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Energy and carbon dioxide emission data uncertainties

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Abstract

As nations complete national inventories of carbon dioxide emissions and attempt to achieve emissions reduction targets as part of international treaty obligations, independent verification of reported emissions becomes essential. However, organizations that report carbon dioxide emissions utilize different methods and produce data that are not directly comparable with each other, making verification of national inventories and climate modeling efforts difficult and potentially misleading.

Carbon emission estimates are based directly on energy use statistics. Unfortunately, there is great unrecognized uncertainty and differences among organizations that independently report energy use statistics. International energy data reporting organizations include different energy sources, utilize different calorific contents of fossil fuels, and utilize different and inconsistent primary energy equivalencies in their annual statistics. Thus although British Petroleum (BP) and the US Energy Information Administration (EIA) report identical quantities of barrels of oil consumed in 2005, the energy content reported differs by over 11%, or 18 Exajoules, roughly double the primary energy supply of the United Kingdom.

These energy discrepancies and different methods persist in carbon emission statistics due to improper choices of fossil fuel emission factors. Furthermore, carbon dioxide statistical organizations all use different accounting methods, include different emission sources, and have different definitions of similarly named emission categories. Differences in reported carbon dioxide emissions for the United States in 2005 by EIA and the US Carbon Dioxide Information Analysis Center (CDIAC), both part of the US Department of Energy, are over .22 Pg CO_2. These discrepancies could greatly affect attempts to develop a global emission trading market. The differences in reported data and methods make comparisons across organizations challenging, and often misleading.

Indeed, these differences can mislead researchers and climate modelers as easily as policymakers. A recent and often-cited publication by Raupach *et al.*, does not adequately address the full uncertainty of carbon emission reports and comes to a faulty conclusion that the world has exceeded the highest and most extreme Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES). Additionally, using different data sources for analyses such as carbon intensities may lead to contradictory results, depending on what assumptions are behind the energy and carbon dioxide statistics.

To facilitate improved understanding of uncertainties and different methodologies of reporting organizations, this paper introduces an online database that consolidates energy and carbon emission reports and allows users to view all organizations' data in

consistent units side-by-side. Furthermore, the database offers the ability to apply consistent methodological assumptions to all organizations' data.

This harmonization does not rectify all discrepancies between organizations, however, especially those resulting from differing fossil fuel calorific values and emission factors. Reporting organizations should develop consistent interagency terminology and standards, and researchers and policymakers utilizing these data should explicitly state assumptions behind these data.

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About the Author

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Energy and carbon dioxide emission data uncertainties

Jordan Macknick

1 Introduction

The threat of global climate change has prompted nations, provinces, states, and cities to take action to reduce anthropogenic sources of carbon dioxide (CO_2) and other greenhouse gases (GHG). For policymakers to make informed decisions and for scientists to understand the relationship between anthropogenic GHG emissions, atmospheric concentrations, and the ultimate climate consequences they must have access to reliable data with known uncertainties. If new policies include measures to monetize carbon emissions, such as a cap and trade system or an emissions tax, the importance of quality data with known uncertainties becomes paramount.

Government policies generally aim at limiting emissions from the energy sector, as it is the main contributor and statistics from this sector are readily available with a comparatively low level of uncertainty (Grubler, 2002). However, uncertainties in official CO_2 emissions reports, and the energy data from which they are derived, are understated, if mentioned at all in scientific studies or policy proposals. These unmentioned uncertainties have the potential to undermine policies and scientific studies.

This paper has three primary objectives: (i) to compare the different methods used by organizations in their published energy and carbon statistics, (ii) to critically examine articles that use energy and CO_2 emissions data, and (iii) to introduce a tool that allows users to compare harmonized energy and carbon statistics across organizations to facilitate uncertainty analyses.

Four organizations publishing energy statistical data are considered here: the International Energy Agency (IEA), the EIA, BP, and the United Nations (UN). Four organizations publishing carbon dioxide data, covering a total of five datasets, are considered: IEA Sectoral Approach (IEA-S) and Reference Approach (IEA-R), the US Energy Information Administration (EIA), the CDIAC, and the Emissions Database for Global Atmospheric Research (EDGAR).

The paper is organized as follows: Section II analyzes data sources and assumptions employed by organizations reporting international energy statistics. Section III conducts a similar analysis for CO_2 emission reporting organizations. Section IV analyzes an influential article on global CO_2 emission trends that has not fully incorporated uncertainties. Section V describes an interactive online database with harmonized energy and carbon emission data for the world and for the top 26 CO_2-emitting countries (representing 80% of global emissions). The paper concludes with recommendations for organizations and researchers to improve reporting standards. Throughout, consideration of global emissions is generally of more interest for understanding anthropogenic impacts on the carbon cycle and the climate, whereas consideration of national emissions is of more interest for policy-making.

2 Energy Data Statistics

This section compares the methodological assumptions employed by the major energy reporting organizations as well as the discrepancies in their reported data. This section also illustrates how discrepancies can be both revealed and minimized through assumption harmonization. Statistics of primary energy consumption are addressed because carbon emission statistics rely directly on these data.

Primary energy refers to the energy embodied in fossil fuels and biomass before undergoing manmade transformations, such as to electricity (Kydes *et al.*, 2007). Electricity and fuels that have been refined from crude petroleum are considered secondary energy forms, and fuels at the point they are used directly by consumers (such as gasoline for a car) are considered final energy. While both secondary energy and final energy data are often referred to as consumption, they do not reflect the energy content that is 'lost' during transformation from one form of energy to another. As such, primary energy analyses indicate the total amount of energy (as well as carbon) that nations utilize. Primary energy 'consumption,' (as it is termed by certain reporting organizations) and the equivalent Total Primary Energy Supply (as it is termed by other reporting organizations and as is used throughout this work) are determined using the concept of apparent consumption. Apparent consumption is equal to: Production + Imports - Exports - Bunkers +/- Stock Changes. It is a top-down approach that assumes all primary energy production in a country is utilized domestically, exported, utilized in ports or in international transit, or added to existing stocks.

