The Use of UN-Supplied Fuel Production and Trade Statistics for the Estimation of Global and National Fossil-Fuel-Derived Carbon Dioxide Emissions

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ABSTRACT

Statistics on the production, transfer, transformation, and consumption of fuel are collected by various governmental, public, and private entities. These statistics are compiled by national statistical offices (NSOs). NSOs forward summaries of these statistics via questionnaires to international organizations such as the United Nations Statistics Division (UNSD) and the International Energy Agency (IEA). These international organizations make these statistics available to the general public, government entities, private firms, and non-governmental organizations through a variety of means. These individual groups then use these statistics for a multitude of applications.

This presentation will focus on one such application: the estimation of global and national carbon dioxide emissions from fossil-fuel consumption. In addition to the fossil-fuel statistics, these estimates also rely on a knowledge of fuel chemistry and combustion conditions. Personnel at the Carbon Dioxide Information Analysis Center (CDIAC) at Oak Ridge National Laboratory (ORNL), USA, have for three decades made annual estimates of fossil-fuel-derived carbon dioxide emissions. New releases of the emissions data are made each year when another year of fuel statistics becomes available from the UNSD. This presentation will briefly review how the emissions estimates are made on both a global and national basis. These estimates are only made after the completion of a quality assurance/quality control (QA/QC) procedure. The QA/QC procedure is an interactive process with the UNSD that helps ensure the UNSD fuel statistics release is internally consistent. The presentation closes with a brief description of a value-added product produced at CDIAC: the distribution of the national emissions at a one degree latitude by one degree longitude scale.

INTRODUCTION

Until very recently, official national statistics did not exist that specifically addressed the emission of gases of interest to the climate change issue. Even today, these climate change statistics are not comprehensive in terms of their global coverage at regular time intervals. However, this recent focus on greenhouse gas emissions and its limited implementation, evidenced by national inventories reported to the UN Framework Convention on Climate Change, has not precluded a long term, systematic, consistent, global exploration of these emissions. For example, the emissions of carbon dioxide from fossil-fuel consumption have now been estimated annually for more than three decades. The initiation of these estimates was stimulated by the measurements of increasing atmospheric carbon dioxide concentration performed at the Mauna Loa Observatory by C.D. Keeling (Keeling, 1960).

This early and continuing estimation of annual emission of carbon dioxide to the atmosphere from fossil-fuel consumption has proved to be important in understanding the global carbon cycle as this emission source has been shown to be the major contributor to the increasing levels of carbon dioxide in the atmosphere (IPCC, 2007). Carbon dioxide, in turn, has been shown to be the single largest contributor to the changing radiative forcing now affecting our climate (IPCC, 2007).

The remainder of this paper will examine the continuing estimation of the annual emission of carbon dioxide to the atmosphere from fossil-fuel consumption. The paper will briefly describe how the data for this estimation are compiled, the estimation process itself, and some of the data products that result from the estimation process.

FOSSIL-FUEL DATA SOURCES

The estimates of carbon dioxide emissions from fossil-fuel consumption are derived from three basic pieces of data: national estimates of fossil fuels consumed, the fraction of that fuel actually combusted, and the carbon content of that fuel. For more detailed information on the mechanics of this estimation process, please see Marland and Rotty (1984) and Andres et al. (1999). The remainder of this section will concentrate on the portions of this estimation process deemed most pertinent to this Conference on Climate Change and Official Statistics.

Figure 1 shows the basic process of energy statistics data flow in the estimation of greenhouse gas emissions. The left-hand portion of the diagram shows the data being increasingly aggregated and consolidated as they move from individual data sources to bodies of increasing geographic scope (e.g., national statistic offices (NSOs) and the United Nations Statistics Division (UNSD)). The energy statistic data collated through this process include data on production, transfer, transformation, and consumption of 35 solid, liquid and gaseous fossil fuels (other fuels and electricity are also surveyed by the UN, but are not discussed here). UNSD gets this information from the NSOs via an annual questionnaire. For all fuels and for all categories of data collection, not every country completes each cell in the questionnaire completely or accurately. This may be due to a variety of reasons, including but not limited to incomplete data collection from the local statistics generation/collection bodies, differences in interpretation of category definitions, and political/economic/environmental reasons. The annual questionnaire allows for revisions of data submitted in prior years. For the year 2004 release of the data, the UNSD data set contains more than 2.2 million individual pieces of fossil-fuel related data with just under 2% (43,578 data points) of this total added specific to the 2004 data year.

