GREENHOUSE EMISSIONS FROM WASTE MANAGEMENT

A survey of data reported to UNFCCC by Annex I countries

Final Report

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Frank Ackerman, William Moomaw, and Robin Taylor
Global Development and Environment Institute
Tufts University
Medford MA 02155, USA

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EXECUTIVE SUMMARY

This report examines reported greenhouse gas emissions related to waste management submitted by Annex I countries under the reporting requirements of the UN Framework Convention on Climate Change. The information evaluated includes data submitted by 27 countries according to the Common Reporting Format (CRF) and information provided by 14 countries in National Inventory Reports (NIR).

The relative types and quantities of greenhouse gases released from solid waste depend upon the composition of the waste and the management system that is used. Hence there can be substantial differences in waste related greenhouse gas emissions among otherwise similar countries. Solid waste can be managed by incineration of combustible components, with or without heat recovery that displaces fossil fuels. Alternatively, it can be disposed of in landfills or open dumps, or recycled or composted. Each of these methods produces differing combinations of carbon dioxide, methane and other gases, at rates that are very site specific. Emissions from land disposal are the largest, on a CO_2-equivalent basis, and the least certain; indeed, UNFCCC reporting rules allow two alternative means for estimating methane from landfills.

Consistent and accurate reporting of greenhouse gas emissions is essential for the equitable and effective functioning of present and future climate agreements. The calculation of emissions of carbon dioxide emissions from fossil fuel combustion and most industrial gases is fairly straightforward, using standardized emission factors. However, because of the physical and chemical processes involved in the release of emissions from waste, the waste sector's emissions are more difficult to determine. Errors or inconsistent reporting affect emission estimates in three ways: national greenhouse gas baselines, subsequent reported emissions, and claimed emission reductions. This will not only have implications on emission totals but will alter the value of emission units that might be traded or counted in other international policies instruments such as Joint Implementation or the Clean Development Mechanism.

Section I of this report assesses the data submitted by countries for the year 2000. Every country reported methane from land disposal, the most important waste emissions category; other emissions are reported by varying subsets of the 27 countries. On a CO_2-

equivalent basis, methane from land disposal accounts for 85% of average per capita emissions from waste management. However, emissions per capita, and per tonne[1] of solid waste, vary widely from one country to another. Incineration data is particularly inconsistent, and is omitted entirely by some countries –because either they do not incinerate, have inconsistent measuring methods, or use the option of reporting incineration emissions under the alternative energy section. The NIRs, which should provide background data that could help explain and substantiate the CRF estimates, are frequently incomplete, and do not contain comparable information from one country to another.

Section II focuses on methane emissions from land disposal. This analysis found numerous errors and inconsistencies in all but four national CRF reports (Netherlands, Greece, Poland, and Slovakia). There are two major reasons reported emissions were found to be incorrect. The first type of errors occurs because of inappropriate application of an approved IPCC emissions estimation methodology or a failure to specify an alternative method of estimation. In accordance with the IPCC good practice guidance, countries can select between IPCC Tier 1, Tier 2, or other methods of estimation that best reflects their national circumstances. Each of these options is selected by a significant number of countries and table 2.1 provides a brief description of the method each country used. The second error type involves use of inaccurate or inappropriate data within a chosen methodology.

To illustrate these inconsistencies in emission estimates a single methodology was used to estimate the emissions of each country. Utilizing the IPCC Tier 1 methodology and correcting the inaccurate data, a revised and consistent emissions estimate was calculated for each of the countries.

Section III addresses several broader issues about greenhouse emissions from waste, including the trends over time, the comparison of different disposal options, and possible conceptual problems in the classification of emissions. The only countries that showed rapid increases in waste-related emissions per capita during the 1990s were economies in transition in Central and Eastern Europe. Most countries showed declines in per capita emissions, at a gradual rate in many cases; Germany and Finland reported relatively rapid declines. In reviewing the implications of alternative disposal options, it is particularly important to describe incinerator emissions, which will include a significant fraction of anthropogenic

[1] Throughout this report, we use exclusively metric units: in particular, 1 tonne = 1000 kg.

carbon emissions in any industrial economy. In the data available for this report, emissions from incineration were less consistently described than emissions from land disposal.

It is also important to guard against a form of double counting that can occur in emissions accounting. If CO_2 emissions from incineration or land disposal of wood and paper are treated as biogenic because they will be offset by forest growth, then the same forest growth should not be counted as a carbon sink or as a net increase in sequestration. There are also equity issues surrounding credit for methane mitigation because of the large differences in Global Warming Potential of methane and carbon dioxide and the very different waste management practices of individual countries.

Section IV summarizes the conclusions that emerge from the analysis in the earlier sections and makes recommendations for improving the comparability and accuracy of reported waste related greenhouse gas emissions.

INTRODUCTION

Solid waste can be managed either by incineration of combustible components, with or without heat recovery that displaces fossil fuels, or it can be disposed of in landfills or open dumps, or recycled or composted. Each of these methods produces differing combinations of carbon dioxide, methane and other gases, at rates that are very site specific. Emissions from land disposal are the largest, on a CO_2-equivalent basis, and the least certain; indeed, UNFCCC reporting rules allow two alternative means for estimating methane from landfills.

Consistent and accurate reporting of greenhouse gas emissions is essential for the equitable and effective functioning of present and future climate agreements. The calculation of emissions of carbon dioxide emissions from fossil fuel combustion and most industrial gases is fairly straightforward using standardized emission factors However, because of the physical and chemical processes involved in the release of emissions from waste, they are more difficult to determine. Errors or inconsistent reporting affect emission estimates in three ways: national greenhouse gas baselines, subsequent reported emissions, and claimed emission reductions. This will not only have implications on emission totals but will alter the value of emission units that might be traded or counted in other international policies instruments such as Joint Implementation or the Clean Development Mechanism.

This report undertakes an evaluation of the data on greenhouse gas emissions from waste management, as submitted by Annex I parties. It is based on data provided by the UNFCCC Secretariat for 27 countries in the Common Reporting Format (CRF). In addition, for 14 of these countries, the more extensive National Inventory Reports (NIR) were also available.

In this assessment a significant number of errors and unclear assumptions were found in the reported waste related greenhouse gas emissions. To determine the source of these problems, each country's emissions were recalculated using the best available data and a common IPCC approved methodology. These recalculated emission values were in close agreement with the national estimates submitted by just four of the 27 countries. The differences between the revised estimates and the remaining countries' submissions are widely scattered, and do not appear to have a single cause or consistent bias. Some nations made arithmetical errors, or inappropriate assumptions that could not be justified by the method that they cited as using. Some nations reported data that appear implausible based upon studies of waste generation and management, without documenting the basis for the values used in their calculations. In a few cases, it was not possible to determine what method was used to produce the reported emissions, or there were major omissions of required information. Three countries submitted almost no information supporting their emissions estimates.

Waste related emissions vary substantially among countries depending on economic levels, consumption patterns and the extent of recycling that diverts material from the waste stream. Higher income countries generally consume more goods, and consume significantly more paper and packaging materials. The paper and packaging deposited in a landfill is responsible for the majority of methane emissions. Also, lifestyle, product choice, willingness to recycle and purchase recycled goods, and the type of disposal system can yield a wide range of waste related emissions in countries with comparable income levels. The relative types and quantities of greenhouse gases released from solid waste depend upon the composition of the waste, climatic conditions, and the management system that is used. Landfills convert paper, food, yard waste, cloth and other biodegradable materials into the important greenhouse gases methane and carbon dioxide in roughly equal proportions (plus water). Plastic and synthetic fibers are not broken down in landfills, but remain sequestered there for extremely long periods of time.

Wetter and warmer climates increase the rate of biodegradation of landfilled materials, thus increasing the rate of release of methane and carbon dioxide. As mentioned above, wastes that have a higher proportion of organic waste, such as paper, produce greater methane emissions. Waste management methods vary from open dumps and poorly managed landfills to highly technical, engineered sanitary landfills. Typically, open dumps produce mostly carbon dioxide and little methane because oxygen from air is involved in the biodegradation process. Sanitary and deeper landfills reduce the level of oxygen available for decomposition and produce a greater fraction of methane.

While each of these gases contains a single carbon atom, methane has a global warming potential that is 7 times that of carbon dioxide per carbon atom when measured over a 100 year time horizon (or 21 times the global warming potential of CO2 on a per tonne basis). Small amounts of other greenhouse gases, including volatile organic compounds, are also emitted by landfills; volatile organics make only a modest direct contribution to global warming, but they produce ozone, a strong greenhouse gas. There is no readily recognized methodology for estimating this indirect contribution from waste to global warming.

When wastes are disposed of by combustion in an incinerator, the primary greenhouse gas released is carbon dioxide plus small quantities of methane, volatile organic compounds and oxides of nitrogen. Plastic and all wastes that are biodegradable are combustible. Wastes that are non-combustible or biodegradable such as metal, glass and soil do not contribute any emissions.

Section I of this report summarizes the availability of data in the CRF, by country and type of greenhouse gas, and also examines the more detailed NIR data submitted by some of the countries. Section II examines the dominant category of waste sector greenhouse gas emissions, namely methane emissions from land disposal, as reflected in the CRF data. This section identifies inconsistencies and areas of incompleteness, offer two approaches to the creation of revised estimates, and suggest some possible reasons for the improbable values reported in some cases, and the many inaccuracies and omissions that were observed. Section III explores several broader issues: it analyzes time trends in emissions, expands the focus from landfill methane to other categories of waste sector emissions, and discusses conceptual problems in the classification and comparison of emissions. Section IV presents conclusions, and offers suggestions for improvement in reporting and analysis of greenhouse emissions from waste management.

I: DATA AVAILABILITY AND QUALITY

I.A. Data Coverage: Countries and Gases

Twenty-seven of the forty-one Annex I countries submitted data on waste related greenhouse gases that could be evaluated for this study. Table 1.1 lists the countries that submitted their national GHG inventory report for the year 2000. While 27 countries filled out the CRF, the amount of information and the degree of detail varies widely from country to country.

The CRF reports emissions data on seven gases. For the three that have the most significant impacts, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual* provides explanations and methods for calculation of emissions from "Solid Waste Disposal Sites," abbreviated SWDS[2] – and from incineration. The other four waste related gases – nitrogen oxides (NO_X), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), and sulfur dioxide (SO_2) – have very small direct impacts on climate change. SO_2 is released in very small quantities from landfills or from incinerators, and has only a short lifetime in the atmosphere so contributes little to global warming.

NO_X and NMVOC react directly and with other gases in the atmosphere to produce atmospheric ozone that is also a greenhouse gas. Carbon monoxide has almost no direct global warming effect, but it does alter atmospheric chemistry so as to change the rate of removal of other greenhouse gases such as methane. There is no published method for calculating the indirect global warming effect of these gases, so this report does not address them or of the emissions of the other Kyoto listed greenhouse gases such as sulfur hexafluoride, perfluorocarbons or hydrofluorocarbons which can be released when certain items that use them are disposed of in landfills or incinerators.

Total waste management emissions, in the CRF, include emissions from wastewater treatment. Wastewater treatment releases a mixture of methane and carbon dioxide, but these amounts are small when compared to solid waste disposal. Sewage treatment is believed to account for only one percent of methane emissions while industrial wastewater is estimated

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[2] In American waste management, the term "disposal sites" might include incinerators. However, it is clear that SWDS refers only to land disposal in IPCC documents and in the data reviewed here.

to account for 9 percent with most of it emitted in developing countries. Since these estimates are so uncertain and the methodology for estimation is not well developed, we have not addressed wastewater in this report. Hence total reported emissions are in some cases slightly greater than the sum of land disposal (SWDS) and incineration emissions. Some of the 27 countries reported only total emissions and did not disaggregate them into land disposal, incineration and wastewater treatment.

I.B. How Complete Are the Data?

Tables 1.1 - 1.3 describe the presence or absence of data, by country and gas. Many items for which values would be expected are omitted, or are reported as exactly zero. Table 1.1 provides data for the total waste sector emissions (including wastewater treatment, not shown separately), Table 1.2 on SWDS emissions, and Table 1.3 on incineration emissions. The following entries appear in the tables.

DATA REPORTED – if a country reported any non-zero level of emissions;
ZERO – if a country reported zero emissions; or
NO DATA – if there is a text entry (usually explaining the absence of data) or blank in place of emissions data.

Tables 1.1 – 1.3 do not attempt to assess the reasonableness of data entries, nor their internal consistency; rather, they identify the cases where any non-zero emissions data were reported. For the waste management sector as a whole, Table 1.1 shows that all 27 countries reported nonzero emissions of methane. About half, or 14 countries, reported CO_2 emissions, while 22 reported N_2O emissions. Between 11 and 15 countries reported nonzero emission levels for one or more of the remaining gases, NO_x, CO, NMVOC, and SO_2.

Table 1.2 provides information on land disposal (SWDS). Every country reported a nonzero value for methane emissions from SWDS. Reporting of other gases was more erratic: only four countries (Hungary, Norway, Spain, and Switzerland) reported any CO_2 emissions from SWDS; similarly, 3 to 10 countries reported some level of NO_X, CO, and NMVOC gases from SWDS. No country reported N_2O or SO_2 from SWDS. (Tables 1.1-1.3)

Table 1.3 outlines the greenhouse gas emissions reported from incineration. Here the situation is more variable from country to country. Reports from 6 countries, Denmark, Estonia, Greece, Ireland, New Zealand, and Poland, showed no use of incineration facilities, so no emissions were reported (with the sole exception of an apparently erroneous entry for NMVOC from incineration in Poland). Another 6 countries, Finland, Germany, Latvia, Netherlands, Slovakia, and Spain, reported no emissions of any type from incinerators. Some of these countries may have counted incineration emissions elsewhere. Because energy is recovered from incinerators, countries are allowed to include their emissions in the energy section of the emissions inventory. To avoid double counting, emissions listed under energy facilities are not repeated under waste management facilities, and we did not examine the energy sector itself even when the same facility serves both purposes.

In summary, every country reported data for methane from land disposal, the most important single category of emissions from waste management. In contrast, there was no standardized reporting format for the remaining GHG gases, including CO_2, NO_x, CO, and NMVOC. Among the countries that reported any incineration emissions, there was fairly complete reporting of the principal incinerator greenhouse gases, namely CO2, methane, and NO_x. However, the number of countries that report incineration emissions in the waste sector was surprisingly small. To ensure transparency, consideration should be given to revising the CRF so that incinerator emissions reported in the energy sector are also identified in the reports on the waste sector.

I.C. How Much Emissions Are Being Reported?

I.C.1 Total Emissions

Total emissions of each of the seven greenhouse gases (in gigagrams, Gg, or thousand metric tonnes) are provided for the entire waste sector in Table 1.4, for SWDS in Table 1.5, and for incineration in Table 1.6. Due to the lack of completeness of data entry, as described above, the totals from these tables are in many cases underestimates of the true 27-country total of emissions. Because countries differ so widely in population, we have neither summed nor averaged entries in Tables 1.4-1.6.

I.C.2 Per Capita Emissions

To allow comparisons of emissions levels among countries of varying sizes, Tables 1.7-1.9 express emissions in kg per capita. Total waste sector emissions are in Table 1.7, SWDS emissions in Table 1.8, and incinerator emissions in Table 1.9. Averages at the bottom of each table are the averages of the nonzero entries in each column.