Although each reporting organization ostensibly publishes the same energy use data, different assumptions and methods lead to sometimes significant discrepancies between organizations. Sources of discrepancies between energy use data reported by reporting organizations result from utilizing different data inputs, categorizing fuels differently, utilizing different conversion conventions, and from reporting data in different units. These sources of discrepancy are summarized in Figure 1 and are addressed in turn below.

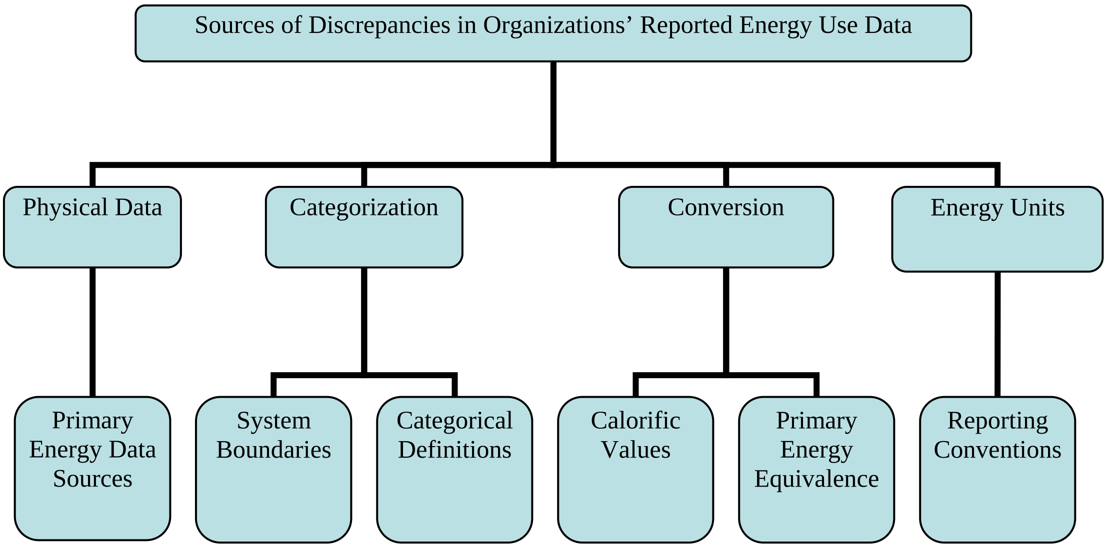


Figure 1: Schematic diagram of sources of discrepancies of energy use data reported by organizations.

2.1 Sources of Discrepancies in Energy Data

Four organizations publishing energy statistical data are considered here: the IEA, the EIA, BP, and the UN Energy Statistics Division. The IEA and UN are international member organizations, based in Paris and New York, respectively. The EIA is an independent statistical agency of the United States Department of Energy, based in Washington, DC. BP is a private sector energy corporation based in London, not an official national or international organization like the others; it is often cited because it produces data much more rapidly than the other organizations and thus offers a first glimpse into recent trends.

2.1.1 Physical data: primary energy data sources

A first source of discrepancies between the energy reporting organizations is the raw data used to compile energy use data. The UN and IEA send annual surveys to member states as the primary method of collecting data.[1] The surveys are not identical, but the UN receives copies of completed IEA surveys for IEA-member states, and does not send its survey to these nations (IPCC, 2006). IEA also uses UN energy data for certain non-member nations. For nations not members to IEA and for incomplete data for the UN, data are collected from national reports, regional agencies such as the Organización Latinoamerica de Energía (OLADE), or estimates are made. In contrast to the direct survey method, BP and EIA rely primarily on national reports and regional agencies. It is often difficult for one particular agency to calculate uncertainties from national data or from survey responses if they are not reported by nations, thus these uncertainties are not reported. Basic information about the organizations and their data compilation methods are provided in Table 1.

[1] For the UN survey, see http://unstats.un.org/unsd/energy/Quest2007English.xls; For the IEA survey, see http://iea.org/Textbase/stats/questionnaire/balance.xls.

Table 1. Overview of energy reporting organizations' methods.

Reporting Organization	International Energy Agency	Energy Information Administration	British Petroleum	United Nations Energy Statistics Division
Code	IEA	EIA	BP	UN
Publications	Energy Balances of Non-OECD Countries Energy Balances of OECD Countries	International Energy Annual	BP Statistical Review of World Energy	Energy Statistics Yearbook Energy Statistics Database
Data Compilation Methods	Direct Annual Surveys to OECD Nations Review of published national data for non-OECD nations	Review of Published National Data	Review of Published National Data	Direct Annual Surveys to Nations

Energy consumption data from nations are generally published and reported to the UN and IEA in terms of physical units (such as metric tonnes of coal or barrels of oil), and organizations convert these values to equivalent energy quantities. However, these reported values are not always equivalent. For example, although BP and EIA use similar methods to obtain natural gas consumption data, EIA reports in 2005 that the world used 2906 billion cubic meters of natural gas, 4.9% more natural gas than BP's reported 2770 billion cubic meters. The UN and IEA do not publish production or consumption values of natural gas in terms of cubic meters, only in Terajoules, yet it is possible to infer production and consumption values from their published natural gas calorific contents. For coal products, data of total world production tonnage differed widely.[2] The UN reports the highest coal production value in 2005 of 6.64 billion tonnes. This value is 4.1% greater than the IEA value, 12.5% greater than the BP value, and 13.1% greater than the EIA value. For petroleum, BP and EIA report the identical quantities of 83 million barrels of oil consumed per day. The UN and IEA do not publish barrel consumption values, but they can be inferred from published crude oil calorific content values. The data collection and compilation methods of organizations contribute to at times vastly different raw data with which organizations work.

2.1.1.1 Categorization: System Boundaries

When determining total energy use, reporting organizations include different sources of energy in global and national totals. Major differences in the system boundaries used by organizations relate to the inclusion or omission of international bunker fuels, modern renewable energy sources, and energy from biomass and wastes.