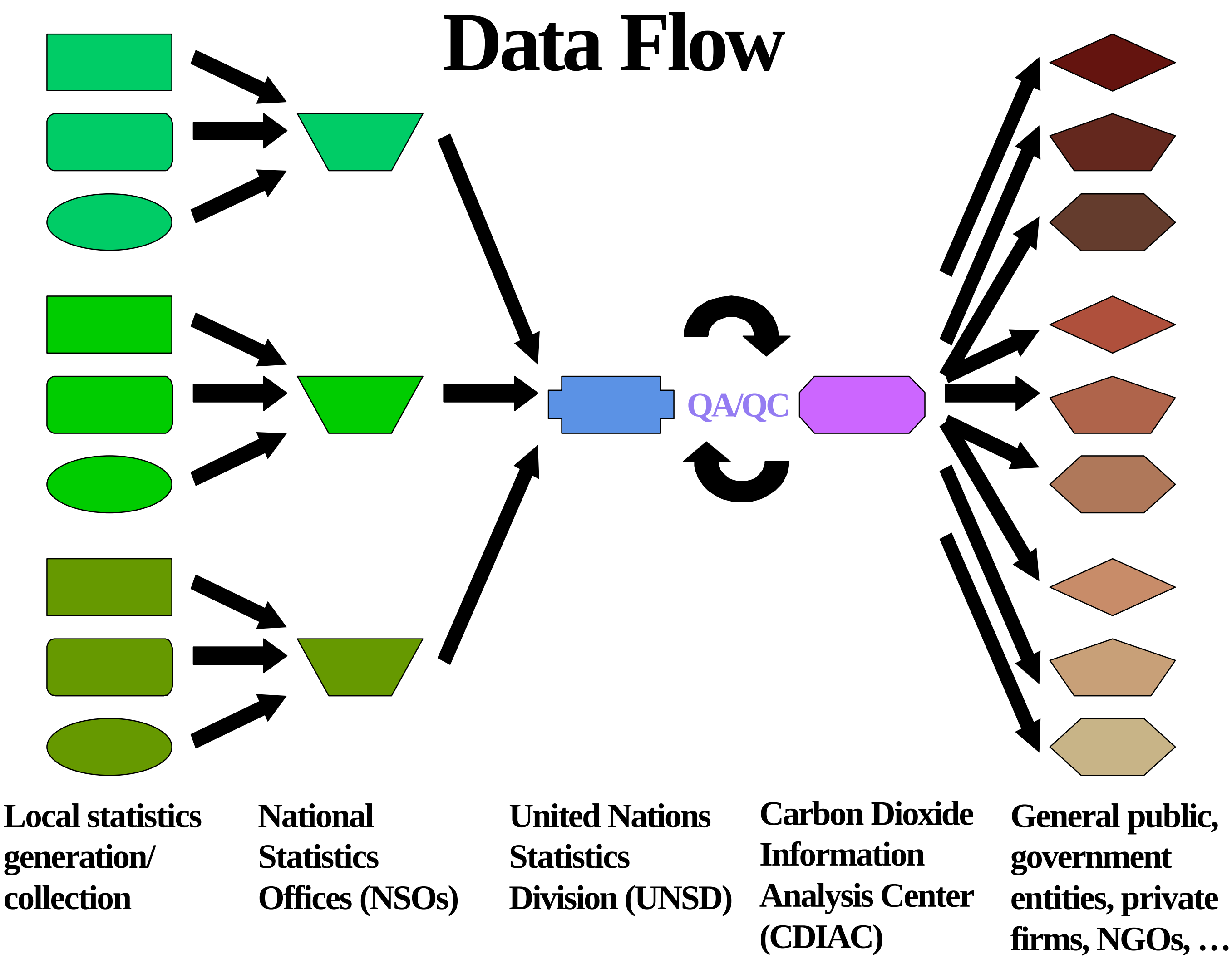

Figure 1. Data Flow Diagram Showing the Nearly Monotonic Flow of Data from Local Statistics Generation to Final Users of Carbon Dioxide Emissions Estimates. An exception to the monotonic data flow from data collection to carbon dioxide estimates is an interactive quality assurance/quality control (QA/QC) process between UNSD and CDIAC. Note that this data flow diagram is drawn from the perspective of personnel at CDIAC and therefore does not reflect QA/QC and other interactive processes at the left-hand side of the diagram.

