factor development. Further research was conducted by EPA to develop emission factors based on relationships between measureable physical parameters related to coal mining. A global estimate of CH_4 emissions from the ventilation air of coal mining operations was also developed in the course of this research. These research results will be provided in a forthcoming EPA report.

Industrial/Other Sources of CH_4

Little attention has been given to smaller anthropogenic sources of CH_4 in past studies characterizing anthropogenic CH_4 emissions. The objectives of the preliminary assessment of industrial/other sources of CH_4 were to identify previously uncharacterized anthropogenic sources of CH_4, to develop preliminary estimates of the amount of CH_4 released by these sources, to evaluate the quality of the data used to make these estimates, and to determine any potential data weaknesses or additional data needs. CH_4 emissions from numerous anthropogenic source types were estimated using a global emissions inventory model. These estimates were compared to other estimates to identify globally significant source types. Model input data were evaluated to assess data quality. The five most significant source groups identified in this assessment were fuel-wood burning, coke production, refuse disposal (not including MSW landfills), miscellaneous industrial other, and rubber, plastic, and other organic chemical manufacturing.

Principal Findings

Principal findings of the research discussed in this report are listed below:

- The most significant group of sources is utility and industrial coal use (including mining), which contributes significant quantities of CO_2, CH_4, and NO_x to the global atmosphere.
- Rice cultivation and general tilling and fertilizing, industrial and residential CFC use, and transportation sector oil consumption also contribute significantly to total global warming.
- Sources of CH_4 (including coal mining, natural gas production/distribution systems, MSW landfills, rice cultivation, and miscellaneous industrial sources) were identified as general areas of uncertainty needing evaluation.
- As a result of the detailed source characterizations, country-specific emission factors were developed for coal-fired utility boilers, natural gas production/distribution systems, transportation sources, municipal solid waste landfills, and rice cultivation.

Future Data Needs

When research projects are conducted on global scales, difficulties are encountered with the availability, reliability, and consistency of various types of data. The research conducted here to improve the understanding of the country-specific emissions characteristics of specific sources is no exception. One objective of these studies was to identify data gaps and data needs; this section summarizes those deficiencies for sources for which detailed assessments were conducted and, to a lesser extent, for some sources where only preliminary assessments were conducted. These data gaps and data needs include:

- Although CO_2 emissions from utility and industrial coal-fired boilers have been extensively researched, less information is available about NO_x. Data needs include information on boiler population and design, combustion parameters, and coal types.
- There are many data gaps in the current understanding of CH_4 emission from natural gas production/distribution systems. Most measurements at transfer points are currently made at an accuracy of about 1%. A methodology is needed to accurately characterize CH_4 losses from natural gas production/distribution systems besides the losses at transfer points.
- Future research on coal mining needs to expand the focus of past research efforts by (1) developing relationships describing coal-bed CH_4 content on the basis of measureable physical parameters, (2) using the information developed in (1) to develop estimates of the CH_4 content of mine ventilation air (the largest single source of CH_4 from mining operations), and (3) ultimately, extrapolating this methodology to develop global estimates of CH_4 emissions from coal mines. This further research will be documented in a forthcoming EPA report.
- Factors affecting CH_4 emissions from MSW landfills which need further characterization include the effect of building landfills above ground rather than below ground, the effects of moisture and ambient temperature on CH_4 production, and the extent of the use of gas collection systems. In addition, more country-specific information on the factors which influence CH_4 generation (e.g., waste composition, per capita waste generation rate, and prevalence of landfills as a disposal method) is needed.
- Factors affecting CH_4 emissions from rice cultivation which need to be further researched include the use of fertilizer, the presence of salts in the paddy water, plant density, and composition and temperature of paddy soils. More country-specific information is generally needed as well, particularly studies which focus on rice cultivation in the Far East.
- In the area of transportation, country-specific retirement rates, emissions control data, import/export, and production data are needed. The effect of fuel efficiency on carbon-based species needs to be quantified.
- Key uncertainties are associated with the raw data and the methods used to interpret and use the data for developing the global CH_4 inventory of miscellaneous sources of CH_4.

An additional analysis conducted as part of this study examined atmospheric chemistry research needs rather than mitigation or control strategy scenarios. This analysis indicated a consensus among atmospheric chemistry modelers that the most significant emissions research need was better inventories of NO_x emissions. This emphasizes the need f better understanding of the global intera tions of NO_x, CH_4, and other RITGs.

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The complete report, entitled "Evaluation of Significant Anthropogenic Sources of Radiatively Important Trace Gases," (Order No. PB 91-127 753/AS; Cost: $23.00, subject to change) will be available only from:
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