The range of per capita emissions is quite large. Total methane emissions from waste management, (Table 1.7, column 2), range from low values of only 1.5 kg/capita in Slovakia to middle range values of 10 kg/capita in Czech Republic, Germany, Iceland, Italy, Luxembourg, and Switzerland to high values of 40 kg/capita in Canada, Estonia, Norway, and US. SWDS methane emissions (Table 1.8, column 2) display a similar range, since land disposal accounts for almost all of the methane from waste management. Some of this variation could reflect national differences in reliance on landfilling vs. incineration, or in the extent of methane capture at landfills. However, some of the variation in SWDS methane emissions reflects the wide range of methods used in the calculations, and apparent problems of inaccurate data or incompleteness and incompatibility of reported data that are described in Section II below.

Emissions of other gases usually associated with SWDS are often not reported. Also the available data appear inconsistent with each other from country to country. For example, for the four countries (Hungary, Norway, Spain, and Switzerland) that reported CO_2 emissions from SWDS, the ratio of CO_2 emissions to CH_4 emissions varies by almost two orders of magnitude, from 3 in Hungary to 0.07 in Spain (compare Columns 1 and 2 in Table 1.8). There is surely a problem with these data.

A similar range of values can be seen in incineration emissions, for the countries that reported on these emissions. CO_2 per capita from incineration varies from low levels of only 3.5 kg/capita in UK and 4.2 kg/capita in Spain to high levels of emissions of 168 kg/capita in Belgium and 175 kg/capita in Switzerland (Table 1.9, Column 1). Methane from incineration falls into one of two levels, differing by an order of magnitude: either 0.01 – 0.03 kg per capita in Austria, Belgium, Canada, Iceland, Luxembourg, and Switzerland, or 0.21 – 0.32 kg per capita in France, Italy, and Spain (Table 1.9, Column 2). For CO and NMVOC, US per capita incinerator emissions are the highest of the 27 countries, more than twice the level in the second-highest country, Spain (Table 1.9, Columns 5 and 6). Some of these differences may reflect differences in the use of incinerators, or in incinerator and pollution control technology; however, some may also reflect errors and omissions in the data entry or calculations.

Countries with similar economies and consumption patterns produce similar waste streams. If they had similar waste management practices and facilities, their emission profiles would be similar. Hence differences in profiles of otherwise similar countries are due to differences in their waste stream management practices including the relative proportions of disposal through land filling, incineration and recycling.

I.C.3 CO_2-Equivalent Per Capita Emissions

Tables 1.10-1.12 convert the data on per capita emissions into CO_2-equivalent terms, for the gases for which estimates of global warming potential are available. The conversion is based on IPCC values for global warming potential per *metric tonne* of gas, based on a 100-year time frame relative to CO_2, i.e.

$CO_2 = 1$

$CH_4 = 21$

$N_2O = 310$

Quantities of emissions per capita are multiplied by these factors, producing the results shown in Table 1.10 for total waste management emissions, in Table 1.11 for SWDS, and in Table 1.12 for incineration.

The averages at the bottom of Tables 1.10-1.12 are again the averages of the nonzero entries reported; thus they do not refer to the same group of countries in each case. However, if a country had exactly the average per capita emissions of each gas, the bottom line of Table 1.10 shows that methane would account for 85% of the country's emissions from waste management, on a CO_2-equivalent basis. In Table 1.11, the same calculation for the "average country" shows methane amounting to 96% of SWDS emissions, while Table 1.12 shows CO_2 representing 90% of incineration emissions, all expressed in terms of CO_2 equivalent.

I.D. National Inventory Reports

I.D.1 Quality of the Reports

National Inventory Reports (NIR) should provide qualitative information on uncertainties regarding methods used to calculate emissions from the waste sector. However, a number of the reports considered for this study did not include a complete discussion of the methodology or an assessment of the emission levels, time trends, and sources of the three main greenhouse gases associated with the waste sector: methane, carbon dioxide, and nitrous oxide. In addition, the NIRs did not follow a standardized format. Many were incomplete and omitted information critical to an evaluation of the reported emissions. Among the missing information is

- a description of the methodology,
- a description of the information used in the inventory, and
- an explanation of the choices of methodology and selected data.

The amount of detail in the reports varied greatly, as did the length, content and descriptive elaboration of the text. Thus, the National Inventory Reports did not serve as a consistent, reliable source of information for all reporting countries.

Among the 27 countries, 14 submitted a National Inventory Report, of which four included little more than summary information, while 10 were relatively detailed. Those 10 did include some level of description of their methodology surrounding their SWDS emissions methodology, but only three countries discussed their methodology for determining incineration emissions.

I.D.2 Methodology and Uncertainty

The majority of NIRs lack information on the method employed to determine methane emissions from land disposal. Many reports omit basic information on input variables, assumptions, and the justification for their choice of methodology for converting waste data into final emissions totals.

Only five of the fourteen countries submitting NIRs used an unaltered IPCC method to estimate methane from land disposal; three used Tier 1, and two used Tier 2 (these methods are defined and discussed in Section II.A below). Seven countries stated that they used an alternative method, and two did not provide any information on methodology. Most countries provided very little detail in their description of their methodology. Five countries referred the reader to an additional document that was not provided with the report.

By far, the greatest portion of emissions from the waste sector comes from methane emissions at solid waste disposal sites, but there is no consistent approach to reporting for this sector. Hence, it is not feasible to compare emissions inventories among countries, either in terms of the numerical data in the CRFs or the explanatory information in the NIRs. The discrepancies among these countries' reports are further illustrated in Sections II and III of this report.

Regardless of the method of estimation, a significant amount of uncertainty surrounds all data on emissions from the waste sector. All data are estimates derived from theoretical models and principles, often resting on relatively little current empirical data. In land disposal sites, the biochemical processes that generate methane occur at variable rates. The numerous factors determining the rate of methane emissions at individual disposal sites are not perfectly understood, but include temperature, moisture, availability of oxygen, and extent of mixing of organic waste in the disposal site. Waste generation itself is a highly decentralized, and often poorly recorded, activity, where data may be based on an alternative set of indirect estimates.

However, no country adequately addresses the uncertainties inherent in its emissions reporting. According to UNFCCC guidelines, each NIR should discuss sources of uncertainty in the data presented, and should quantify the range of uncertainty either for total emissions or for each variable. A detailed methodology for discussion of uncertainty is outlined in IPCC good practice guidance. None of the NIRs reviewed for this report includes such a discussion.

One report explains briefly why it was difficult to provide an uncertainty estimate. New Zealand's NIR explains that the level of uncertainty associated with some data inputs (such as quantity of methane generated and rate of methane recovery) was unknown, and therefore it was "not possible to perform a statistical analysis to determine uncertainty levels."

The principal gas emitted by incineration is CO_2, with smaller fractions of N_2O and methane. However, reporting on CO_2 from incineration is sparse, and only one NIR reported on all three of these gases in its discussion of incineration. Three NIRs reported methane emissions from incinerators, and two reported N_2O emissions from incinerators. It is not clear whether the other countries failed to measure such emissions, whether they reported on them in a separate section, or whether the lack of data indicates that they had no incineration capacity. No countries included information on their waste categorization methods, method for obtaining carbon content, fossil carbon fraction, or N_2O emission factors.

IPCC good practice guidance requires either collection of accurate emissions measurements or use of IPCC default emission factors. The difficulty in comparing results across countries results in part from failure to specify which option a country has chosen. In addition, no information is available on how each country chose to conduct its emissions measurements. A common set of practices would make for effective comparability in the reporting.

II: METHANE FROM LAND DISPOSAL

II.A. Methods of Estimation Used in Reports

Because methane emissions from land disposal are important, but difficult to measure directly, countries typically estimate these emissions using mathematical or engineering models. IPCC technical guidance documents offer two alternate methods of estimating methane emissions from land disposal, referred to as Tier 1 and Tier 2. The CRF offers countries a choice of using either of the two methods, or any specified alternative country-specific method.

Table 2.1 tabulates the methods used by countries to estimate methane emissions from SWDS, showing that 8 countries reported using the Tier 1 method and 7 reported using Tier 2. The remaining 12 countries – all of which reported nonzero methane emissions from SWDS – used a method differing from either IPCC method, or gave no useful information about their method of estimation.

There is little evidence that the choice of method of estimation of methane emissions was the source of variation among countries. Dividing countries into three groups, those that used Tier 1, Tier 2, or neither, produced no statistically significant differences between the groups' average values of methane per capita, or between their average values of methane per tonne of waste. However, this finding reflects the small number of countries in each category, as well as the large variance within the categories (implying that the confidence intervals around the category means are very wide). It does not necessarily imply that a single country would get the same estimate of emissions regardless of the choice of method of estimation.

New Zealand was the only country that performed an explicit comparison of Tier 1 and Tier 2. It reported that its Tier 1 estimates of methane emissions were higher than Tier 2 by 3.5% in 1990, and by 4.8% in 2000.

The findings in Table 2.1 emphasize the lack of consistency in the existing national data on emissions from waste management. This has potentially serious equity implications for any agreement on targets, standards, or trading of emissions. For example, if a country finds that alternative methodologies lead to different estimates of emissions, it could create an apparent improvement in performance by changing statistical methodology, an easier (and less useful) alternative than actual emissions reduction.

II.B. Methods for Evaluating Estimates

II.B.1 The Logic of Tier 1

The IPCC Tier 1 method provides a convenient basis for checking countries' estimates of methane emissions. Tier 1 is a mass balance approach, which provides a step-by-step calculation in which reasonable default values can be used in the absence of country-specific data. It can be thought of as an eight-step calculation, as shown in Box 1.

BOX 1: OUTLINE OF IPCC "TIER 1" LANDFILL METHANE ESTIMATION

1. Population * waste per capita = Total waste
2. Total waste * fraction landfilled = Quantity of waste landfilled
3. Waste composition information yields % degradable organic carbon (DOC)
4. Quantity landfilled * % DOC = Quantity of DOC
5. DOC * fraction that actually degrades (default .77) = Carbon released
6. Carbon released * fraction as methane (default .5) = Methane generated
7. Subtract methane captured by landfill gas recovery systems
8. Subtract fraction oxidized in passage through landfill (default 0)

The remainder is **METHANE EMISSIONS**

More formally speaking, Tier 1 relies on the following equations:

BOX 2: TIER 1 EQUATIONS

(1) Methane Emissions (Gg/yr) =

$$(MSWt * MSWf * MCF * DOC * DOCf * F * 16/12 - R) * (1-OX)$$

(2) MSWt = Population * WGR (kg/person/day) * 365/1000

(3) DOC = .4 (A) + .17 (B) + .15 (C) + .3 (D)

The variables in Equations (1) – (3) are defined as follows:

MSWt = total municipal solid waste (MSW) generated (Gg/yr)

Calculated in Equation (2), or reported directly.

MSWf = fraction of MSW disposed to SWDS

This fraction is country-specific; IPCC offers default estimates for each country, based on past research.

MCF = methane correction factor

This loosely estimated adjustment factor is primarily of importance for developing countries: MCF is 1.0 for managed landfills, while it is smaller for informal disposal sites such as open dumps, reflecting their lower rates of methane generation.

DOC = degradable organic carbon, as a fraction of waste stream

This fraction is calculated in Equation (3).

DOCf = fraction of DOC that actually degrades (default is .77)

F = fraction of carbon that degrades to methane rather than carbon dioxide (default is .5)

16/12 = Carbon to methane conversion (weight ratio)

R = recovered methane (Gg/yr)

This is a country-specific value; no default values are available.

OX = fraction of methane that is oxidized before emission (default is 0)

WGR = per capita waste generation rate (kg/person/day)

Population = population generating waste reflected in WGR.

Total population should be used in developed countries; urban population should be used in developing countries where it is assumed that the rural population does not benefit from managed waste collection and disposal.

Equation (3) in Box 2, calculates the fraction of waste that is degradable organic carbon, using the following variables (the numerical coefficients in Equation (3) represent technical estimates of carbon content):

A = fraction of waste that is paper and textiles

B = fraction of waste that is garden waste or other non-food organic putrescibles

C = fraction of waste that is food waste

D = fraction of waste that is wood or straw

II.B.2 The logic of Tier 2

IPCC's Tier 2 method is a "kinetic" or first-order decay model, recognizing the physical principle that emissions are not constant over time. Emissions from any given quantity of waste are assumed to follow an exponential decline over time. Other kinetic models were used (and adequately described) by Canada and Denmark; the limited information provided by the Czech Republic, Estonia, Iceland, Italy, Latvia, Portugal, and Slovakia did not allow determination of the methods they used, although they reported that did not use either Tier 1 or Tier 2.

A first-order decay model has frequently been used in scientific analysis of methane generation. Box 3 presents such a model, for a single disposal site.

BOX 3: FIRST-ORDER DECAY MODEL OF METHANE EMISSIONS

$$Q = L_0 R (e^{-kc} - e^{-kt})$$

Q = methane generation in current year (m^3/year)
L_0 = methane generation potential (m^3/Mg of waste)
R = average annual waste disposal during active life of disposal site (Mg/year)
k = methane generation rate constant (1/year)
c = years since disposal site closed, or 0 if still open
t = years since disposal site opened

IPCC's Tier 2 method rests on the first-order decay equation modified for application to a whole country, as shown in Box 4. Current emissions are estimated separately from waste of each past vintage, in the first equation; these are then summed over all past years in the second equation.

BOX 4: THE TIER 2 METHOD OF ESTIMATION

$$Q_{T,x} = k R_x L_0 e^{-k(T-x)}$$

$$Q_T = \Sigma Q_{T,x} \text{ (summation for x = initial year to T)}$$

R_x = waste disposed in year x (Mg)
$Q_{T,x}$ = methane generated in year T by waste disposed in year x
Q_T = total methane generated in year T
x = year of disposal
T = current year
(Other parameters defined as in Box 3)

The kinetic approach is in theory an advance over Tier 1, which ignores the time-dependence of methane emissions. Tier 1 assumes, in effect, that all methane is emitted in the year when waste is landfilled. This will produce accurate annual estimates only if there is no change from year to year in the quantity of waste landfilled (or more precisely, no change in the methane generating potential of each year's waste). If quantities of landfilled waste are growing, Tier 1 will overestimate methane emissions, whereas if quantities of landfilled waste are declining, Tier 1 will underestimate emissions.

Despite this limitation, Tier 1 appears to be more appropriate for use in analyzing and comparing national emissions. While Tier 2 rests on a widely accepted theoretical model, it can be difficult to apply in practice. The results depend on the parameters L_0, the total amount of methane that will eventually be released, per tonne of landfilled waste, and k, the rate constant governing the decay of emissions. As the IPCC guidelines note, L_0 can vary by more than a factor of 2, and k can vary by a factor of 100, from site to site. Estimation of these parameters requires all the information used in the Tier 1 method, but organizes the information in a much less transparent manner.

Moreover, the theoretically desirable modeling of time dependence of emissions is only useful if detailed information is available on the quantities of waste landfilled annually in the past. If, as sometimes happens, the lack of data makes it necessary to assume that the quantity of waste landfilled has been constant for many years, then a kinetic model loses its advantage. The static mass balance approach of Tier 1 also assumes constant annual landfill volumes, and is accurate if that assumption is valid. If landfill volumes are changing only gradually (as seems likely for many countries), then only minor errors are introduced by the failure to explicitly model variation in emissions over time.