[2] Aggregated world tonnage values are used (as opposed to individual coal products) because EIA and BP only report total tonnage values. World production values (as opposed to consumption values) are used here so BP values could be considered. BP reports production values in tonnes and in energy equivalents but only energy equivalents for consumption values. Because of these two assumptions, these discrepancies do not exactly correspond to energy use discrepancies, but they do provide accurate approximations of the degree of difference between organizations' data.

According to the IEA, in 2005 around 9% of petroleum was consumed in international ports, airports, or during international transport. Energy data reports refer to this petroleum as international bunker fuel consumption. Reporting organizations address bunker fuels differently, which can have significant effects on national totals. EIA and BP include bunker fuels in national totals as well as in aggregated global totals. IEA includes bunker fuels in global totals, but excludes these values from national totals. The UN excludes bunker fuels from both global and national totals, and instead includes these data in a separate category that does not contribute to total energy consumption values. For countries such as Singapore and the Netherlands, which have internationally significant ports, EIA and BP report much higher petroleum values than IEA and UN. These discrepancies are to some degree minimized for global aggregates for EIA, BP, and IEA, but as UN excludes these fuels from global totals its lower values persist. Table 2 shows a summary of treatment of international bunker fuels.

Table 2. Treatment of international bunker fuels by reporting organizations.

IEA	EIA	BP	UN
Included in global totals Excluded from national totals	Included in global and national totals	Included in global and national totals	Excluded from global and national totals Included in separate category

Although modern renewable energy sources (solar photovoltaics, wind energy, geothermal, tidal power, etc.) comprise less than 1% of current total global energy use, they have been rapidly increasing and could play a larger role in the future energy mix. IEA, EIA, and the UN include electricity produced from these sources, whereas BP does not include electricity from these sources.

All organizations report consumption of biomass fuels and wastes to some degree, yet there is great variation in what is included in these categories. The UN and the IEA are the most extensive, including energy from wastes, liquid and gaseous modern biofuels, and estimates of non-commercial (i.e. non-traded) sources such as firewood and dung. The latter category is not included by BP or EIA. For the UN and IEA, however it often represents a significant portion of the total primary energy supply of developing nations, making the omission by BP and EIA important. EIA, IEA, and the UN include biogas and wastes in their global and national totals, whereas BP does not. All organizations include liquid biofuels (such as corn- or sugar-based ethanol) in their global and national totals.

2.1.1.2 Categorization: Categorical Definitions

Even if organizations include similar categories of fuels (such as coal or traditional biomass sources) their definitions of those categories can differ greatly. Additionally, organizations disaggregate broad categories such as coal in different manners. The UN reports aggregated fossil fuel energy consumption in terms of solids, liquids and gases, whereas the other organizations aggregate fossil fuels in the not always equivalent terms of coal, petroleum, and natural gas. Within these categories there are further differences. The UN and IEA both utilize ten different categories for coal products, although the makeup of these categories differs slightly. The UN reports a "hard coal" category, whereas IEA reports two separate categories that approximate this category. In turn, IEA aggregates coal briquettes into one category whereas these are in separate categories in UN energy data. The UN and IEA both publish total individual category values as well as aggregated values for coal products. EIA and BP, in contrast, only report aggregated values for coal, not for individual coal products. For petroleum, the UN, IEA, and EIA all publish data for crude oil as well as for specific categories, though these categories are also slightly different. BP reports only aggregated amounts of crude oil. While these definitional differences do not lead to major discrepancies between reported data, the differences in fuel disaggregation (or lack thereof in the case of EIA and BP coal and BP petroleum) make direct comparisons of data difficult.

For biomass-based fuels, there are similarly different categorical definitions. The UN category of "Traditional Fuels" is essentially equivalent to the IEA category of "Combustible Renewables and Wastes," except the latter category includes biofuels and biogas. For UN data, biofuels and biogases are included under the respective categories of Liquids and Gases. Biofuels are included in EIA in the category "Wood and Wastes," which EIA claims is "similar" to IEA's Combustible Renewables and Wastes category (EIA, 2008). However, other than biofuels, EIA only includes energy from this category if it produces electricity, and therefore does not include estimates of non-commercial energy sources such as fuelwood and dung. BP includes biofuels in its petroleum consumption category, similar to the UN convention. Biomass sources In addition to standard energy-related fossil fuel categories, organizations also include categories for wastes, traditional, and biomass-based fuels. The categorical organizations for wastes and biomass-based fuels are summarized in Table 3.

Table 3. Summary of wastes and biomass categories reported by organizations.

	IEA	EIA	BP	UN
Wastes	Industrial, Municipal subcategories included in "Combustible Renewables and Wastes"category	Wastes used to produce electricity are included in category "Wood and Wastes"	N/A	Included in own subcategory under category "Traditional Fuels"
Traditional Fuels	Included in "Combustible Renewables and Wastes" category	Only fuels used to produce electricity are included in category "Wood and Wastes"	N/A	Included in category "Traditional Fuels"
Liquid Biofuels	Included in own subcategory in "Combustible Renewables and Wastes" category	Included in category "Wood and Wastes"	Included in category "Oil"	Included in own subcategory under category "Liquids"
Biogas	Included in own subcategory in "Combustible Renewables and Wastes" category	Included in category "Wood and Wastes"	N/A	Included in own subcategory under category "Gases"

2.1.1.3 Conversion: Primary Energy Equivalences

Reporting organizations must make a decision regarding the energy equivalent of electricity produced from sources such as nuclear, hydroelectric, and modern renewables, in which there is no obvious primary energy content as there is with fossil fuels and biomass. There are two competing methods for addressing this issue. One is termed the substitution equivalent method. In this method, electricity consumption (in kilowatt-hours) is treated in primary energy equivalent terms as if it were produced in a conventional fossil fuel thermal power plant with an average (electricity only) conversion efficiency of around 30-40%. Thus, if a 33% efficiency were chosen for nuclear power, the total primary energy equivalent of one kilowatt-hour generated from that source would be (1/(33%))*(1 kWh) = 3 kWh = 10.8 MJ. The other method is termed the direct equivalence method and simply takes the energy value of one kWh as the primary energy equivalent (assuming 100% conversion efficiency). The energy equivalent of one kilowatt-hour generated from a source such as hydropower would be (1/(100%))*(1 kWh) = 1 kWh = 3.6 MJ. It is important to note which methods and efficiencies are chosen, as values reported can be different by a factor of three.