After the questionnaires are received by UNSD, the data they contain are input into the UNSD data system. When all countries have reported data from a complete year, the data are shared with the Carbon Dioxide Information Analysis Center (CDIAC) at the Oak Ridge National Laboratory (ORNL), United States. CDIAC then performs some quality assurance/quality control (QA/QC) checks before using the data to estimate carbon dioxide emissions. This QA/QC process is an interactive process with the UNSD that helps ensure the completeness and consistency of the energy statistics data set. These QA/QC checks include items such as a review of the consistency of time series data, identification of improper or missing codes (e.g, country codes, transaction codes, fuel types, mass or volume units), and that sums of disaggregated quantities equal the aggregated quantity. Simple inconsistencies are addressed with the UNSD before release of the year's data to the general public. Other inconsistencies are made over the ensuing year(s) as their nature is more fully explored and clarified.

With release of the UN data to the general public, CDIAC then combines the UN fuel statistics with information on the fraction of that fuel actually combusted and the carbon content of that fuel to produce its estimates of carbon dioxide emissions from fossil-fuel consumption. These estimates are then compiled in a variety of formats and value-added products (discussed below) and ultimately released to the general public and other interested parties, primarily through internet-based means.

Before describing the data products of CDIAC, we briefly digress and describe the time to delivery of the final data product to the general public. As an example, we examine data from the latest available year. In December 2007, CDIAC received from UNSD the energy statistics for 2005. Thus, after the conclusion of the 2005 calendar year, it took almost two years for the data to be fully transported from the Local Statistics Generators to the NSOs to UNSD, to be compiled, supplemented where necessary, and checked. This time frame has been typical over the last few decades. The QA/QC process at CDIAC is now ongoing. CDIAC expects to release the 2005 carbon dioxide emissions estimates early in the late spring or early summer of 2008. Thus, the full process from close of the calendar year to release of carbon dioxide emissions data products to the general public takes approximately 2.5 years.

CDIAC DATA PRODUCTS

CDIAC-produced data releases are based on a relatively simple equation:

carbon dioxide emitted = fuel consumed * fraction of that fuel actually combusted * carbon content of that fuel.

The implementation of this equation becomes a bit more involved as one keeps track of the 35 fossil solid, liquid and gaseous fuels, their relative combustion efficiencies, and their relative carbon contents. However, good accounting and database principles make this a tractable problem.

In addition to estimating carbon dioxide emissions from fossil-fuel consumption, the CDIAC-generated data products also include carbon dioxide emissions from cement manufacture. The basis for this inclusion is relatively similar to that for fossil fuels: there are reliable statistical data which track cement manufacture, by nation, globally (USGS, 2007). Additionally, cement production is one of the larger emitters of carbon dioxide after fossil-fuel consumption (approximately 3% of the fossil-fuel-produced carbon dioxide total). It is important to note that the carbon dioxide emissions from cement manufacture arise from the conversion of calcium carbonate (often in the form of limestone) to cement clinker (the dry product used as the basis for making cement). Chemically, this can be represented as:

$CaCO_3 \rightarrow CaO + CO_2$.

The carbon dioxide produced by the fuel consumed to drive this transformation is tracked under the fossil-fuel-derived carbon dioxide emissions, not the cement-derived emissions.

Two primary data products are derived from the UNSD-supplied energy statistics: an estimate of global carbon dioxide emissions from fossil-fuel (and cement) production and an estimate of national carbon dioxide emissions from fossil-fuel (and cement) consumption. Global estimates are based on production statistics rather than on consumption statistics for several reasons:

1. There are relatively fewer entities involved in the production of fossil fuels as compared to their consumption. Thus, the universe of entities to be surveyed is smaller.
2. The production of fossil fuels is closely monitored by most nations as it is an important source of tax revenue.
3. Production statistics ignore some of the complexities involved in national consumption statistics such as imports, exports, changes in stocks, and bunker fuels (i.e., those fuels used in international trade and thus are not accountable to any one nation by commonly accepted protocols) as well as fuels consumed for non-fuel uses (e.g., petroleum being consumed to produce plastics).
4. The ratio of fuel stockpiling to fuel production is small so that essentially all fuel produced in a given year is also consumed in that given year.
5. The four reasons listed above lead to a more accurate and thus lower error estimate for a global total based upon production statistics than one based upon national consumption statistics. Global consumption statistics are not tracked, per se. This leads to an accuracy estimate of 6 to 10% for the global numbers at the 90% confidence interval (Marland and Rotty, 1984).