The choice of Tier 1 is not without cost. A tradeoff exists between the advantages of providing the most accurate, country-specific calculation method on the one hand, and ensuring inter-country consistency, compatibility, and transparency of estimates, on the other. The appropriate choice may depend on the goal of the data collection process. If emissions inventories are to be used for establishing emissions baselines, reductions, global carbon trading, or for some other implementation mechanism where comparability is necessary, then it is important to use both the Tier 1 method for SWDS methane emissions and a single, consistent approach to emissions from incineration (a much simpler task). This approach will allow equitable and consistent data comparisons across countries. In contrast, if models and data are to be used primarily for scientific inquiry on climate change, the most accurate, site-specific method should be used whenever possible. As better methods emerge and the scientific consensus about landfill methane emissions evolves, IPCC guidelines will undoubtedly be updated to reflect newer techniques.

II.C. Calculated and Revised Values

To evaluate the national estimates of methane emissions, the authors of this report applied the Tier 1 method in two different ways. The first application of Tier 1 simply used all of the submitted background data, yielding what we refer to as the "calculated" value for each country. Thus the "calculated" values show what countries would have estimated for methane emissions if they had correctly applied the Tier 1 equations to the data they submitted. Differences between submitted and calculated values reflect either differences in the methodology used (for those who did not use Tier 1) or errors in calculation (for those who did use Tier 1). Only 15 countries submitted sufficiently detailed background data to allow this calculation.

The second application of Tier 1 first revised identified errors in national input data, and applied IPCC default values or other published values in cases where the necessary data were not submitted. This result is reported as the "revised" value for each country. The "revised" values are the best estimates of methane emissions we can make, based on the information available in the reports. Tier 1 input data and "revised" estimates of methane emissions were constructed for all 27 countries, although the estimates rely heavily on published defaults values for lack of up-to-date, country-specific inputs in some cases. The "revised" estimates differ from the "calculated" estimates, when both are available, only where errors (described below) were revised, or where omissions in the input data were filled in.

Figures 2.1 through 2.6 compare the submitted, calculated, and revised methane emissions, expressed both in per capita terms and per tonne of landfilled waste. Each figure also includes the 45^0 line (y=x); if the two methods of estimation shown on a graph agreed with each other, the data points would fall on this line. Figures 2.1, 2.3, and 2.5 compare the "revised", "calculated "and submitted values on the basis of emissions per capita; the data for these figures can be found in Table 2.2. Figures 2.2, 2.4, and 2.6 look at the same comparisons on the basis of emissions per tonne of waste sent to SWDS (land disposal), using data shown in Table 2.3.

As Figures 2.1 and 2.2 demonstrate, there is literally no correlation between the submitted and revised estimates.[3] The mean values (see Tables 2.2 and 2.3) are nearly identical for methane per capita, and are not significantly different for methane per tonne of waste. But only four countries fall close to the line of equality (i.e., their submitted estimates are essentially equal to the "revised" estimates), while others are scattered both above and below, in some cases quite far from the line.

Figures 2.3 and 2.4, contrast "calculated "and submitted estimates, and display a similarly broad scatter. The gap between the "calculated "and the submitted estimates reflects errors in calculation, and/or inconsistencies introduced by the use of differing methods of estimation. Thus the graphs suggest that these factors are of great importance.

On the other hand, Figures 2.5 and 2.6, comparing the "revised" and "calculated" estimates, show a much stronger relationship, with 11 of the 15 countries quite close to the line – i.e., for 11 countries the two estimates are very similar. These two estimates differ only by our correction of incorrect or missing input data. Thus the graphs suggest that, at least for those 11 countries, errors and omissions in input data are of minimal significance.

II.D. Factors Influencing the Accuracy and Comparability of Estimates

II.D.1. Overview

The submitted estimates of methane emissions differ, often significantly, from the "revised" values; moreover, the submitted estimates are not strictly comparable from one country to another. There are at least three factors that limit the accuracy and comparability of the submitted estimates of methane emissions: differences in methodology; alterations of

[3] For both methane per capita and methane per tonne, the adjusted r^2 for regression of corrected vs. submitted values is close to zero. The p value for the regression (probability of getting the observed correlation by chance alone) is .23 in one case, .60 in the other.

technical parameters and relationships; and errors in compiling country-specific input data. Problems potentially caused by differences in methodology have been discussed above. This section examines the other factors.

II.D.2. Technical Variables

Estimation of methane emissions is a highly technical process, with crucial parameters and relationships reflecting the current state of knowledge about the biochemistry of land disposal sites. The IPCC guidelines provide a series of equations to calculate MCF, L_0, and DOC based on country specific data. (See Section II.B and Boxes 1-4 above for definitions of these variables.) In addition, the IPCC guidelines provide a range of simple numerical estimates for k, F, OX, and DOCf. Two problems arise in the implementation of this approach. First, some countries fail to use IPCC's equations and values, and introduce their own. Second, the ranges suggested by IPCC are broad and the criteria are not always clear for the choice of specific values within the ranges.

For example, the calculation of the quantity of degradable organic carbon (DOC) in disposal sites, a key starting point, requires a mix of country-specific data and technical relationships. Calculation of carbon degradation depends on three elements: measured or estimated waste composition; the DOC equation, which is provided by IPCC; and the fraction that actually degrades (DOCf), a parameter also provided by IPCC.

The IPCC guidelines allow countries a wide range of choice for some of the technical parameters, provided that their choices are explicitly documented. Many countries did vary the technical parameters, in most cases failing to include any explanation of their changes. The recommended default value for DOCf is 0.77, yet there are allowances for countries to set the fraction as low as 0.5, depending on whether they choose to include lignin in their estimates of degradable organic carbon. This flexibility introduces a wide range of variability in emissions estimates, based on a reporting decision about an obscure technical issue. Other parameters such as OX (the fraction of methane that is oxidized as it passes through the landfill) and F (the fraction of carbon emitted as methane) have suggested ranges of 0 to 0.1 and 0.4 to 0.6, respectively. Thus substantial variation can be introduced simply through choices made within IPCC's recommended ranges for these parameters. The choices made by countries on these parameters were virtually never explained in their submissions.

The calculation of the amount of methane generated from a given quantity of degradable organic carbon is an almost entirely technical matter. Unless reliable information is available, agencies compiling emissions inventories should probably be discouraged from altering default assumptions about the parameters used in this calculation.

As in the question of methodology selection, the appropriate response to this problem may depend on the final goal of the inventories. If the goal is consistency, it is important to limit each country's options to manipulate parameters; to that end, IPCC guidelines should become more explicit and prescriptive about the use of currently accepted technical values. If the goal is accuracy in scientific research, modification of technical parameters may be appropriate – at least by researchers who are familiar with the subject. It is not clear how many of the parameter modifications found in CRFs and NIRs are grounded in scientific knowledge about specific national conditions.

II.D.3. Errors in Input Data

Additional problems arise in less technical inputs, such as inputting clearly erroneous national data. Errors were found in basic data such as total national population. Some countries reported that the fraction of waste sent to land disposal was 100% despite the fact that they also engaged in incineration, recycling, or both. Errors in recording data such as these suggest a need for greater care in collecting and reporting basic information.

It is possible that many of the data appear unimportant, especially for countries using their own methods of estimation and simply reporting the results of separate, external calculations. However, the decision to treat these entries as unimportant undermines any efforts for reliable comparative analysis.

It is also possible that the standard spreadsheet formats and awkward, overlapping variable names promote confusion: the Tier 1 formulas, as presented above, require the user to distinguish between DOC and DOCf, as well as MSWt and MSWf. A more user-friendly interface could certainly be designed, and might increase accuracy and compliance. We recommend a spreadsheet for whichever method or methods are approved that would automatically calculate emissions once appropriate national data were entered.

To illustrate the general obstacles to accuracy, and to shed more light on the problems in the submitted estimates of methane generation, the following subsections provide a detailed examination of errors and ambiguity in the input data, focusing on the Tier 1 inputs mentioned in Box 1, above. (Most of these data are also needed for Tier 2 estimation.) Three countries, Belgium, Germany, and Luxemburg, provided no input data; the other twenty-four submitted data of varying degrees of completeness.

Definition of MSW

The definition of MSW (municipal solid waste) was not consistent from country to country, despite the fact that IPCC provides an unambiguous definition. Canada and the United States are among the countries that used an incorrect definition. In the US there are two widely cited, inconsistent sets of data on the quantity of MSW; the US CRF inappropriately combines data from both sets.[4]

Population

Only ten of the twenty-four reporting countries entered their population data correctly (Canada, Greece, Italy, Latvia, Netherlands, New Zealand, Portugal, Spain, Switzerland, and United States). Two gave population figures that were incorrect by orders of magnitude, presumably reflecting clerical errors (Slovakia and United Kingdom). Eight countries did not report any population data (Czech Republic, Denmark, Estonia, France, Iceland, Norway, Poland and Sweden), and four countries reported only on urban population (Austria, Finland, Hungary, and Ireland). Errors in reporting population affect estimates of total emissions only if the per capita waste generation rate is used to calculate these totals (See below).

The use of urban rather than total population is almost certainly a mistake for developed industrial countries. Waste-related emissions are appropriately based on the urban rather than total population only in low-income developing countries. There it can reasonably be assumed that the rural population does not benefit from formal waste collection and landfill disposal, but instead uses informal local disposal options. While

[4] One set of data is collected by Franklin Associates for EPA; the other is published by BioCycle magazine. The BioCycle data, based on the more inclusive (and varying) definitions of the waste stream used by state governments, are routinely at least 50% higher than the Franklin/EPA data. The Franklin/EPA data should be used in the CRF and NIR.

posing potential sanitary problems, such disposal generates little if any methane. Food waste, the principal source of carbon in rural developing country waste streams, will typically degrade to carbon dioxide in informal disposal sites, thus remaining part of the biogenic carbon cycle.

For Annex I countries, in contrast, it seems likely that virtually everyone benefits from formal waste disposal of some sort – and virtually everyone discards noticeable quantities of paper and plastic items (which cause anthropogenic carbon emissions in landfills and incinerators, respectively). Therefore, it is inappropriate for Annex I countries to base emissions estimates only on urban populations.

Waste Generation Per Capita

Eleven countries submitted data on waste generation per capita that appeared plausible (Austria, Canada, Estonia, Finland, Greece, Italy, Latvia, New Zealand, Portugal, Spain, and Switzerland). Ten countries submitted no data (Czech Republic, Denmark, France, Hungary, Iceland, Ireland, Norway, Poland, Sweden, and the UK); three submitted data including significant errors (Slovakia, Netherlands, and the United States). One country, Slovakia, apparently submitted a per year estimate incorrectly labeled as a per day estimate (it became comparable to other countries' data when divided by 365). In another case, one country, the United States, based its per capita estimate on an incorrect definition of MSW that is 50% higher than the standard estimate (see footnote 4). In a third case, the Netherlands had an error that could not be traced back to its source; this error led to a significant underestimate of total annual waste generation. These estimates were revised using the default values provided in the IPCC Reference Manual, as well as waste generation rates derived from World Bank data and economic levels[5].

The per capita waste generation rate is only important when it is used to calculate the quantity of waste disposed in SWDS (land disposal sites). However, most countries calculated the SWDS waste quantity from independent sources, and did not depend on the per capita generation rate.

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[5] Hoornweg, D. (1999). *What a Waste: Solid Waste Management in Asia*. West Asia and Pacific Region, World Bank: Urban Development Sector Unit.

SWDS fraction

This number is the fraction of the total waste stream that is disposed at SWDS (landfills). The SWDS fraction of solid waste disposal was reported by 19 countries (Austria, Estonia, Finland, France, Greece, Hungary, Iceland, Italy, Latvia, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Switzerland, United Kingdom, and United States). The Netherlands submitted SWDS fraction data that included an obvious error of an order of magnitude. Only the United States submitted a value comparable to the default values given in the IPCC guidelines. The reported figures were assumed to be correct unless an inconsistency appeared in later calculations

Many reported figures did not correlate with other data that were submitted by the same country. For instance, Greece and Portugal reported a fraction of 1, implying that 100% of their waste goes to landfills; yet they also provided figures on recycling or incineration totals. In addition, at least seven countries' SWDS waste totals were incompatible with their reported SWDS fraction. (Austria, France, Greece, Iceland, Italy Netherlands, Norway, and Portugal)

The SWDS fraction is a part of the equation used to calculate the total amount of waste disposed at SWDS in a country (in Box 1 above, it is used in line 2; in the equations in Box 2, it is the variable MSWf). Use of an incorrect SWDS fraction can have a significant impact on the emissions total. As an alternative to using the SWDS fraction, some countries apparently estimated the SWDS waste total separately.

SWDS waste total

The SWDS total represents the total amount of waste disposed on land in one year. It is a crucial input in the equation for calculating total methane emissions. The SWDS total can be calculated as a function of the variables discussed above.

Four countries did not report a value for the SWDS total (Canada, Denmark, Estonia, and Switzerland). In addition, four countries made significant errors in their SWDS totals (Austria, France, UK, and US); in each of these cases, the error elevated the final value. We revised these mistakes, but assumed the rest of the values to be correct.

Degradable Organic Carbon

It is not the entire quantity of waste in a landfill that generates methane, but only the degradable organic carbon (DOC). Hence the key to estimation of emissions is the calculation of the quantity of DOC in disposal sites. Unlike the variables discussed above, DOC is not observable by ordinary means; technical information is needed to calculate DOC. (In Tier 2, the same information is needed to calculate L_0, which depends on the DOC per tonne of waste.)

The IPCC method for estimating DOC begins with the composition of the waste stream, then multiplies its components by parameters representing the quantity of degradable carbon in each waste type, to obtain the DOC fraction of the waste stream (see Box 1, line 3; Box 2, Equation 3). The resulting fraction is then multiplied by the SWDS waste total to produce the quantity of DOC - measured in weight terms, e.g. in gigagrams (Box 1, line 4).

Most countries' calculations were problematic in this area, in one or more of the following three aspects.

a) Waste composition

Sixteen countries submitted waste composition data: Austria, Finland, Greece, Hungary, Ireland, Italy, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, United Kingdom, and the United States.

Data for a few countries was significantly lower than for comparable countries. For instance Slovakia submitted a food percentage of 1.4% lower than most countries by at least an order of magnitude. Another example is Austria's reported paper content of the waste stream as 8.18%, the lowest paper percentage reported by any country. Most countries with similar economic levels have paper percentages between 28 and 36%. Greece and New Zealand submitted incomplete data, by not reporting either the textile percentage or the food fraction. Sweden, the UK and the US submitted the data as a fraction rather than as a percentage.

b) DOC equation

Five countries did not submit data on the results of the DOC equation (Canada, Czech Republic, Denmark, Iceland, and the US) (Box 2, Equation 3). Six countries submitted numbers that were significantly higher or lower than the figures calculated using waste composition values and the DOC equation (Austria, Estonia, Ireland, New Zealand, Switzerland, and the UK).