The World Energy Council (WEC), an energy information organization founded in 1923 with over 90 member countries, has proposed a convention of 38.6% efficiency for nuclear, hydroelectric, and renewable energy electricity production (WEC 1993). None of the organizations addressed in this study utilize this convention, and no two organizations use the same primary energy equivalences. Assumptions for primary energy equivalencies are displayed in Table 4, with summaries below.

Table 4. Summary of primary energy equivalences assumptions (Efficiencies used to convert kWh electricity output to kWh primary energy equivalent).

	IEA	EIA	BP	UN
Nuclear	33%	29-35%	38%	100% (Direct)[3]
Hydro	100% (Direct)	34.4%	38%	100% (Direct)
Renewables	100% (Direct)	34.4%	N/A	100% (Direct)
Geothermal	10%	16%	N/A	100% (Direct)[4]

Primary Energy Equivalencies-Nuclear

IEA assumes 33% efficiency for all plants, based on an average efficiency of thermal fossil fuel power plants in Europe. The EIA has individual country efficiencies, ranging from 29-35%. BP assumes 38%. The UN uses a direct equivalence approach. Electricity production in terawatt-hours from nuclear power in France in 2005 for IEA and the UN differ are equivalent, yet primary energy use reported associated with this consumption differs by a factor of three, equivalent to 3.3 Exajoules. IEA, BP, and EIA report nuclear to comprise between 35-40% of France's total primary energy mix, whereas this amount is just 20% for the UN. Globally, UN reports 20 Exajoules

[3] UN claims a nuclear efficiency of 33% (UN, 2008). However, calculations reveal use of 100% efficiency.
[4] UN claims a geothermal efficiency of 10% (UN, 2008). However, calculations reveal use of 100% efficiency.

less primary energy from nuclear production than does EIA, despite reporting 5.3% more terawatt-hours of production.

Primary Energy Equivalencies-Hydropower

IEA and the UN use a direct equivalence approach. EIA uses 34.4% for all countries; this number is based on average US power plant efficiencies and can change each year. BP again uses 38%. For 2005, all organizations report hydroelectric production in Canada to be within 1% of 360 TWh. However, IEA and the UN report this to correspond to a primary energy equivalent of 1.3 EJ, BP states it to be 3.3 EJ, and EIA states it to be 3.8 EJ. Thus using EIA data hydroelectric power makes up 25% of the total primary energy supply, but for IEA data it only accounts for 11% of the primary energy supply. The UN and IEA report hydropower primary energy values that are 21 Exajoules less than EIA, nearly the same amount by which UN nuclear power is less than other agencies. Note how IEA utilizes the substitution equivalent method for nuclear, yet the direct equivalence approach for hydropower; this has the effect of portraying the share of nuclear power in global primary energy supply in to be nearly three times that of hydropower, despite hydropower generating 6% more TWh.

Primary Energy Equivalencies-Modern Renewables

For modern renewable sources, such as wind power and solar photovoltaics, UN and IEA use a direct equivalence approach while EIA uses the same 34.4% based on US power plant efficiencies. BP does not report electricity generated from these sources. Although these modern renewable sources do not make up a substantial percentage of most countries' primary energy supply, renewable portfolio standards or other policy goals to achieve a certain percentage of renewables in the primary energy makeup could be manipulated or affected by choices of primary energy equivalences, if these standards are based on production values. Such standards are therefore best formulated at the level of secondary energy, i.e. the percent share in total watt-hours generated.

Primary Energy Equivalencies-Geothermal

For geothermal-based electricity production, IEA uses a primary energy equivalence efficiency of 10%, the UN uses a direct equivalence of 100%, and EIA uses an efficiency of 16%. BP does not report geothermal electricity generation or the resulting primary energy equivalence.

2.1.1.4 Conversion: Calorific Values

The calorific value of a particular fuel, or the total amount of energy released during combustion for a specified unit of mass (or volume), is an important determination of reported values of energy consumption. Most nations report their consumption in physical units of metric tonnes, not in terms of energy content. Reporting organizations determine heating contents for each country for each year, and they must decide between utilizing the gross calorific value (GCV) or the net calorific value (NCV). The difference between these two calorific values relates to the energy obtained from the condensation of water vapor produced during combustion. This value is included for GCV and excluded for NCV[5]. In general, EIA uses GCV, the UN and IEA use NCV, and BP uses a mix of the two (EIA, 2008). Table 5 provides a summary of the calorific assumptions employed by energy reporting organizations.

Table 5. Summary of calorific value assumptions for petroleum, natural gas, and coal.

	IEA	**EIA**	**BP**	**UN**
Oil	NCV Country-specific Variable by year	GCV Country-specific Variable by year	NCV Country-Specific Variable by year	NCV Country-specific Variable by year
Natural Gas	NCV[6] Country-specific Variable by year	GCV Country-specific Variable by year	GCV[7] Identical for each country, except US Identical each year	GCV[8] Country-specific Variable by year
Coal	NCV Country-specific values for individual products Variable by year	GCV Country-specific aggregated value Variable by year	GCV[9] Country-specific aggregated value Variable by year	NCV Country-specific values for individual products Variable by year

Calorific Value-Petroleum

Perhaps the most drastic and important difference between energy reporting organizations' calorific values is for petroleum. EIA uses GCV, whereas the other organizations use NCV. However, these differences are not easily identified, as they are masked by the different manners in which calorific values or crude petroleum physical properties are published. The UN publishes specific gravities (ratio of density of petroleum to density of water) for each country. EIA publishes two values: BTU per barrel as well as barrels of crude oil per metric tonne for producing countries. BP does not publish calorific values but these can be inferred from statistics of barrels and metric tonnes. IEA publishes calorific values (kJ/kg) for all petroleum products for each country, but does not report barrel consumption. In sum, no two agencies publish directly comparable values. Calorific values in terms of energy per barrel can be found directly from EIA, must be inferred from published data for UN and BP, and cannot be inferred from IEA data. Calorific values in terms of energy per tonne can be found directly from IEA, must be inferred from EIA data, and is assumed to be 41.868 GJ per tonne for BP and the UN.