Estimates of global carbon dioxide emissions from fossil-fuel (and cement) production are released to the general public from the CDIAC website in both tabular and graphic formats (Figure 2).

Estimates of national carbon dioxide emissions from fossil-fuel (and cement) consumption are based on apparent consumption where

apparent consumption = production + imports - exports - changes in stocks - bunker fuels - production of non-fuel products

From this equation, it is clear that the sum of national emissions (calculated from apparent consumption statistics) will not equal the global total (calculated from production statistics) due to the exclusion of bunker fuels (Figure 3). The other terms of the apparent consumption equation also contribute to the difference. Despite the increased complexity in the calculation of the national totals, the average national total has an error estimate of 8.3% (similar to the global error estimate), but has a greatly expanded range of error estimates ranging from -340% (an underestimate) to 88% (an overestimate) (Andres et al., 1996).

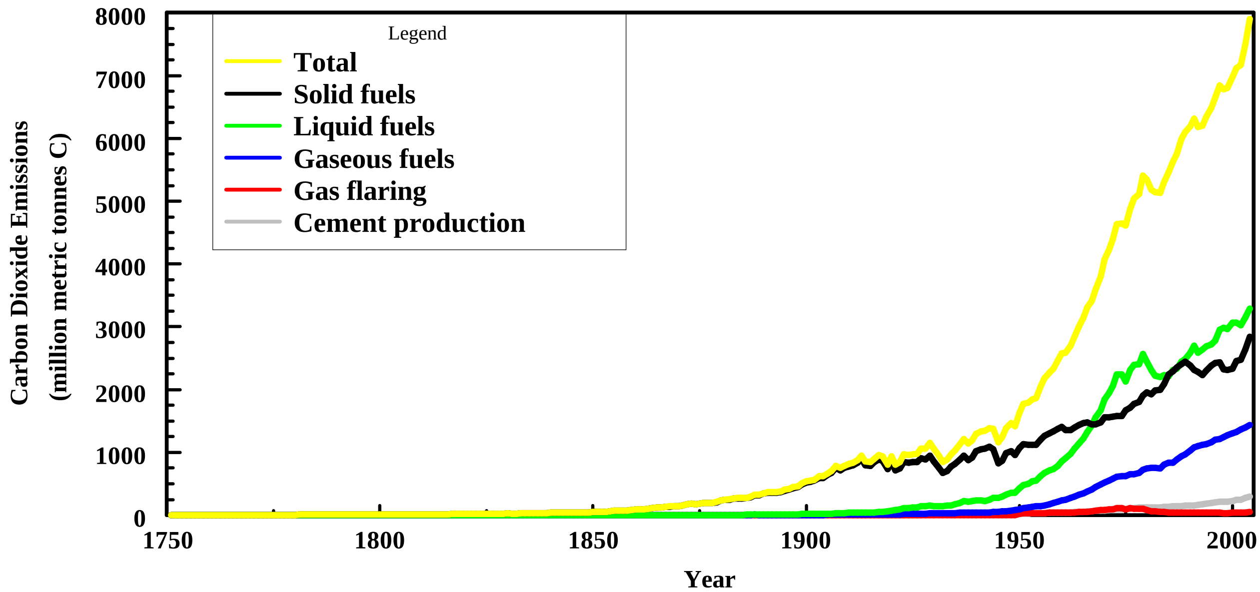

Figure 2. Global Carbon Dioxide Emissions from Fossil-Fuel (And Cement) Production. The pre-1950 data are from non-UNSD sources as described in Andres et al. (1999).