Roughly speaking, the equation says that the DOC fraction of a waste stream is 40% of the paper fraction plus 16% of the food and yard waste fraction.[6] For a plausible waste composition, the result should not exceed a value of 0.2 (i.e., 20%). However, Estonia and Ireland reported a value of 1, and Austria and New Zealand reported values near 0.5, and Switzerland and Slovakia reported a value of zero.

c) DOC quantity

Given the difficulties with waste composition and DOC fraction data, it is not surprising that there were also problems in the DOC quantity data. Seven countries (Canada, Denmark, Hungary, Iceland, Netherlands, Switzerland, and the US) did not submit a value for quantity (weight) of DOC. Five countries, Czech Republic, Estonia, Ireland, New Zealand, and Slovakia, submitted values that were clearly incorrect. No country reported a DOC quantity that matched the recommended values used in the calculations for this report; only four countries had a DOC value that was within 20% of the calculated value: Greece, Latvia, Norway, and Poland.

Methane Correction Factor (MCF)

The MCF is used to correct for varying land disposal practices. It is set at 1.0 for formal, managed landfills, and lower for other disposal categories such as informal, open dumping (because decomposition is presumably more aerobic in smaller, less managed disposal sites). Any reduction in this figure below 1.0 will result in a proportional reduction in calculated emission levels. The IPCC guidelines make the MCF a function of the mix of disposal categories. These guidelines, which appear to have been written with developing countries in mind, may go too far in encouraging the option of lowering the MCF by developed countries.

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[6] This is a simplified form of Equation (3) in Box 2, combining food and yard waste since they have nearly identical coefficients, and ignoring wood and straw waste, which are rarely reported.

For Annex I countries, the most likely situation is that virtually all land disposal consists of formal landfills, implying a MCF of 1.0. Estonia and Ireland lowered their MCFs below 1.0, but provided no documentation explaining the reasoning behind their choices. In effect, reducing MCF below 1.0 provides an undocumented opportunity to lower arbitrarily the technical parameters governing the estimate of methane emissions.

Methane Recovery

In the final stage of the calculations, some amount of methane may be captured and used for energy, or simply flared. In either case, combustion transforms it to carbon dioxide, which is then typically viewed as biogenic (since it is derived largely from paper, food, and yard waste in landfills). Here there is no source of information except reports from countries on the extent of methane recovery.

One issue regarding methane recovery did arise in the recalculations of emissions. In several cases, the calculated methane emissions were substantially smaller than those reported by countries. This created the possibility that (unrevised) reported methane recovery could exceed 100% of the revised emissions estimates. US EPA analyses suggest that the maximum efficiency for methane recovery over the life cycle of a landfill is around 75%. Therefore, the calculations assume a maximum methane recovery limit of 75% of total emissions. In all of the calculations, methane recovery is the lesser of the amount reported by the country, or 75% of calculated emissions.

III. EMISSIONS FROM WASTE: BROADER PERSPECTIVES

This section expands the analysis from landfill methane to the broader questions of emissions from the waste management system as a whole. In particular, two general questions are explored here: the reasonableness of the reported time trends in emissions, and the likely accuracy of the treatment of different waste disposal options.

III.A. Time Trends and Changes since the Baseline

To assess the accuracy of emission estimates throughout the ten-year time span from 1990 to 2000, and the consistency of reported baselines (1990) with later data, this section analyzes the time trends in waste-related emissions. Data were available for 26 of the 27 countries, with only Luxemburg failing to provide a time series for emissions.[7] Based on the analysis of the emissions inventory reports for the year 2000, in Section II above, it seems likely that similar errors, omissions, and inconsistencies exist in the data for earlier years as well. This section does not attempt to repeat the year 2000 analysis, but rather examines the time trends to identify countries that report significant increases, reductions, or fluctuating patterns in emission levels from year to year.

First, the total waste-related emissions, expressed as kg of CO_2 equivalent per capita were examined. (A preliminary analysis suggested that the trends are qualitatively the same in the data for methane per tonne of landfilled waste. To avoid repetition, only emissions per capita will be discussed here.) An initial classification separated the countries that experienced only gradual change throughout the decade from those that had a 10% or greater year-to-year change.

As seen in Figure 3.1, there were 15 countries where emissions per capita never changed by as much as 10% in either direction in a single year. Figure 3.2 shows the 5 countries where per capita emissions increased by 10% in at least one year; all five are countries with economies in transition in Central and Eastern Europe. The only other country in this category, Slovakia, narrowly missed the cutoff value, with a maximum annual increase of 8.8%. Each of these countries experienced sweeping institutional changes during

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[7] The Czech Republic presented no data for 1991-95, Hungary's data begins in 1991, and UK's time series ends in 1999; the rest of the 26 countries submitted complete time series for the eleven years 1990-2000.

the decade, and in some cases suffered severe economic downturns followed by rapid recovery. Institutional change could have affected the ability to collect comparable data from year to year (note that the Czech Republic did not report emissions for 1991-95), while rapid economic change could have led to rapid change in quantities of waste disposal and associated emissions.

Figure 3.3 shows the 6 countries where per capita emissions decreased by as much as 10% in a single year. Several of these countries have taken initiatives to reduce reliance on landfilling; it is plausible that they have had significant reductions in emissions.

The change in per capita emissions over the entire decade, from 1990 to 2000, is summarized in Table 3.1. This table shows the 26 countries, listed in order of the percentage change in per capita emissions. Almost all countries reported a decrease or only slight increase. More specifically, eight countries had ratios of emissions in 2000 to emissions in 1990 (both in per capita terms) between .4 and .8. Seven countries fell between .8 and .9; seven more were between .9 and 1.1 (in fact, between .9 and 1.05); and four had ratios of more than 1.1 – i.e., 2000 emissions were more than 10% higher than 1990.

The sharpest declines were reported by Germany and Finland, which eliminated more than half of their base year per capita emissions. There are good reasons to think that emissions in fact declined in both of these countries. Germany instituted a very extensive recycling program in the 1990s, diverting most paper waste (the principal source of landfill methane) away from disposal; the country also continued to move toward incineration, rather than landfilling, of solid waste. Finland also instituted new waste reduction and recycling programs, and moved to divert waste from landfills to incinerators.

However, it is also possible that the decline, while real, is overstated in the two countries' statistics. Neither Germany nor Finland reported any incinerator emissions in the CRF (see Section I above); the net decline would be less dramatic if the two countries' reports included the emissions from the growing quantity of incinerated waste. Germany presented no explanation of the inputs into its calculations, so it is difficult to assess the reasonableness of its figures. Finland reported a 36% reduction in waste generation over the decade, from 1.70 to 1.25 kg per capita per day; if the definition and measurement of waste generation is the same for both figures, this is a remarkable accomplishment. Finland also reported using a methane correction factor (MCF – see explanation of Tier 1 calculation and variables in Section II) of 0.7, despite the IPCC recommendation that developed countries with managed landfills use a MCF of 1.0. (If used consistently throughout the decade, a lower MCF would reduce the level of methane emissions, but would not affect the percentage change in those emissions.)

The four countries with most rapid growth included Latvia, where reported emissions per capita more than tripled. This ratio is large enough to cast doubt on the comparability of Latvia's data throughout the decade although the institutional change experienced by this country in the 1990s provides a potential explanation for such a finding. The other three countries with the highest emissions growth rates were Portugal, Greece, and Spain, with 17% to 51% increases over the decade. These are among the faster-growing economies represented in the data set, where living standards and hence, presumably, waste generation rates rose more rapidly than in most (though not all) other countries. However, in Spain in particular, reported emissions grew much faster than GDP. This could reflect a shift toward waste-intensive consumption patterns, or toward methane-producing disposal practices; it could also, of course, reflect errors, omissions, or changes in definitions of key data categories.

One concern about the time trends is whether countries might have overestimated their initial baseline emissions, and then underestimated for subsequent years. Only eleven countries included an explicit baseline estimate, and ten of those eleven were equivalent to 1990 emissions; in Poland, the baseline was slightly lower than 1990 emissions. Thus the question is essentially whether 1990 emissions were overestimated relative to later years, leading to an exaggerated estimate of subsequent emissions reductions. A detailed evaluation of the 1990 data, comparable to the evaluation of 2000 data in Section II above, would be required to assess the reliability of the base year figures. However, changes following the base year can be easily determined. The only countries in the data set reporting more than a 12% reduction in emissions per capita from 1990 to 1993 are Estonia (45% reduction), Germany (36%), and Finland (26%).

A few countries included descriptions of the policies that have affected, or will affect, waste emissions, in their NIRs. It would be useful for other countries to do the same. For example, France attributed its decline in emissions to the development of methane recovery systems as well as a decline in the amount of waste that is disposed. On the other hand, Norway's total emissions were comparatively stable even with important policy changes in 1996 and 1999. New policies included regulations that prohibit easily degradable carbon waste from disposal, a tax that was introduced on waste delivered at landfill sites, and a requirement that any landfill that is allowed to accept biodegradable waste must collect and treat landfill gas. It is possible that those changes may have come too late in the decade to have perceivable impacts before 2000.

III.B. Assessment of Different Disposal Methods

How realistic is the description of different methods of solid waste disposal in the reports by Annex I countries? **Landfilling**, the disposal method that accounts for most waste-related carbon emissions has been discussed at length in Section II above. It is an exceedingly difficult subject for realistic assessment: theoretical models of first-order decay processes do not easily translate into statistical methods suitable for reporting purposes; the parameters of the preferred theoretical model vary widely from site to site, and are difficult to estimate. The alternative, the static mass balance approach of the Tier 1 method, achieves greater clarity and transparency at the cost of some simplifying approximations. The limited available evidence suggests that there is not a large difference between the two methods in practice. Thus for comparability and transparency reasons, we recommend use of the more tractable Tier 1 method, despite the fact that it rests in part on oversimplified assumptions.

Incineration, the most important alternative disposal method, has far more predictable emissions than landfilling, and varies less from site to site. However, it has received much less attention in the national data submissions, and in the IPCC guidelines – perhaps because it accounts for a smaller quantity of anthropogenic carbon emissions, or because it is often included in the data for the energy sector. IPCC suggests a simple mass balance calculation, multiplying the quantity of waste incinerated, the fraction of the waste composed of fossil carbon, and the efficiency of combustion.

A more complete methodology, comparable to the Tier 1 method for estimating emissions from land disposal, might start from the composition of incinerated waste (data that countries frequently possess). Estimates of the anthropogenic carbon fraction of each waste stream component could then be applied, with relatively large fractions for plastics, synthetic rubber, and synthetic textiles, and little if any for other materials. In this process estimates could be incorporated, if and when appropriate, for the *unsustainable* fraction of paper, wood, and other organic products (i.e., the fraction that is not replaced by regrowth of living plants). N_2O emissions could also be estimated in detail, on the basis of waste stream composition and incinerator technology.

To create a complete picture of waste-related emissions, it is important to have comparable data on incineration from all countries. If waste incineration is included in the energy sector, there is a need for a procedure that can echo that data in the waste sector, while identifying it as already counted elsewhere to avoid double counting.

Other disposal methods are of lesser importance. **Open dumping** is a significant issue in developing countries; measurement of methane emissions from such sites is one of the areas where new empirical research is most needed. The current values of the adjustment factor for uncontrolled disposal sites (MCF in the Tier 1 formulas) are surrounded by considerable uncertainty. For the most part, Annex I countries need to have clearly articulated reasons for adjusting this parameter in their reports; countries that have modern waste management, and well-enforced regulations on waste dumping, generally do not have significant numbers of uncontrolled disposal sites (and thus should use the default MCF of 1.0).

Composting, particularly of yard and garden waste, has become common in many countries. However, US EPA research suggests that it has only minor impacts on net carbon emissions. Composting of organic waste releases carbon as CO_2, or sequesters it in the final product. In contrast, landfilling of the same waste releases some carbon as methane, but apparently sequesters a significant fraction of the carbon in the landfill. The net effect of diverting organic waste from landfills to compost sites could be quite small from a climate change perspective (though advocates may favor it on economic and local environmental grounds). More research is needed to confirm this surprising finding. Still, as of now it appears that the omission of composting is not a serious problem in the inventories of carbon emissions from waste management. It should be noted that waste paper and paperboard in landfills are by far the most important source of methane emissions, and these wastes are virtually never composted.

III.C Issues in Classification and Comparison of Emissions

III.C.1 The Biogenic Assumption

Landfill gas consists of roughly 50% methane and 50% CO_2. The CO_2 emitted from landfills is excluded, because it is considered biogenic, by most but not all reporting countries.

Two conditions must be met in order to ensure that landfill CO_2 emissions do not represent an anthropogenic increase in atmospheric carbon. First, the landfilled waste that releases the carbon must come from trees or other plants that are being replaced. To cite the most important example, if trees are made into paper, which degrades or combusts to yield CO_2, which is then absorbed by the growth of an equal volume of new trees, the result is no net anthropogenic emission. However, if a fraction of the trees used for paper production are not replaced by new growth, then only the replaced fraction of the CO_2 emissions from paper waste should be counted as anthropogenic. While potentially important in times and places of deforestation, this approach is cumbersome and difficult to verify.

Second, if the trees used for paper production are replaced, the growth of the new trees must not be separately counted as a carbon sink. Nor should the new growth get credit for carbon sequestration, in the inventory of the country that grows the trees (which may or may not be the country where waste disposal occurs). The growth of those trees has already been counted once, in offsetting the carbon emissions from paper waste disposal. If it is also counted as a sink or gets sequestration credit, then double counting has occurred.

The same issues arise with regard to incinerator emissions. Some, but not all, NIRs provide evidence of the inclusion of anthropogenic CO_2 emissions from incinerators. Here, in addition to the questions about paper production, there should be a calculation of the fraction of the incinerated carbon that came from fossil fuels or other anthropogenic sources. Plastics, synthetic textiles, and synthetic rubber are important waste stream components that give rise to anthropogenic CO_2 emissions when burned. Thus, essentially every incinerator burning mixed waste from an industrial economy is generating some non-biogenic anthropogenic carbon emissions.

Although there is little if any research that systematically addresses these questions to date, they will become increasingly important as carbon inventories come to form the basis for international emissions policies under the Kyoto Protocol in the future.

III.C.2 Comparability Among Waste Management Options

Stepping back from the specifics of reporting waste-related greenhouse gases, there is an important but largely unexamined issue that concerns the comparability of alternative methods of waste management and mitigation of waste emissions. This waste emission issue is different from other sectors such as agriculture, since the same amount of carbon produces vastly different Global Warming Potentials depending upon which waste management option is selected, and alternative waste management strategies provide such vastly different credits for mitigation. Because of the much greater Global Warming Potential of methane and nitrous oxide relative to carbon dioxide, mitigation of the high GWP gases provides much greater credits per tonne than does mitigation of carbon dioxide. Hence a nation that chooses inexpensive landfilling of municipal solid waste will release methane and have much higher CO_2-equivalent emissions per tonne of waste, compared to a nation that chooses more costly incineration and releases carbon dioxide.