The importance of calorific value differences is highlighted through the use of the US as an example. BP and EIA report identical petroleum barrel consumption values for

[5] For natural gas, the difference between NCV and GCV is around 9-10%. For coal and oil it is around 5%.
[6] IEA Energy Statistics use GCV, but NCV is used in IEA Energy Balances; a 10% difference is assumed between GCV and NCV.
[7] BP does not declare GCV or NCV. GCV was inferred from physical units and energy use data.
[8] UN reports it uses NCV, yet data suggest GCV; CDIAC also obtains CO2 emissions using a GCV emission factor.
[9] BP does not declare GCV or NCV. GCV was inferred from physical units and energy use data.

the United States in 2005, yet their reports of petroleum energy use differ by 7%, or 3 Exajoules. This difference is wholly attributable to differences calorific value assumptions by these two organizations. As a comparison of crude oil calorific values in terms of tonnage, IEA reports a calorific value (NCV) for the US in 2005 of 43.06 GJ per tonne. EIA reports a calorific value (GCV) of 44.87 GJ per tonne, a difference of 4.2%. Given that the US consumes roughly 25% of global petroleum, this represents a large discrepancy. On a global scale, BP and EIA 2005 petroleum energy use values differed by 10.8%, or 17 Exajoules, despite EIA only reporting 1.1% more barrels consumed.

Calorific Value-Natural Gas

Calorific values for natural gas are given in terms of energy per unit volume, such as MJ per cubic meter. EIA utilizes GCV. Natural gas calorific values for IEA are published in terms of GCV, although the calculation of energy resulting from this calorific value utilizes NCV. IEA calculates NCV to be exactly 90% of GCV. The UN publishes calorific values for various countries in both NCV and GCV, but claims to use NCV to calculate energy use. However, since 1990 UN natural gas consumption values have closely followed EIA values (which use GCV), and carbon dioxide emissions from UN energy data utilize an implied GCV emission factor. EIA reports GCV for all countries each year and utilizes these values to calculate energy use. BP, with the exception of the United States, uses one value applied to all countries. Globally, this assumption leads BP to be an average of 3.5% less than EIA and 3.5% greater than IEA values.

Calorific Value-Coal

Coal comes in a variety of qualities and thus calorific values. IEA and the UN present calorific values in terms of NCV, whereas EIA gives GCV. EIA provides an aggregated calorific value based on anthracite, bituminous, and lignite coal production, whereas IEA and the UN include 10 categories (EIA, 2008). Taking global energy use data (in energy units) divided by production values (in tonnes), we see initial differences in calorific contents used. The UN data implies a general global calorific content of 17.98 GJ/kg. IEA data implies a value of 19.00 GJ/kg. BP data implies a value of 20.64 GJ/kg, and EIA has the highest value of 21.75 GJ/kg. The 21% difference between EIA and UN implied calorific values explains why EIA reported the least amount of coal production (in tonnes) in 2005 of all the agencies, yet had the highest value in terms of energy. Similarly, the UN reported the largest amount of coal production (in tonnes) in 2005, yet reported the lowest amount of energy.

Differences in calorific values lead to substantial discrepancies in overall energy consumption. Improving the consistency of methods by having each agency apply identical GCV or NCV values would lessen the discrepancies when comparing data across organizations. Although this report does not intend to state that any one agency’s values are more correct or better than the others, it does highlight the very significant differences that result from organizations using different and sometimes inconsistent methods.

2.1.1.5 Energy Units: Reporting Conventions

The discrepancies above are to some degree masked by different units for reporting conventions used by energy reporting organizations. These different units make rapid direct comparisons between different datasets challenging. No two energy reporting organizations utilize identical units for physical units or for energy. The UN and IEA utilize energy unit conventions that are the most similar. The UN displays its data in three different energy units and is the only agency to use the official International System of Units (SI) standard of the Joule. Table 6 summarizes the different reporting conventions of energy reporting agencies in terms of physical units of fossil fuels, electricity, and energy units.

Table 6. Summary of reporting conventions of energy reporting organizations.

	IEA	**EIA**	**BP**	**UN**
Coal (Physical Units)	Thousand tonnes	Thousand short tons	Million tonnes	Thousand tonnes
Natural Gas (Physical Units)	N/A	Billion cubic feet	Billion cubic meters Billion cubic feet per day	N/A
Petroleum (Physical Units)	Thousand tonnes	Thousand barrels per day	Thousand barrels per day	Thousand tonnes
Electricity	Gigawatt-hours (10^9 watt-hours)	Billion kilowatt-hours (10^{12} watt-hours)	Terawatt-hours (10^{12} watt-hours)	Million kilowatt-hours (10^9 watt-hours)
Energy	Thousand tonnes oil equivalent (ktoe)	Quadrillion British Thermal Units (BTU)	Million tonnes oil equivalent (Mtoe)	Thousand tonnes coal equivalent (Tce) Thousand tonnes oil equivalent (ktoe) Thousand Terajoules (PJ)

Although conversions between physical and energy units are straightforward, different conventions used by energy reporting organizations make it necessary to perform these conversions before comparing energy use data. It is deceptively simple to take aggregate energy values reported by organizations and convert them to consistent energy units for comparison, however, due to the multitude of different assumptions and methods that contribute to aggregate energy use data. The implications of these differences are addressed in the following section.