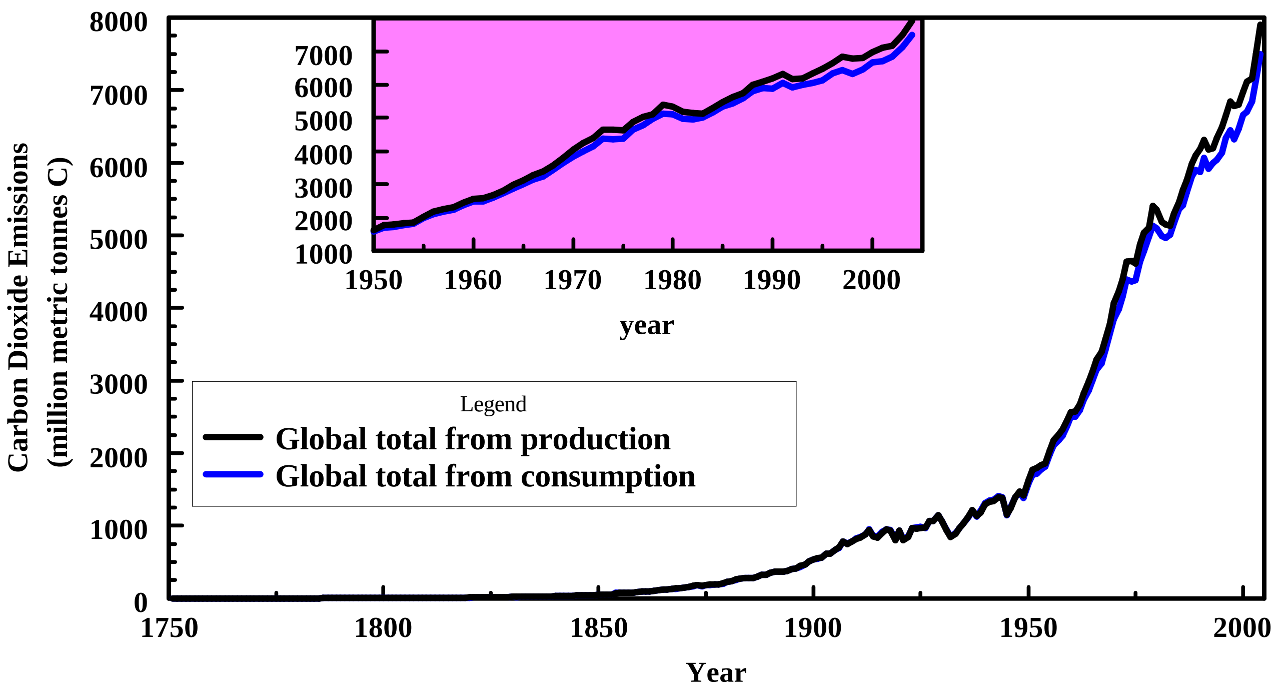

Figure 3. A Comparison of the Global Totals (as Calculated from Production Statistics) and Sum of the National Totals (as Calculated from Apparent Consumption Statistics). The inset is a zoom view of the 1950-2004 year interval.

After global and national fossil-fuel-derived carbon dioxide emissions are estimated, CDIAC then transforms these estimates into a variety of additional and value-added products. These products include regrouping of the national emissions in to regional totals, regrouping of the national emissions into Annex B and non-Annex B country totals as per the Kyoto protocol, combination of the national emissions with other statistical data to produce monthly emission estimates for some countries, combination of the national emissions with information on the stable carbon isotopic signature to produce the stable carbon isotopic signature of fossil-fuel carbon dioxide emissions (Andres et al., 2000), and the mapping of the national emissions onto a global 1 degree latitude by one degree longitude grid (Andres et al., 1996). All of these products supplement the carbon dioxide emissions data set (calculated from the UNSD-supplied energy statistics) with information supplied by other sources to meet end user needs. The remainder of this presentation will briefly describe the last of these products.

The mapping of national emissions onto a global grid (Figure 4) serves two major purposes. First, it allows easy visualization of the emissions; this is a distinct advantage over tabular listings of those same emission totals. Second, the gridding of emissions is of value to modelers who want to incorporate the spatial aspect of those emissions into their representations of the global carbon cycle.