When some landfill methane is recovered, the landfilling nation will register a large, real and credited reduction in greenhouse gas emissions. However, since it is not possible to recover more than about three-quarters of the methane, there is still a larger CO_2-equivalent release of global warming gases into the atmosphere than if the waste had been burned.
A related issue involves the credits attributable to recycling programs, an issue that has not been touched on here, but is closely related to the issues we have discussed. For the reasons just described, recycling will appear to be "worth" more in carbon reduction terms in a country that landfills significant amounts of paper, rather than one that burns its waste. Moreover, an additional problem of credit arises here: a country that has not yet reached high rates of paper recycling will be eligible for significant credits, while those that have already institutionalized vigorous recycling efforts will not be similarly rewarded. The emission reduction credits may be important to the finances of recycling programs, under a carbon trading regime; thus it is important to establish a consistent, equitable understanding of the baseline from which reductions will be credited.

IV. CONCLUSIONS

The assessment of the reports submitted by the 27 countries has identified a need for greater care in data entry and calculation, inter-country consistency of methods, and better documentation of unique national circumstances and assumptions. This concluding section summarizes the recommendations suggested earlier.

The principal recommendations are as follows:

1. Countries should present a complete set of emissions data, covering all relevant gases from all major waste disposal options. International default values for emissions per tonne of waste[8] should be suggested as replacements for missing values; zero is seldom a reasonable estimate for omitted data.
2. Emissions from incineration should be consistently reported as part of the emissions from waste management, in a format that systematically develops emissions estimates from basic data, much as is currently done for landfill methane. If incinerator emissions have already been counted as part of the energy sector, a system should be developed for indicating the emissions here (for completeness and inter-country comparability), while noting that they have been counted elsewhere, in order to avoid double counting. Our preference, because of its simplicity, is to count all emissions from the waste sector as contributions to global warming, and then count as offsets only those that displace fossil fuels for energy production. It is essential to develop a specific reporting system that it is the same for all countries.
3. The assumption that all carbon dioxide emissions from wood and paper waste are biogenic should be examined in relation to FAO or other international agency estimates of rates of deforestation.
4. When carbon dioxide emissions from wood and paper waste are treated as biogenic, the amount of forest growth that replaces these wastes should be identified, and should not be separately counted as net sequestration, in order to avoid double counting. It is important to have a set of guidelines for crediting forest growth used for paper production against emissions from either landfills or incinerators due to

[8] See IPCC's Good Practices Guidance and Uncertainty Management in National Greenhouse Gas Inventories (1996); Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual; and Hoornweg, op.cit.

wood and paper disposal. It may be simpler to count all emissions from landfills and incinerators as contributing greenhouse gases and then treat all sequestration by additional planting and net growth of trees as an offset to total emissions.

5. A single, standard method of estimation should be adopted for methane emissions from land disposal. Based on the present state of knowledge, it appears that the IPCC Tier 1 method should be the standard for estimating methane emissions. This choice should be periodically reconsidered as the knowledge of landfill biochemistry advances.
6. The technical parameters used in estimating landfill methane emissions should be presented in the form of precisely specified international standards, subject to revision as knowledge advances. For the sake of inter-country consistency, the reasons for variation in these parameters, based on climate, waste composition, or other factors, should be clearly defined, leaving little or no room for judgmental variation in technical relationships.
7. The role of the methane correction factor should be clarified. Based on the understanding of this factor, it should rarely be adjusted below 1.0 in Annex I countries. Waste from the entire population, not just the urban sector should be included in the calculations, unless a country provides an explicit justification for treating its rural population differently.
8. A more user-friendly reporting format, such as a standardized spreadsheet with built-in formulas for key calculations, could be created and distributed by the UNFCCC Secretariat or its subsidiary bodies. Use of such a customized reporting format might reduce the rate of errors and omissions in country submissions.
9. Clear formats and standards should be provided for documentation of inputs and explanation of changes in default relationships. Countries reporting substantial year-to-year changes, in either direction, should be called on to explain the changes. A specific section in the report should be provided for this information.
10. In the development of procedures for assigning carbon credits, attention should be paid to the problems of comparability among countries that rely on different waste management options and mitigation strategies, since these alternatives have substantially different carbon emissions per tonne of waste.

TABLES AND FIGURES

Table 1.1: TOTAL WASTE MANAGEMENT-GHGs Reported

Country	TOTAL WASTE MANAGEMENT GHG Reported				
	CO2	*CH4*	*N2O*	*NOx*	*CO*
Austria	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Belgium	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Canada	Data Reported	Data Reported	Data Reported	Zero	Zero
Czech Republic	Data Reported	Data Reported	Data Reported	Zero	Zero
Denmark	Zero	Data Reported	Zero	Zero	Zero
Estonia	Zero	Data Reported	Zero	Zero	Zero
Finland	Zero	Data Reported	Data Reported	Zero	Zero
France	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Germany	No Data	Data Reported	Data Reported	No Data	No Data
Greece	Zero	Data Reported	Zero	Zero	Zero
Hungary	Data Reported	Data Reported	Data Reported	Zero	Zero
Iceland	Data Reported	Data Reported	Zero	Data Reported	Data Reported
Ireland	Zero	Data Reported	Data Reported	Zero	Zero
Italy	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Luxembourg	No Data	Data Reported	Data Reported	Data Reported	Data Reported
Latvia	No Data	Data Reported	Data Reported	No Data	No Data
Netherlands	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
New Zealand	Zero	Data Reported	Data Reported	No Data	No Data
Norway	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Poland	Zero	Data Reported	Data Reported	Zero	Zero
Portugal	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Slovakia	Zero	Data Reported	Data Reported	Zero	Zero
Spain	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Sweden	Zero	Data Reported	Zero	Zero	Zero
Switzerland	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
UK	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
US	Zero	Data Reported	Data Reported	Data Reported	Data Reported

Table 1.2: Land Disposal (SWDS)- GHGs Reported

Country	Land Disposal GHGs Reported				
	CO2(1)	*CH4*	*N2O*	*NOx*	*CO*
Austria	Zero	Data Reported	No Data	Zero	Data Reported
Belgium	No Data	Data Reported	No Data	No Data	No Data
Canada	Zero	Data Reported	No Data	Zero	Zero
Czech Republic	Zero	Data Reported	No Data	Zero	Zero
Denmark	Zero	Data Reported	No Data	Zero	Zero
Estonia	Zero	Data Reported	No Data	Zero	Zero
Finland	Zero	Data Reported	No Data	Zero	Zero
France	Zero	Data Reported	No Data	Zero	Zero
Germany	No Data	Data Reported	No Data	No Data	No Data
Greece	Zero	Data Reported	No Data	Zero	Zero
Hungary	Data Reported	Data Reported	No Data	Zero	Zero
Iceland	Zero	Data Reported	No Data	Zero	Zero
Ireland	Zero	Data Reported	No Data	Zero	Zero
Italy	Zero	Data Reported	No Data	Zero	Zero
Latvia	No Data	Data Reported	No Data	No Data	No Data
Luxembourg	No Data	Data Reported	No Data	No Data	No Data
Netherlands	Zero	Data Reported	No Data	Zero	Zero
New Zealand	No Data	Data Reported	No Data	Zero	Zero
Norway	Data Reported	Data Reported	No Data	Zero	Zero
Poland	Zero	Data Reported	No Data	Zero	Zero
Portugal	Zero	Data Reported	No Data	Zero	Zero
Slovakia	Zero	Data Reported	No Data	Zero	Zero
Spain	Data Reported	Data Reported	No Data	Data Reported	Data Reported
Sweden	Zero	Data Reported	No Data	No Data	No Data
Switzerland	Data Reported	Data Reported	No Data	Data Reported	Data Reported
UK	Zero	Data Reported	No Data	Zero	Zero
US	Zero	Data Reported	No Data	Data Reported	Data Reported

Table 1.3: GHGs Reported from Incineration

Country	INCINERATION GHG REPORTED				
	CO2	*CH4*	*N2O*	*NOx*	*CO*
Austria	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Belgium	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Canada	Data Reported	Data Reported	Data Reported	No Data	No Data
Czech Republic	Data Reported	Zero	Zero	No Data	No Data
Denmark	Zero	Zero	Zero	No Data	No Data
Estonia	Zero	Zero	Zero	No Data	No Data
Finland	No Data	No Data	No Data	No Data	No Data
France	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Germany	No Data	No Data	No Data	No Data	No Data
Greece	Zero	Zero	Zero	No Data	No Data
Hungary	Data Reported	Zero	Data Reported	No Data	No Data
Iceland	Data Reported	Data Reported	Zero	Data Reported	Data Reported
Ireland	No Data	No Data	No Data	No Data	No Data
Italy	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Latvia	No Data	Data Reported	Data Reported	Data Reported	Data Reported
Luxembourg	No Data	No Data	No Data	No Data	No Data
Netherlands	No Data	No Data	No Data	No Data	No Data
New Zealand	No Data	No Data	No Data	No Data	No Data
Norway	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Poland	Zero	Zero	Zero	No Data	No Data
Portugal	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Slovakia	Zero	Zero	Zero	No Data	No Data
Spain	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
Sweden	No Data	No Data	No Data	No Data	No Data
Switzerland	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
UK	Data Reported	Data Reported	Data Reported	Data Reported	Data Reported
US	Zero	Zero	Zero	Data Reported	Data Reported

Table 1.4: TOTAL WASTE MANAGEMENT GHG Reported (Gg)

Country	TOTAL WASTE MANAGEMENT GHG Reported (Gg)					
	CO2	*CH4*	*N2O*	*NOx*	*CO*	*NMVOC*
Austria	105.98	247.60	0.09	0.24	16.77	0.41
Belgium	1705.02	131.51	0.63	4.04	0.43	0.33
Canada	281.54	1094.66	3.30	0.00	0.00	0.00
Czech Republic	357.00	103.51	0.65	0.00	0.00	0.00
Denmark	0.00	57.00	0.00	0.00	0.00	0.00
Estonia	0.00	56.93	0.00	0.00	0.00	0.00
Finland	0.00	80.18	0.27	0.00	0.00	2.00
France	2358.54	800.42	3.51	20.79	284.06	33.60
Germany	NE	694.75	4.00			
Greece	0.00	253.30	0.00	0.00	0.00	0.00
Hungary	855.95	145.19	0.05	0.00	0.00	0.00
Iceland	16.52	2.25	0.00	0.03	0.13	0.00
Ireland	0.00	73.32	0.21	0.00	0.00	0.00
Italy	1010.53	573.11	3.76	13.76	249.58	26.28
Luxembourg		3.08	0.02	0.29	0.01	0.02
Latvia	NO	62.94	0.24	NO/NE	NO/NE	NO/NE
Netherlands	452.74	406.31	0.57	0.29	0.14	0.82
New Zealand	0.00	106.39	0.50	NE	NE	NE
Norway	125.44	186.94	0.35	0.08	0.36	0.00
Poland	0.00	885.81	2.60	0.00	0.00	2.11
Portugal	406.37	318.92	1.69	1.76	0.51	5.37
Slovakia	0.00	83.35	0.03	0.00	0.00	0.21
Spain	199.79	628.07	3.84	7.19	199.79	37.84
Sweden	0.00	96.88	0.00	0.00	0.00	0.00
Switzerland	1393.00	61.57	0.33	4.98	2.74	0.97
UK	208.16	696.97	3.81	1.10	3.67	6.78
US	0.00	11056.36	27.28	80.74	3273.18	527.99

Note: Text entries in Tables 1.4, 1.5, and 1.6 are copied directly from country data submissions.

Table 1.5: Land Disposal (SWDS) -GHGs Reported (Gg)					
Country	Land Disposal GHGs Reported (Gg)				
	CO2	*CH4*	*N2O*	*NOx*	*CO*
Austria	0.00	210.66		0.00	16.68
Belgium	NE	115.90		NE	NE
Canada	0.00	1075.37		0.00	0.00
Czech Republic	0.00	75.98		0.00	0.00
Denmark	0.00	57.00		0.00	0.00
Estonia	0.00	46.52		0.00	0.00
Finland	0.00	78.59		0.00	0.00
France	0.00	750.85		0.00	0.00
Germany	NE	694.75			
Greece	0.00	227.02		0.00	0.00
Hungary	275.95	92.24		0.00	0.00
Iceland	0.00	2.22		0.00	0.00
Ireland	0.00	73.32		0.00	0.00
Italy	0.00	449.25		0.00	0.00
Luxembourg		2.66			
Latvia	NO	58.58		NO/NE	NO/NE
Netherlands	0.00	403.79		0.00	0.00
New Zealand	NE	98.60		0.00	0.00
Norway	39.10	186.51		0.00	0.00
Poland	0.00	809.70		0.00	0.00
Portugal	0.00	296.39		0.00	0.00
Slovakia	0.00	48.26		0.00	0.00
Spain	31.99	480.90		0.13	2.44
Sweden	0.00	96.88		IE	IE
Switzerland	133.00	59.90		0.57	0.73
UK	0.00	660.00		0.00	0.00
US	0.00	9689.60		1.81	5.44

Note: Text entries in Tables 1.4, 1.5, and 1.6 are copied directly from country data submissions.

Table 1.6: Incineration- GHGs Reported (Gg)					
Country	INCINERATION GHG REPORTED (Gg)				
INCINERATION	CO2	CH4	N2O	NOx	CO
Austria	105.98	0.07	0.01	0.24	0.09
Belgium	1705.02	0.29	0.30	4.04	0.43
Canada	281.54	0.33	0.19	NE	NE
Czech Republic	357.00	0.00	0.00		
Denmark	0.00	0.00	0.00	IE	IE
Estonia	0.00	0.00	0.00		
Finland	IE	IE	IE	IE	IE
France	2358.54	17.41	1.35	20.79	284.06
Germany	NE	NE	NE		
Greece	0.00	0.00	0.00	NO	NO
Hungary	580.00	0.00	0.05		
Iceland	16.52	0.01	0.00	0.03	0.13
Ireland	NO	NO	NO		
Italy	1010.53	11.92	0.45	13.76	249.58
Luxembourg		0.01	0.01	0.29	0.01
Latvia	NE	NE	NE	NE	NE
Netherlands	IE	IE	IE	IE	IE
New Zealand	NE	NE	NE	NE	NE
Norway	86.35	0.02	0.00	0.08	0.36
Poland	0.00	0.00	0.00	NE	NE
Portugal	406.37	0.05	0.10	1.76	0.51
Slovakia	0.00	0.00	0.00	IE	IE
Spain	167.80	12.84	0.36	7.06	197.35
Sweden	IE	IE	IE	IE	IE
Switzerland	1260.00	0.09	0.26	3.91	1.60
UK	208.16	0.08	0.17	1.10	3.67
US	0.00	0.00	0.00	78.02	3267.73

Note: Text entries in Tables 1.4, 1.5, and 1.6 are copied directly from country data submissions.