2.1.2 Discussion of discrepancies in energy use data

No two reporting organizations utilize identical system boundaries, calorific values, primary energy equivalencies, or treat energy use from biomass sources the same. Despite these methodological differences, the reported values for primary energy use do not always differ greatly. These similarities between data sources should not be taken on face value, however. Real differences in global and national data between organizations are hidden beneath the aggregated published datasets. Using consistent assumptions across agencies highlights the large discrepancies in reported primary energy use.

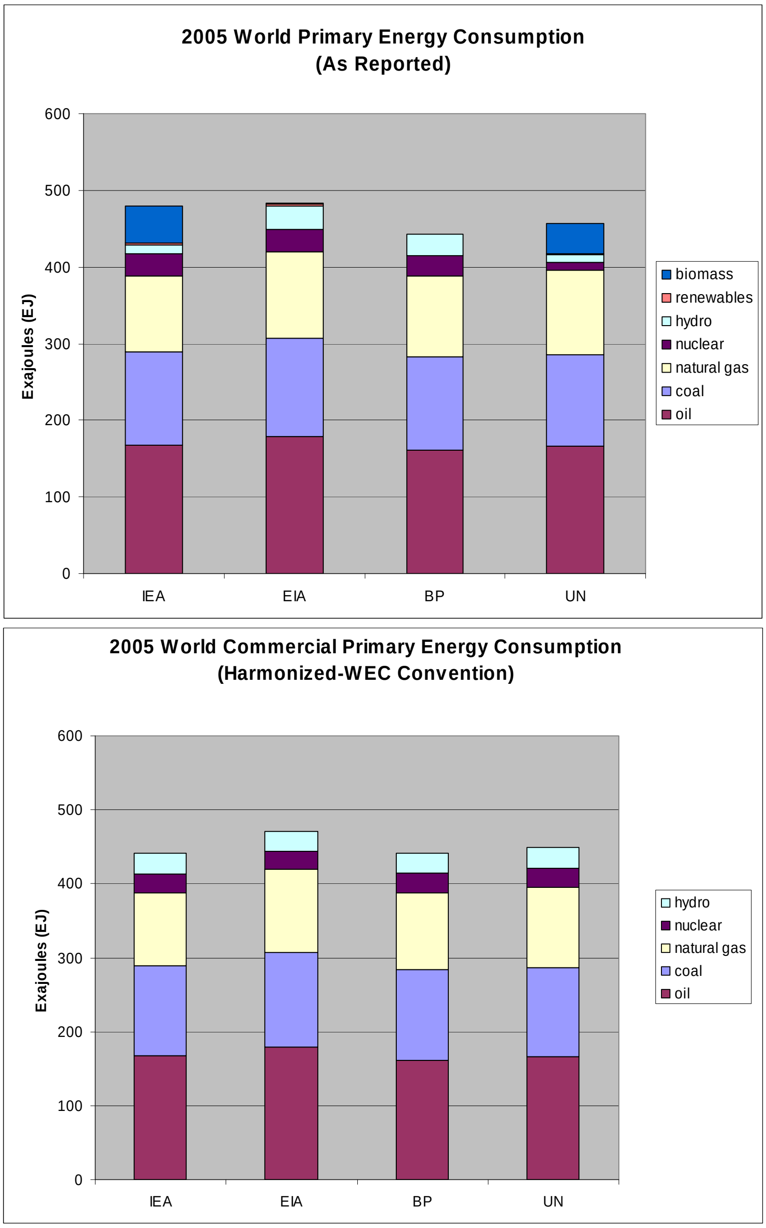


Figure 2: 2005 global primary energy use as reported (top) and with harmonized assumptions, including only commercial energy and utilizing a primary energy equivalence of 38.6% (bottom).

Figure 2 shows world primary energy consumption by fuel category as reported by organizations as well as after harmonizing data by considering only commercial energy sources and by utilizing the WEC primary energy equivalent efficiency convention of 38.6% for nuclear and hydro sources. Note how total values in the unmodified graph for IEA and EIA are nearly identical. However, the components that make up that energy value differ greatly. The differences caused by EIA's use of GCV for fossil fuels and IEA's use of direct equivalence for hydropower equal the IEA category of Combustible Renewables and Wastes. On the surface these organizations appear to have nearly identical values, yet after harmonization it is evident that there are significant differences between the organizations. Considering the harmonized graph, note how IEA and BP are nearly identical. However, this fact does not imply that IEA and BP agree completely on fossil fuel consumption either.

Because of the use of different calorific values, IEA reports 6 EJ more petroleum consumption than BP, which cancels out its reporting 6 EJ less natural gas consumption than BP. Figure 2 shows a comparison of energy use by fuel, highlighting the differences between individual fuels.

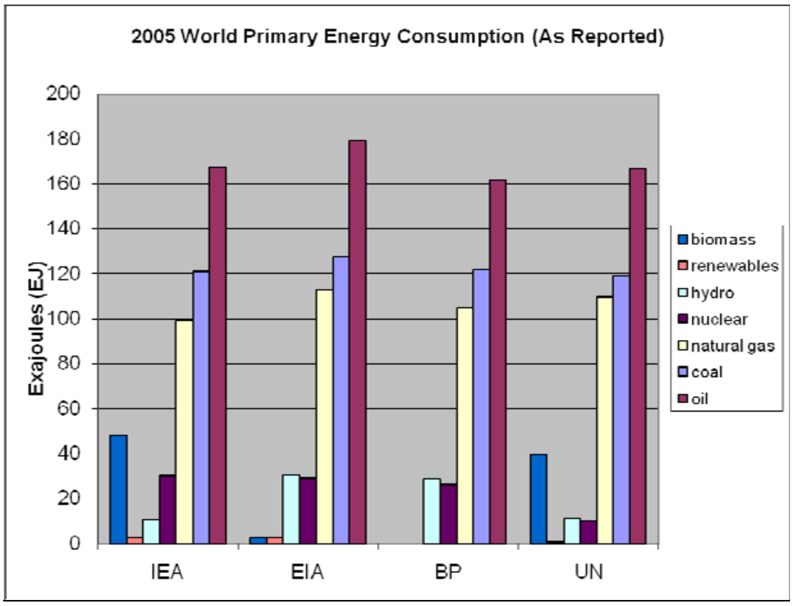


Figure 3: 2005 global primary energy use as reported by institutions.