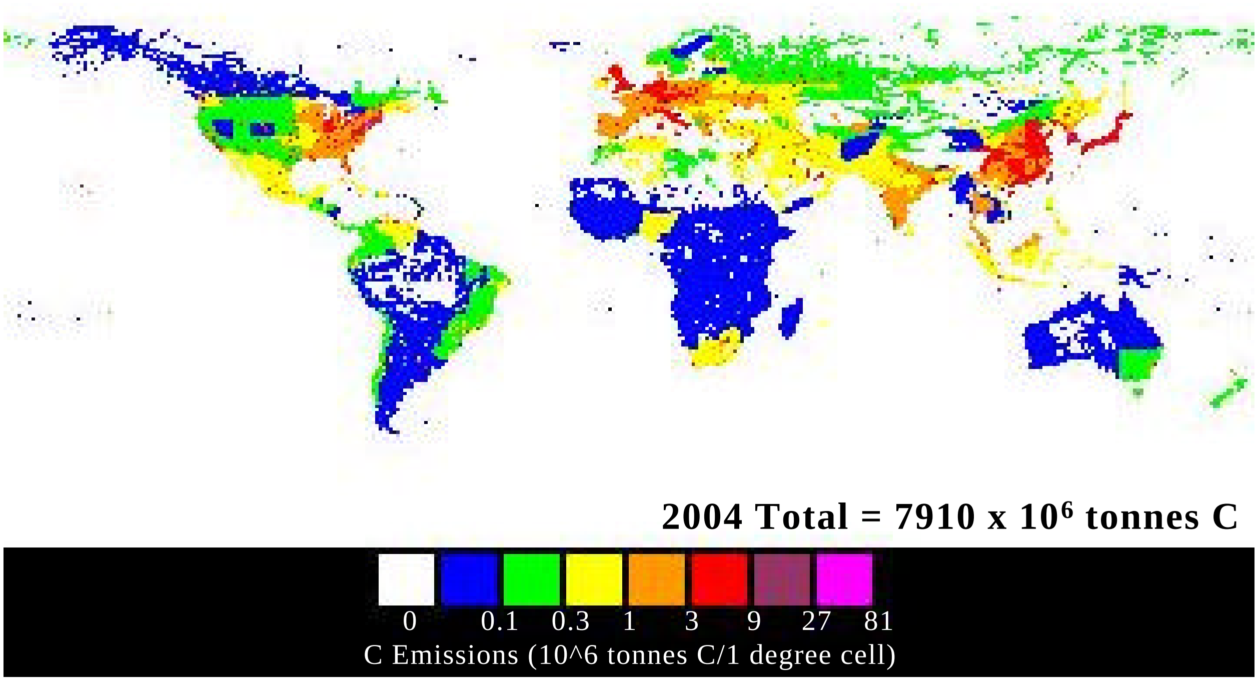

Figure 4. A One Degree Latitude by One Degree Longitude Plot of National Fossil-Fuel-Derived Carbon Dioxide Emissions (As Calculated from Apparent Consumption Statistics).

The gridding process is the result of the combination of three separate pieces of information. First, tabular data of the national emissions is obtained from CDIAC. Second, the tabular data are associated with a one degree latitude by one degree longitude map of countries; this gives the tabular data a geographic representation. Third, within each country, the emissions are distributed by a population distribution expressed on that same one degree scale; this further enhances the geographic representation as to a first order, higher emissions rates are associated with higher populations. Work is ongoing by persons at CDIAC and elsewhere to improve this emissions distribution by replacing the population proxy with a better distribution algorithm.

CONCLUDING REMARKS

Whether we are ready for it or not, national statistics are already being used to examine the climate change issue from a variety of angles. For example, over the year 2000- 2001 time interval, the data products CDIAC produces were downloaded from the World Wide Web an average of 74 times per day by unique users which include a variety of political, public, scientific, NGO, and other entities. The strategy CDIAC has adopted is to provide the best data possible and in the most useful formats as our resources allow. This has led us to examine the entire data flow process, our data processing algorithms, and our data distribution systems. For example, our interactive QA/QC process with UNSD is driven by our desire to have the best input data set possible. Likewise, we are continuously looking at our data algorithms to determine if a better processing algorithm exists based upon research that we or others have completed. Finally, our value-added products are a recognition that tabular data are not always the best way to convey the information that our data processing produces; new data products are developed as a community needs are identified and can be successfully addressed. CDIAC is supported by the United States Department of Energy and all data products are made available to users throughout the world at no cost. CDIAC staff are responsive to a wide variety of requests for further information, data products, and data formats from users. It is hoped that this presentation will not only encourage us all to produce the best data possible in our respective areas, but also encourage us to create productive collaborations where we can learn from the experience that each of us has gained in our respective areas.

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