TABLE 1.7: TOTAL WASTE MANAGEMENT - GHG Per Capita (kg/ person)

Country	TOTAL WASTE MANAGEMENT GHG Reported (kg/person)					
	CO2	*CH4*	*N2O*	*NOx*	*CO*	*NMVOC*
Austria	13.07	30.54	0.01	0.03	2.07	0.05
Belgium	168.08	12.96	0.06	0.40	0.04	0.03
Canada	9.16	35.60	0.11	0.00	0.00	0.00
Czech Republic	34.47	9.99	0.06	0.00	0.00	0.00
Denmark	0.00	10.85	0.00	0.00	0.00	0.00
Estonia	0.00	40.04	0.00	0.00	0.00	0.00
Finland	0.00	15.56	0.05	0.00	0.00	0.39
France	39.81	13.51	0.06	0.35	4.80	0.57
Germany	No Data	8.11	0.05	0.00	0.00	0.00
Greece	0.00	23.01	0.00	0.00	0.00	0.00
Hungary	83.94	14.24	0.01	0.00	0.00	0.00
Iceland	59.63	8.12	0.00	0.09	0.46	0.00
Ireland	0.00	20.22	0.06	0.00	0.00	0.00
Italy	17.47	9.91	0.06	0.24	4.31	0.45
Luxembourg	0.00	7.41	0.06	0.69	0.02	0.05
Latvia	No Data	26.50	0.10	No Data	No Data	No Data
Netherlands	28.54	25.61	0.04	0.02	0.01	0.05
New Zealand	0.00	27.73	0.13	No Data	No Data	No Data
Norway	28.59	42.61	0.08	0.02	0.08	0.00
Poland	0.00	22.71	0.07	0.00	0.00	0.05
Portugal	40.50	31.78	0.17	0.18	0.05	0.54
Slovakia	0.00	1.54	0.00	0.00	0.00	0.00
Spain	5.00	15.73	0.10	0.18	5.00	0.95
Sweden	0.00	10.77	0.00	0.00	0.00	0.00
Switzerland	193.47	8.55	0.05	0.69	0.38	0.14
UK	3.47	11.62	0.06	0.02	0.06	0.11
US	0.00	38.76	0.10	0.28	11.48	1.85
Average	**51.80**	**19.41**	**0.07**	**0.24**	**2.21**	**0.35**

Table 1.8: Land Disposal (SWDS) -GHG Per Capita (kg/ person)

Country	Land Disposal GHGs Reported (kg/person)					
	CO2	*CH4*	*N2O*	*NOx*	*CO*	*NMVOC*
Austria	0.00	25.98	0.00	0.00	2.06	0.02
Belgium	No Data	11.43	0.00	No Data	No Data	No Data
Canada	0.00	34.97	0.00	0.00	0.00	0.00
Czech Republic	0.00	7.34	0.00	0.00	0.00	0.00
Denmark	0.00	10.85	0.00	0.00	0.00	0.00
Estonia	0.00	32.71	0.00	0.00	0.00	0.00
Finland	0.00	15.25	0.00	0.00	0.00	0.15
France	0.00	12.67	0.00	0.00	0.00	0.13
Germany	No Data	8.11	0.00	0.00	0.00	0.00
Greece	0.00	20.62	0.00	0.00	0.00	0.00
Hungary	27.06	9.05	0.00	0.00	0.00	0.00
Iceland	0.00	8.02	0.00	0.00	0.00	0.00
Ireland	0.00	20.22	0.00	0.00	0.00	0.00
Italy	0.00	7.77	0.00	0.00	0.00	0.15
Luxembourg	0.00	6.40	0.00	0.00	0.00	0.00
Latvia	No Data	24.67	0.00	No Data	No Data	No Data
Netherlands	0.00	25.46	0.00	0.00	0.00	0.05
New Zealand	No Data	25.70	0.00	0.00	0.00	0.00
Norway	8.91	42.52	0.00	0.00	0.00	0.00
Poland	0.00	20.76	0.00	0.00	0.00	0.00
Portugal	0.00	29.54	0.00	0.00	0.00	0.45
Slovakia	0.00	0.89	0.00	0.00	0.00	0.00
Spain	0.80	12.04	0.00	0.00	0.06	0.02
Sweden	0.00	10.77	0.00	No Data	No Data	No Data
Switzerland	18.47	8.32	0.00	0.08	0.10	0.09
UK	0.00	11.00	0.00	0.00	0.00	0.11
US	0.00	33.97	0.00	0.01	0.02	0.12
Average	**13.81**	**17.67**	**0.00**	**0.03**	**0.56**	**0.13**

Table 1.9: Incineration -GHG Per Capita (kg/ person)

Country	Incineration GHG Reported (kg/person)				
	CO2	*CH4*	*N2O*	*NOx*	*CO*
Austria	13.07	0.01	0.00	0.03	0.01
Belgium	168.08	0.03	0.03	0.40	0.04
Canada	9.16	0.01	0.01	No Data	No Data
Czech Republic	34.47	0.00	0.00	0.00	0.00
Denmark	0.00	0.00	0.00	No Data	No Data
Estonia	0.00	0.00	0.00	0.00	0.00
Finland	No Data	No Data	No Data	No Data	No Data
France	39.81	0.29	0.02	0.35	4.80
Germany	No Data	No Data	No Data	0.00	0.00
Greece	0.00	0.00	0.00	No Data	No Data
Hungary	56.88	0.00	0.01	0.00	0.00
Iceland	59.63	0.03	0.00	0.09	0.46
Ireland	No Data	No Data	No Data	0.00	0.00
Italy	17.47	0.21	0.01	0.24	4.31
Luxembourg	0.00	0.02	0.02	0.69	0.02
Latvia	No Data	No Data	No Data	No Data	No Data
Netherlands	No Data	No Data	No Data	No Data	No Data
New Zealand	No Data	No Data	No Data	No Data	No Data
Norway	19.68	0.00	0.00	0.02	0.08
Poland	0.00	0.00	0.00	No Data	No Data
Portugal	40.50	0.00	0.01	0.18	0.05
Slovakia	0.00	0.00	0.00	No Data	No Data
Spain	4.20	0.32	0.01	0.18	4.94
Sweden	No Data	No Data	No Data	No Data	No Data
Switzerland	175.00	0.01	0.04	0.54	0.22
UK	3.47	0.00	0.00	0.02	0.06
US	0.00	0.00	0.00	0.27	11.46
Average	**49.34**	**0.08**	**0.012**	**0.25**	**2.20**

Table 1.10: TOTAL WASTE MANAGEMENT - GHG Per Capita (kg/ person CO2 Equivalent)				
Country	**TOTAL WASTE GHG Reported (kg CO2 Equivalent)**			
	CO2	***CH4***	***N2O***	
C02 equivalent	*1*	*21*	*310*	
Austria	13.07	641.37	3.25	
Belgium	168.08	272.25	19.27	
Canada	9.16	747.57	33.22	
Czech Republic	34.47	209.86	19.38	
Denmark	0.00	227.78	0.00	
Estonia	0.00	840.78	0.00	
Finland	0.00	326.74	16.29	
France	39.81	283.75	18.38	
Germany	No Data	170.27	14.47	
Greece	0.00	483.18	0.00	
Hungary	83.94	299.01	1.55	
Iceland	59.63	170.43	0.00	
Ireland	0.00	424.52	17.69	
Italy	17.47	208.07	20.15	
Luxembourg	0.00	155.66	18.03	
Latvia	No Data	556.52	31.30	
Netherlands	28.54	537.89	11.19	
New Zealand	0.00	582.32	40.40	
Norway	28.59	894.85	24.66	
Poland	0.00	476.85	20.66	
Portugal	40.50	667.48	52.09	
Slovakia	0.00	32.40	0.17	
Spain	5.00	330.34	29.84	
Sweden	0.00	226.20	0.00	
Switzerland	193.47	179.58	14.29	
UK	3.47	243.94	19.69	
US	0.00	814.02	29.65	
				All three gases
Average	**51.80**	**407.54**	**20.71**	**480.05**
percent of total	*11%*	*85%*	*4%*	*100%*

Table 1.11: Land Disposal (SWDS) - GHG Per Capita (kg/ person CO2 Equivalent)			
Country	Land Disposal GHG Reported (kg)		
	CO2	CH4	
C02 equivalent	1	21	
Austria	0.00	545.67	
Belgium	No Data	239.93	
Canada	0.00	734.40	
Czech Republic	0.00	154.05	
Denmark	0.00	227.78	
Estonia	0.00	686.99	
Finland	0.00	320.28	
France	0.00	266.17	
Germany	No Data	170.27	
Greece	0.00	433.05	
Hungary	27.06	189.96	
Iceland	0.00	168.46	
Ireland	0.00	424.52	
Italy	0.00	163.10	
Luxembourg	0.00	134.39	
Latvia	No Data	517.97	
Netherlands	0.00	534.56	
New Zealand	No Data	539.68	
Norway	8.91	892.82	
Poland	0.00	435.88	
Portugal	0.00	620.32	
Slovakia	0.00	18.76	
Spain	0.80	252.93	
Sweden	0.00	226.20	
Switzerland	18.47	174.71	
UK	0.00	231.00	
US	0.00	713.39	
			Both gases
Average	**13.81**	**371.01**	**384.82**
percent of total	*4%*	*96%*	*100%*

Table 1.12: Incineration - GHG Per Capita (kg/ person CO2 Equivalent)			
Country	**Incineration GHG Reported (kg CO2-equivalent)**		
	CO2	***CH4***	***N2O***
C02 equivalent	*1*	*21*	*310*
Austria	13.07	0.17	0.31
Belgium	168.08	0.60	9.09
Canada	9.16	0.23	1.93
Czech Republic	34.47	0.00	0.00
Denmark	0.00	0.00	0.00
Estonia	0.00	0.00	0.00
Finland	No Data	No Data	No Data
France	39.81	6.17	7.05
Germany	No Data	No Data	No Data
Greece	0.00	0.00	0.00
Hungary	56.88	0.00	1.55
Iceland	59.63	0.60	0.00
Ireland	No Data	No Data	No Data
Italy	17.47	4.33	2.40
Luxembourg	0.00	0.49	4.84
Latvia	No Data	No Data	No Data
Netherlands	No Data	No Data	No Data
New Zealand	No Data	No Data	No Data
Norway	19.68	0.07	0.07
Poland	0.00	0.00	0.00
Portugal	40.50	0.10	3.02
Slovakia	0.00	0.00	0.00
Spain	4.20	6.75	2.83
Sweden	No Data	No Data	No Data
Switzerland	175.00	0.25	11.19
UK	3.47	0.03	0.90
US	0.00	0.00	0.00

	CO2	CH4	N2O	**All three gases**
Average	**49.34**	**1.65**	**3.76**	**54.75**
percent of total	*90%*	*3%*	*7%*	*100%*

Table 2.1: SWDS Methodology

Country	Methane Estimation Method
Austria	Tier 1
Belgium	No Data
Canada	neither
Czech Republic	Unknown
Denmark	neither
Estonia	Unknown
Finland	Tier 1
France	Tier 2
Germany	No Data
Greece	Tier 1
Hungary	Tier 1
Iceland	Unknown
Ireland	Tier 1
Italy	Unknown
Luxembourg	No Data
Latvia	Unknown
Netherlands	Tier 2
New Zealand	Tier 1
Norway	Tier 2
Poland	Tier 1
Portugal	Unknown
Slovakia	Unknown
Spain	Tier 2
Sweden	Tier 2
Switzerland	Tier 1
UK	Tier 2
US	Tier 2

Table 2.2: Methane Emissions Per Capita

Country	Times 1E6		
	Revised	Calculated	Submitted
Switzerland	3.16	0.00	8.32
Spain	6.25	4.92	12.04
Slovakia	9.19	5.07	8.00
Sweden	4.76	6.51	10.77
Ireland	14.93	16.48	20.22
Austria	1.94	17.81	25.99
Finland	15.85	18.52	10.71
Poland	20.82	20.89	20.74
Greece	21.85	21.85	23.07
Portugal	22.74	22.78	29.54
Hungary	25.20	25.20	9.05
Norway	29.76	34.65	42.51
Italy	34.03	38.89	7.77
US	23.84	57.57	33.97
UK	25.10	94.00	11.00
Belgium	8.76	NA	6.51
Canada	21.93	NA	34.97
Czech Republic	14.88	NA	7.34
Denmark	4.67	NA	10.85
Estonia	16.59	NA	32.71
France	5.80	NA	12.67
Germany	12.11	NA	8.11
Iceland	46.42	NA	8.01
Latvia	4.60	NA	24.67
Luxembourg	10.63	NA	11.43
Netherlands	25.09	NA	25.45
New Zealand	39.38	NA	25.70

mean	17.42	25.68	17.86
st dev	11.56	24.00	10.54
st dev / mean	0.664		0.590

Table 2.3: Implied Methane Emissions x 1000

Country	Methane / tonne of waste landfilled		
	Revised	Calculated	Submitted
Switzerland	51.5	0.0	135.7
Spain	19.9	15.7	38.3
Slovakia	42.5	23.4	37.0
Sweden	32.1	44.0	72.7
Ireland	39.9	44.0	54.0
Finland	49.8	58.2	33.6
Greece	59.2	59.2	62.6
Poland	67.2	67.5	67.0
Hungary	74.4	74.4	26.7
Portugal	83.9	84.0	108.9
Italy	80.9	92.4	18.5
Norway	88.2	102.7	126.0
Austria	12.6	116.2	169.5
US	51.2	123.7	73.0
UK	44.1	165.3	19.3
Belgium	50.8	NA	66.2
Canada	41.1	NA	65.5
Czech Republic	58.6	NA	28.9
Denmark	50.8	NA	118.0
Estonia	34.7	NA	68.5
France	21.5	NA	47.0
Germany	50.8	NA	34.0
Iceland	78.9	NA	13.6
Latvia	14.3	NA	76.8
Luxembourg	50.8	NA	31.1
Netherlands	76.5	NA	77.7
New Zealand	45.2	NA	29.5
mean	50.8	71.4	62.9
st dev	20.9	44.3	39.5
st dev / mean	0.412		0.628