Differences among organizations for non-fossil fuels are similarly large. Figure 3 compares global non-fossil fuel energy consumption for each agency for the year 2005. Here the importance of primary energy equivalencies choices is clear. The UN reports consumption from nuclear and hydropower sources to be nearly 40 EJ less than EIA, nearly twice the total energy consumption of Japan.

The importance of including biomass or traditional fuels is also clear from Figure 4. Although UN nuclear and hydro data are much lower than those of EIA, the inclusion of biomass from traditional sources makes the amount of energy reported from non-fossil fuel sources nearly equivalent, hiding the inherent discrepancies between the organizations' methods.

The effect of including traditional fuels and biomass can also be seen when looking at trend data within a particular country. Figure 5 shows the primary energy fuel mix for India from IEA and EIA sources for 1980-2006. IEA data (top) show a transition away from traditional sources of energy to increasingly larger shares of oil, coal, and natural gas. EIA data (bottom), which do not include traditional sources, show relatively constant proportions of fuel mix, with the exception of a small increase in natural gas consumption. Thus, although overall quantities of traditional energy sources in India have been increasing, more modern forms of energy have been increasing at a more rapid rate, highlighting the country's modernization. This interpretation is absent from EIA or BP data which do not report estimates of traditional energy sources.

While it is important to consider energy consumption from traditional sources, there remains considerable uncertainty regarding overall quantities being consumed worldwide. Figure 5 shows estimates of traditional biomass consumption (e.g. non-commercial fuelwood) along with modern biofuels consumption (e.g. ethanol from sugarcane) as reported by IEA and UN from 1971-2006. Both organizations show a relatively steady increase in consumption, with the exception of two major jumps by the UN, and the estimates are slowly converging. However, there is still a discrepancy of 8 Exajoules between the two organizations.

The inclusion of biomass sources can also significantly affect other energy trend analyses, such as energy intensity, measured in terms of energy use per unit of GDP. In general, as a nation develops and transitions from a manufacturing economy to a service-based economy, the energy intensity of the economy decreases. Including different factors such as traditional biomass can severely alter trends in energy intensity, especially for developing nations as they replace fuelwood consumption with more modern cleaner fuels (Ausubel and Waggoner, 2008). As an example, depending on which data source is used, Indonesia can be seen as having a net increase or a net decrease in its energy intensity for the period 1990-2005.

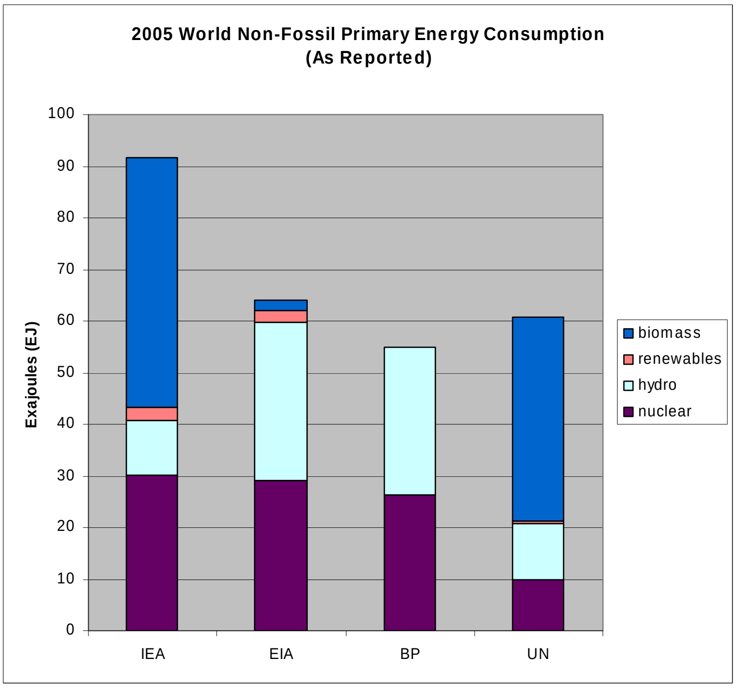
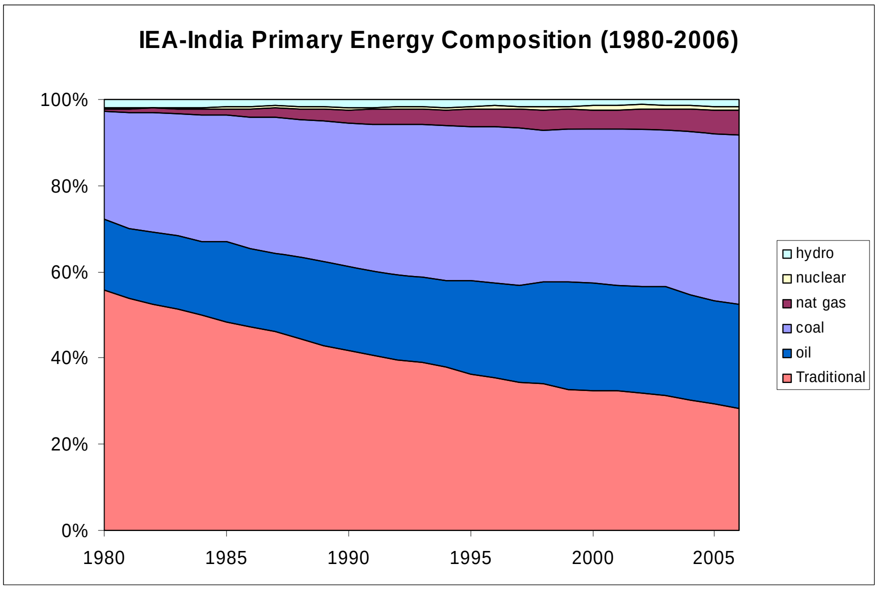


Figure 4: 2005 global primary energy supply of non-fossil fuels as reported by institutions.