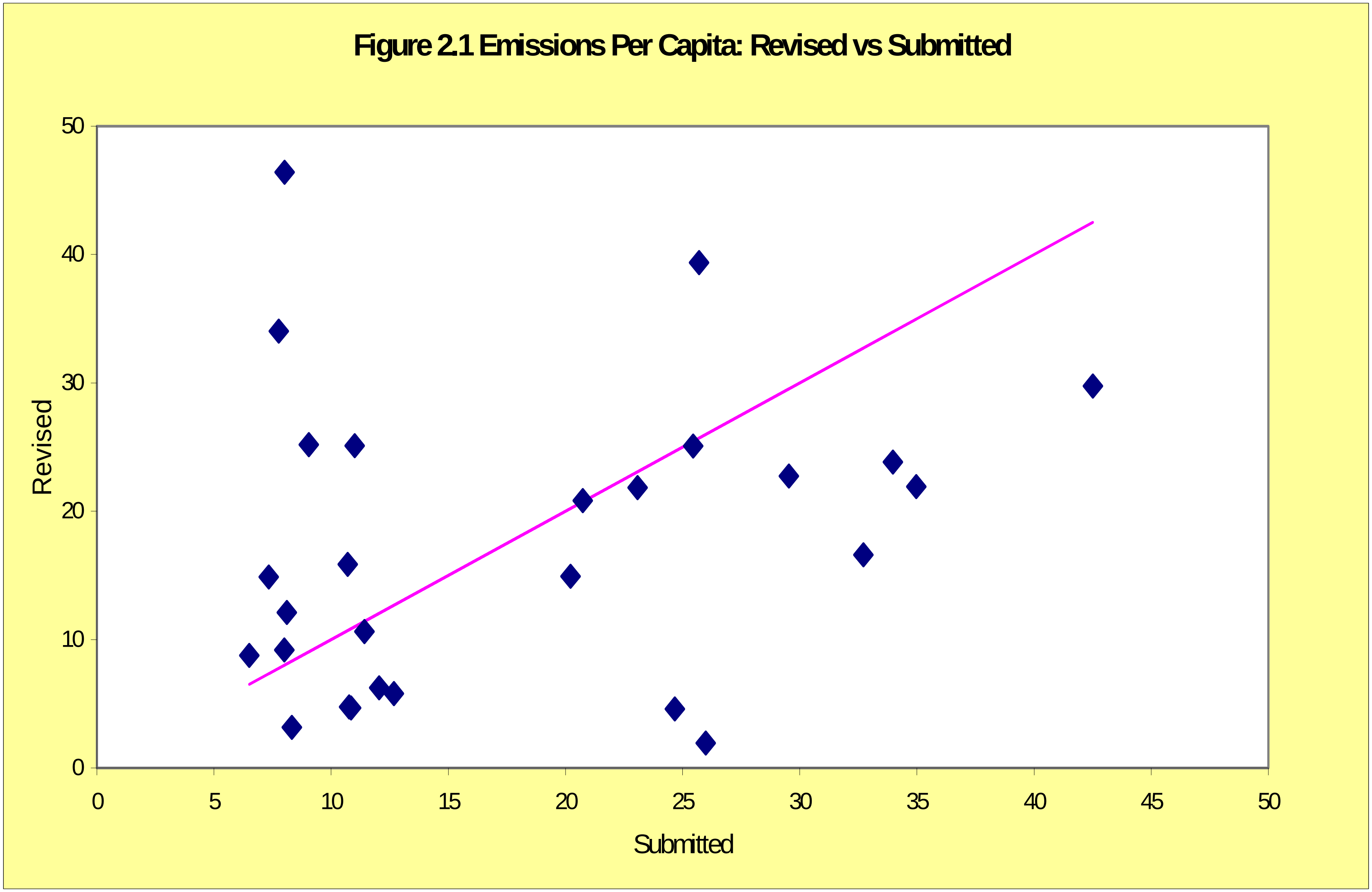
Figure 2.1 Emissions Per Capita: Revised vs Submitted
Revised
Submitted
0
10
20
30
40
50
0
5
10
15
20
25
30
35
40
45
50

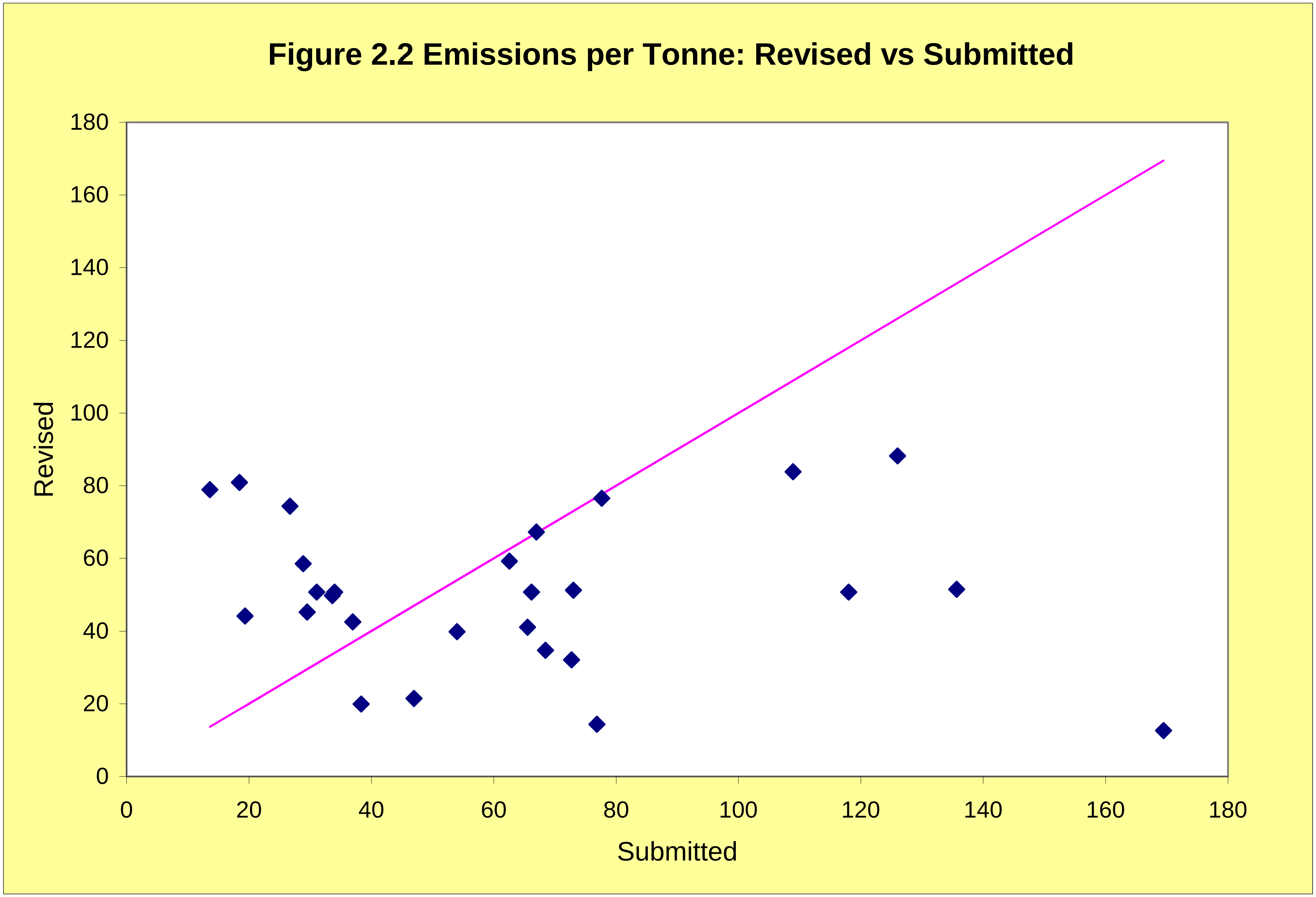
Figure 2.2 Emissions per Tonne: Revised vs Submitted
Revised
Submitted
0
20
40
60
80
100
120
140
160
180

Figure 2.3 Emissions per capita: calculated vs submitted

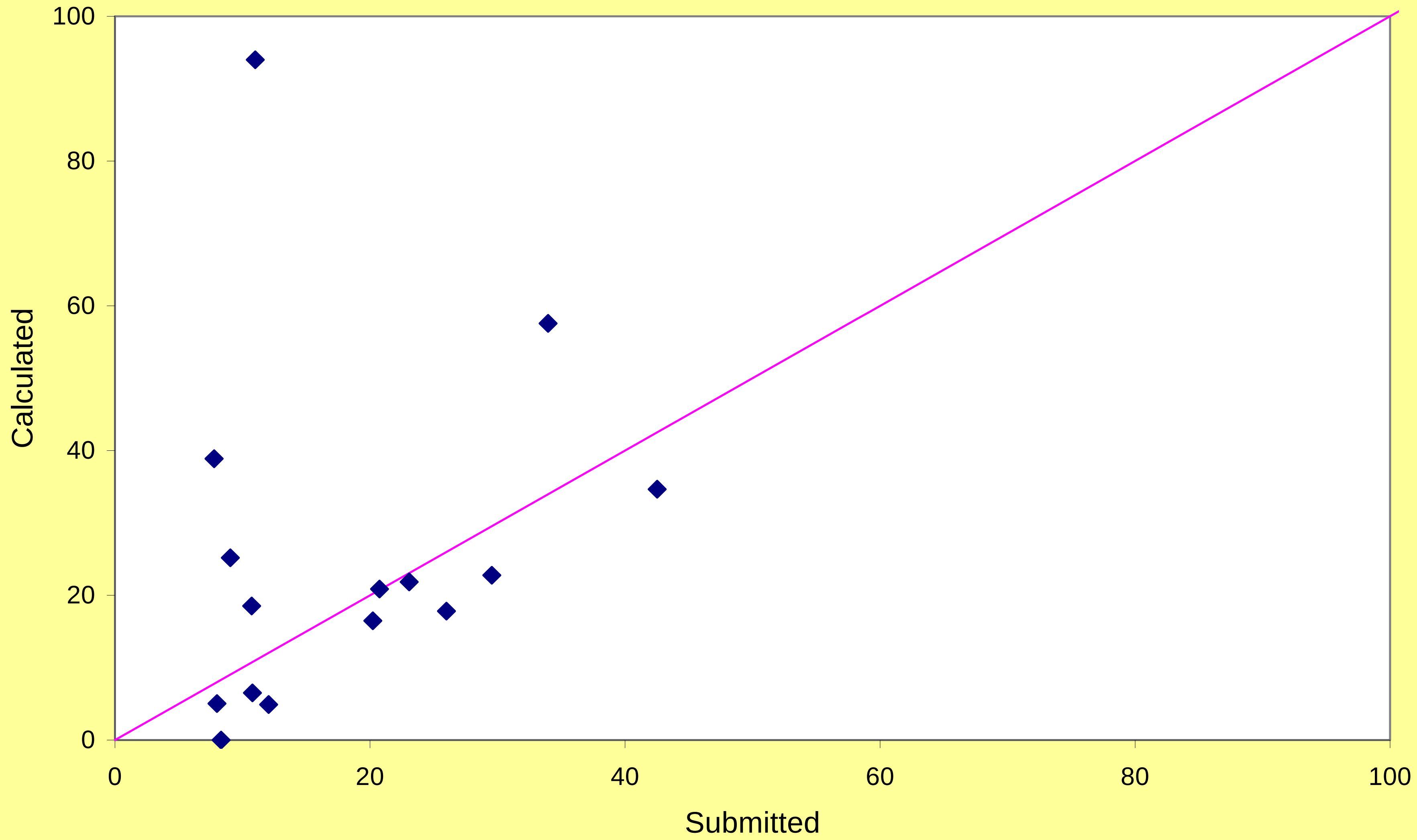

Figure 2.4 Emissions per tonne: calculated vs submitted

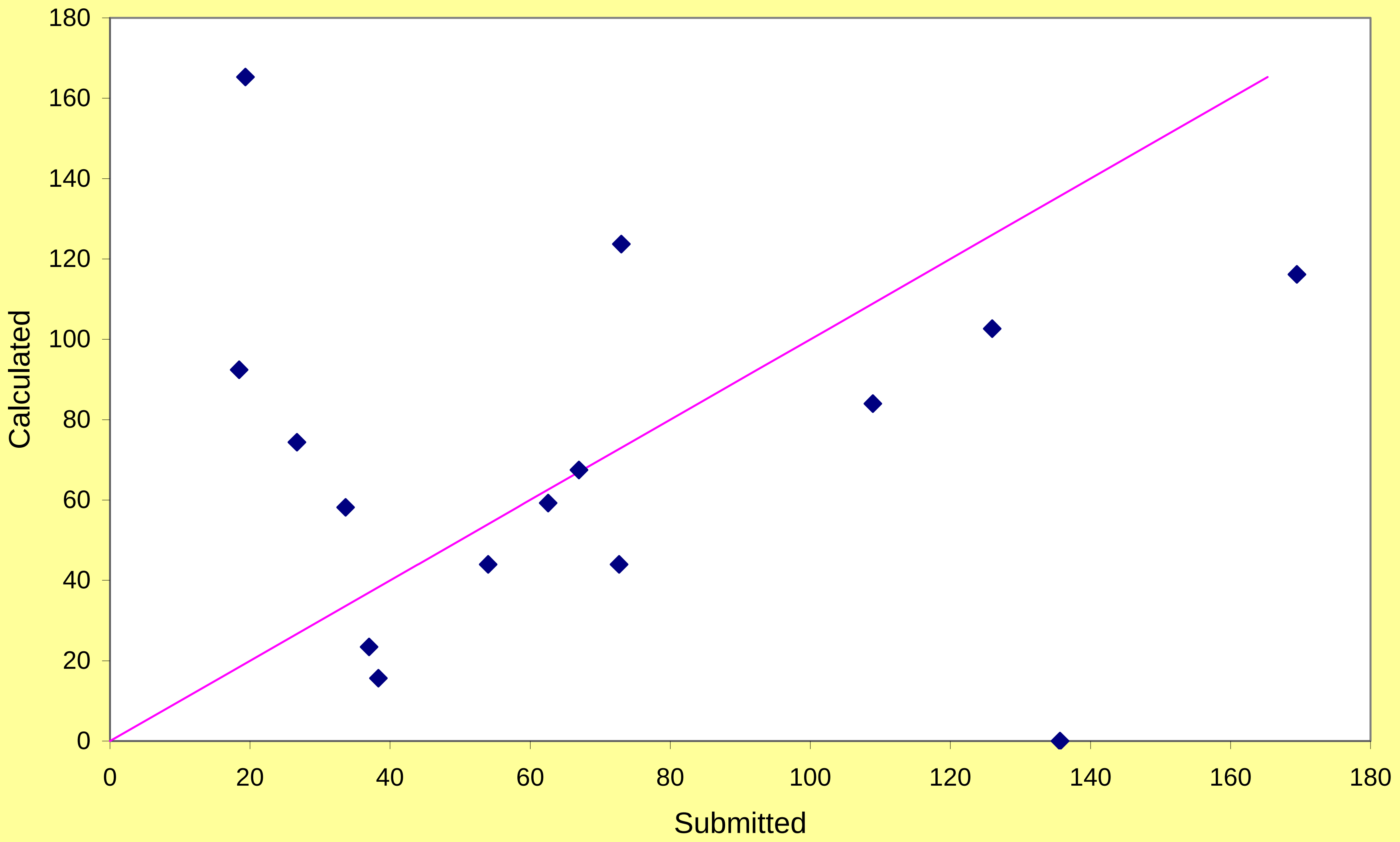

Figure 2.5 Emissions per capita: Revised vs Calculated

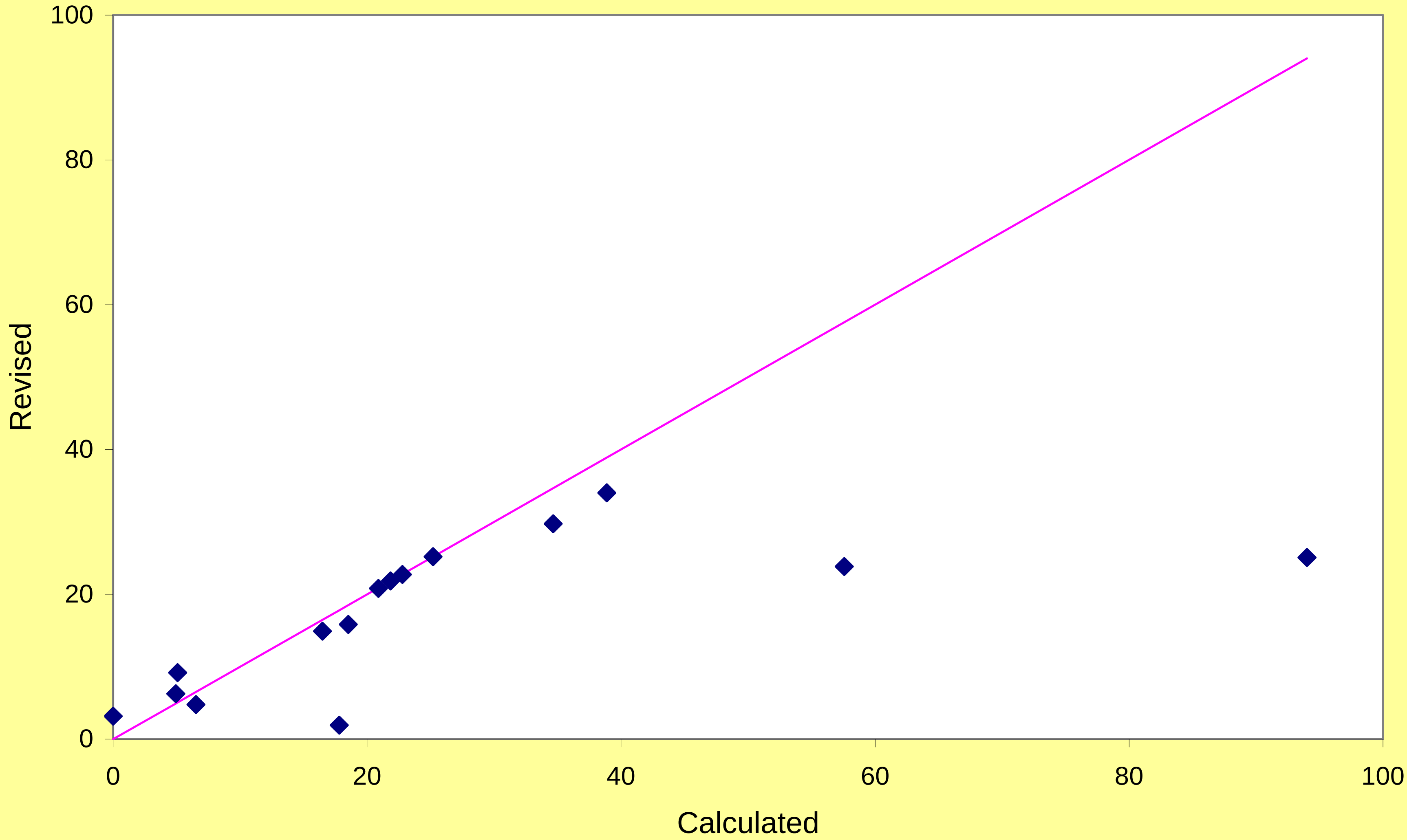

Figure 2.6 Emissions per tonne: Revised vs Calculated

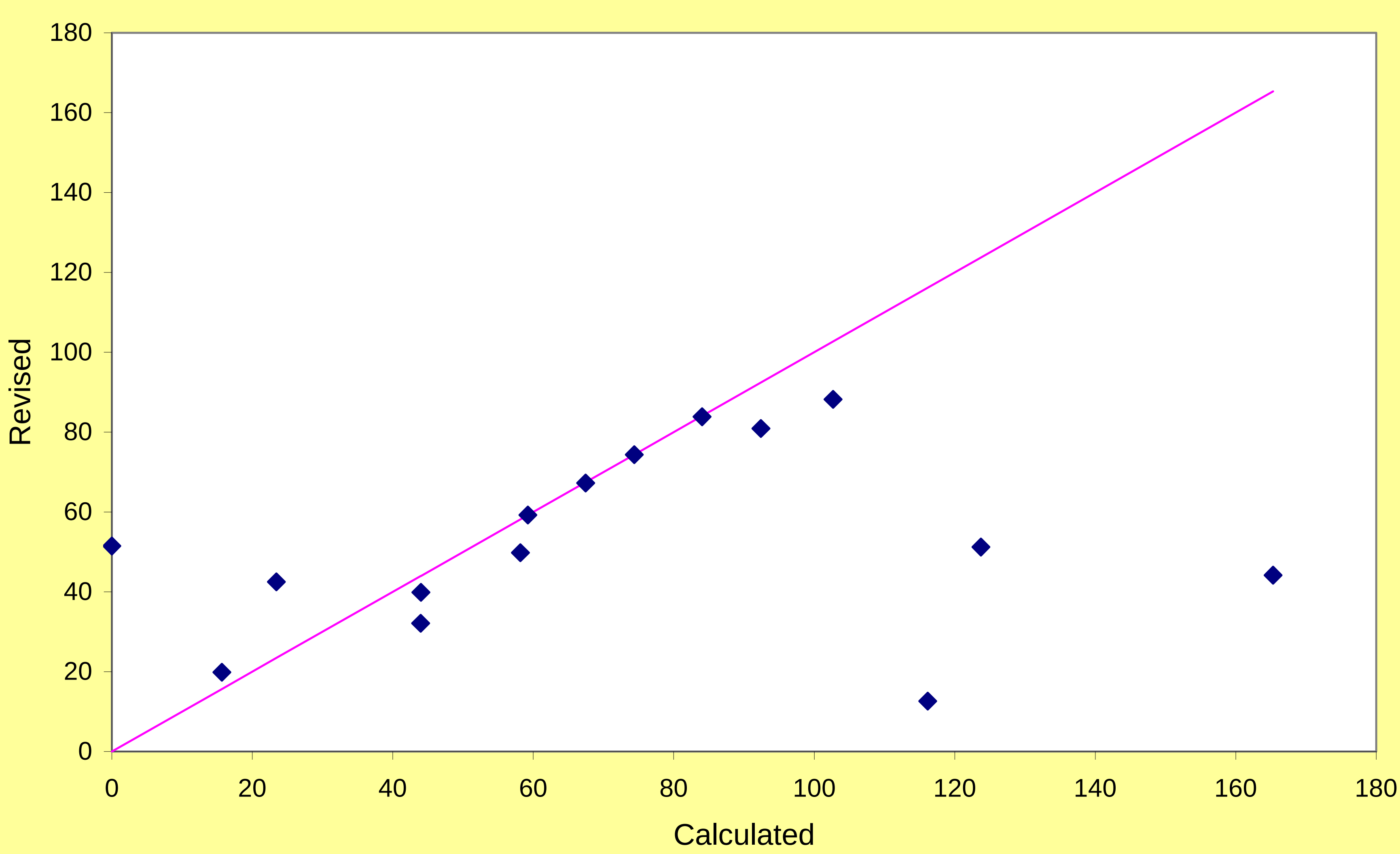

Table 3.1. Waste sector emissions

kg CO_2 equivalent per capita, 2000 vs 1990

	value in 2000 / value in 1990
Germany	0.405
Finland	0.451
UK *	0.633
Hungary **	0.644
Netherlands	0.687
New Zealand	0.707
Iceland	0.738
Sweden	0.758
Austria	0.811
Slovakia	0.821
Estonia	0.823
Ireland	0.844
US	0.862
France	0.892
Denmark	0.894
Czech Republic	0.911
Switzerland	0.929
Poland	0.996
Belgium	1.015
Norway	1.018
Italy	1.031
Canada	1.048
Portugal	1.175
Greece	1.305
Spain	1.507
Latvia	3.199

* - ratio of 1999 value / 1990 value
** - ratio of 2000 value / 1991 value

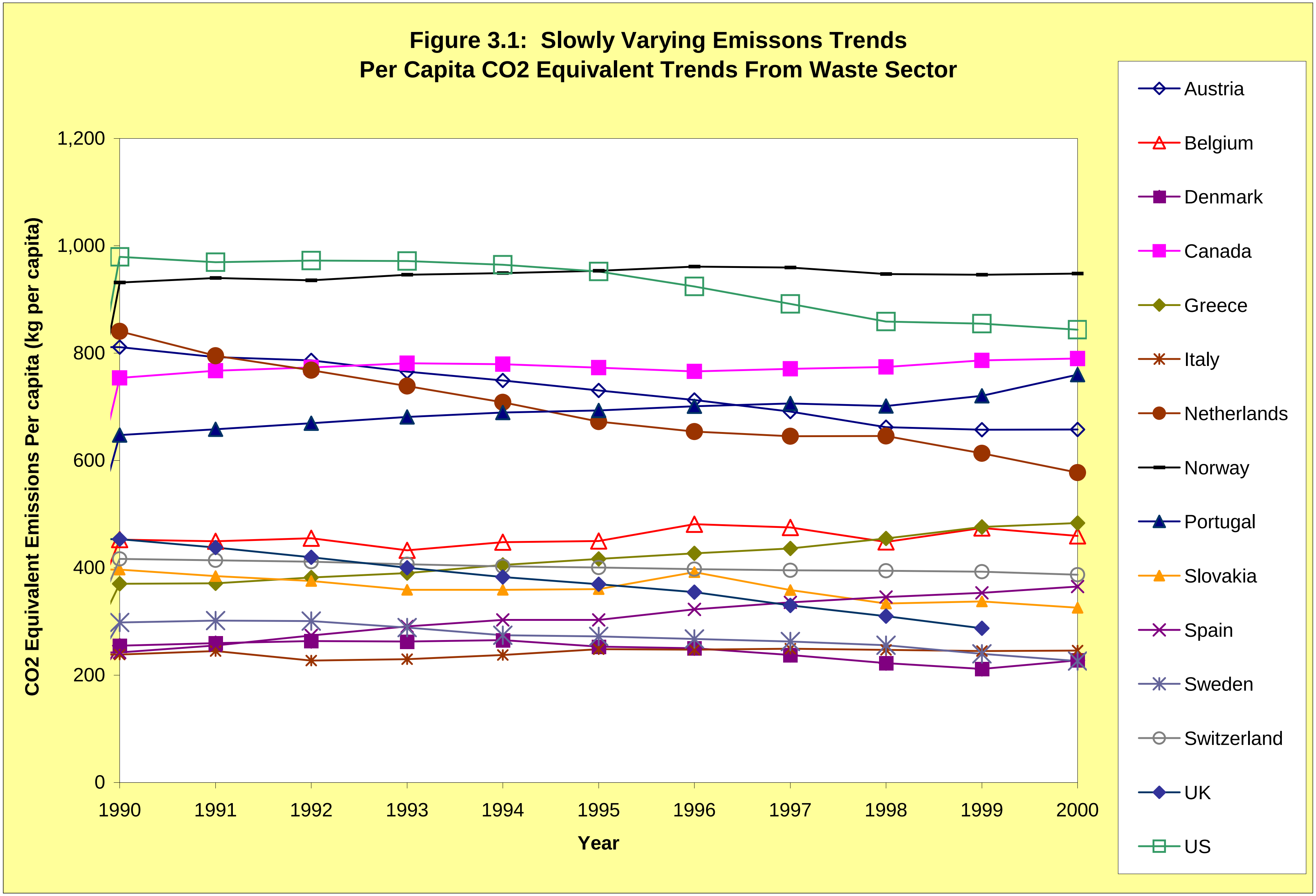
Figure 3.1: Slowly Varying Emissons Trends
Per Capita CO2 Equivalent Trends From Waste Sector
CO2 Equivalent Emissions Per capita (kg per capita)
1,200
1,000
800
600
400
200
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Year
Austria
Belgium
Denmark
Canada
Greece
Italy
Netherlands
Norway
Portugal
Slovakia
Spain
Sweden
Switzerland
UK
US

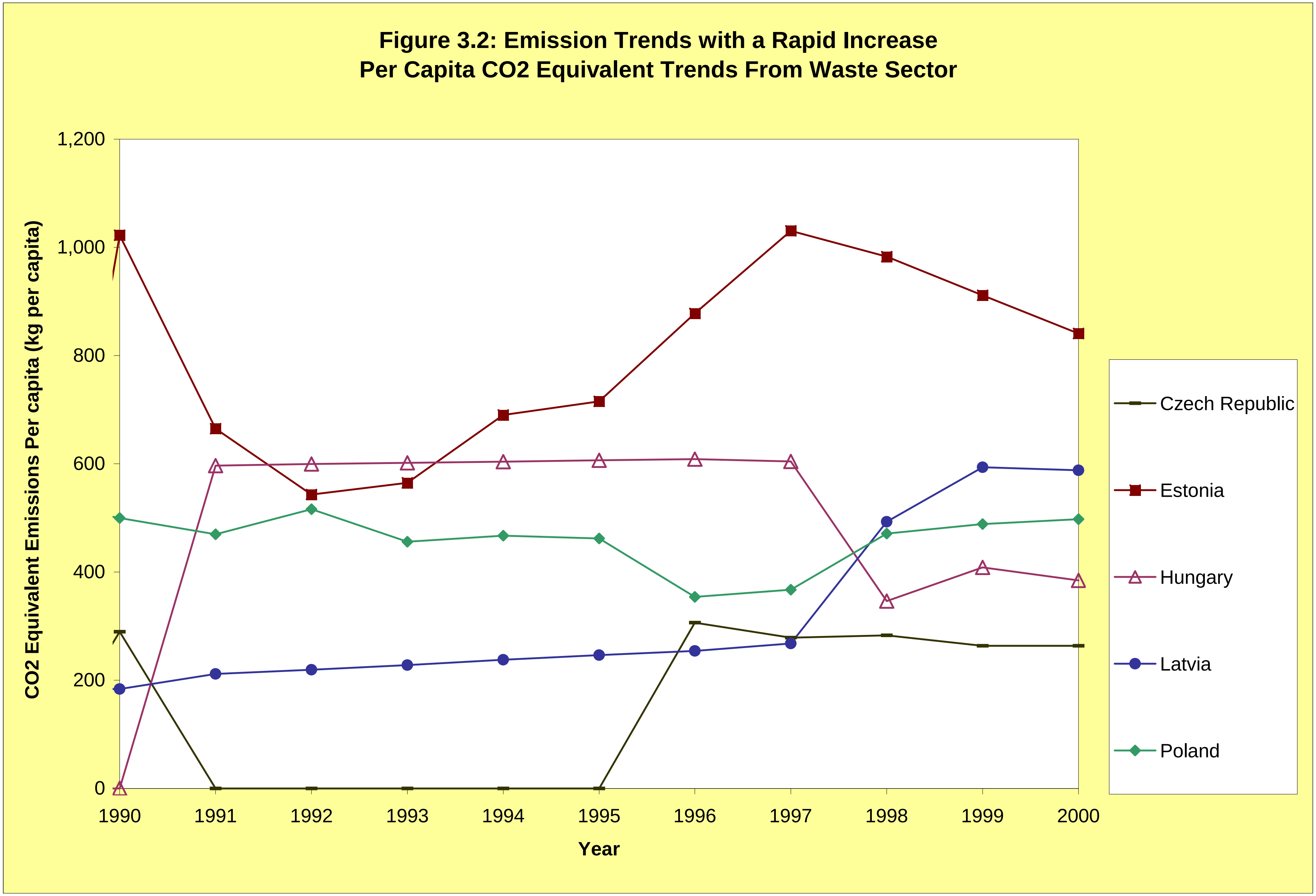
Figure 3.2: Emission Trends with a Rapid Increase
Per Capita CO2 Equivalent Trends From Waste Sector
CO2 Equivalent Emissions Per capita (kg per capita)
1,200
1,000
800
600
400
200
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Year
Czech Republic
Estonia
Hungary
Latvia
Poland

Figure 3.3: Emissions Trends with a Rapid Decline
Per Capita CO2 Equivalent Trends From Waste Sector