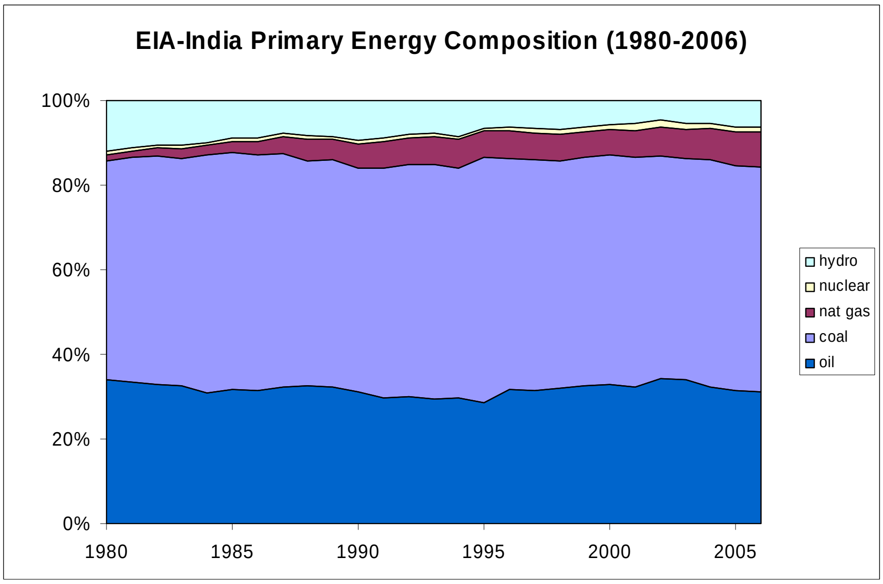


Figure 5: Primary energy composition of India from 1980-2006 as reported by IEA (top) and EIA (bottom). Modern renewable sources have been excluded as they represent a small fraction of total primary energy.

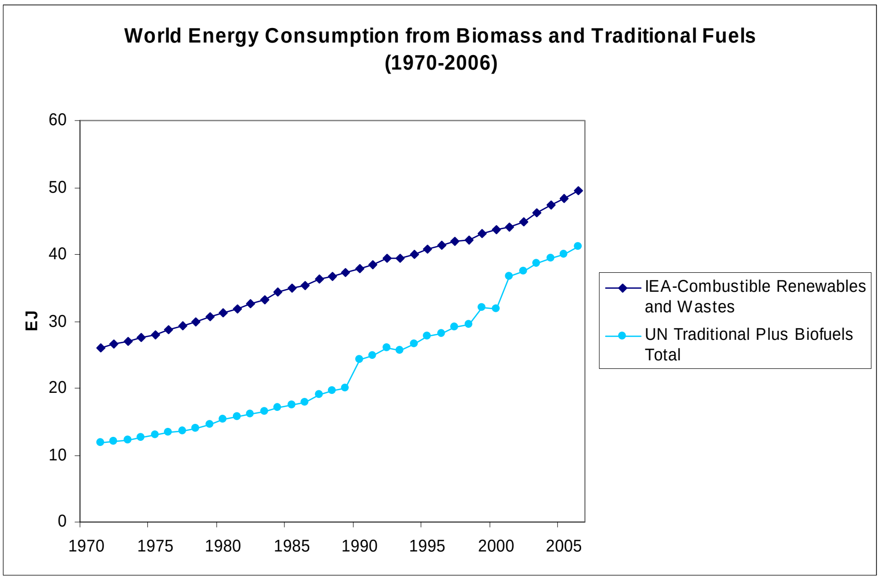


Figure 6: Global primary energy supply of traditional fuels, biomass-based fuels, and modern renewables from 1971-2006 as reported IEA and the UN.

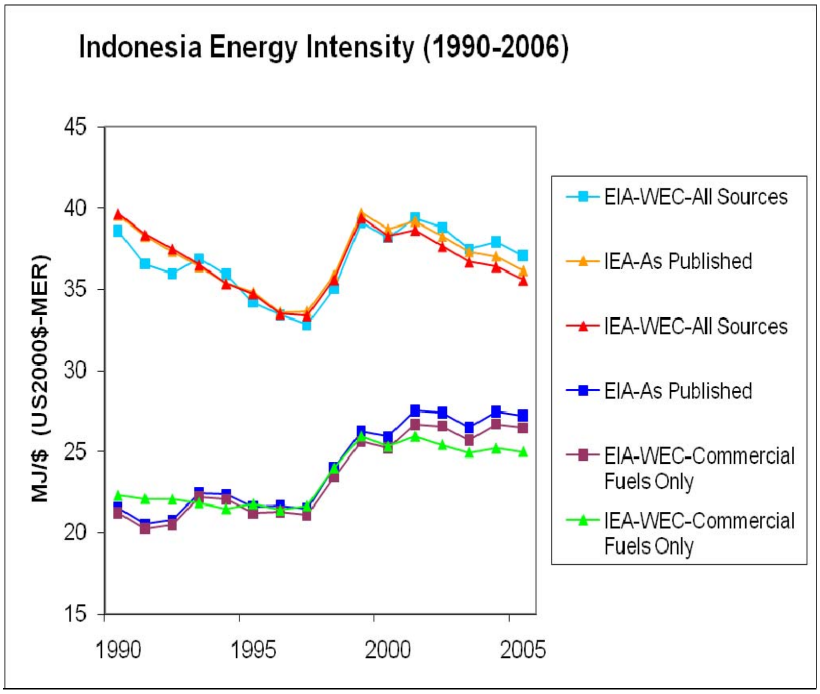


Figure 7: Energy intensity of Indonesia, 1990-2006, both as reported and using harmonized assumptions from EIA and IEA. Harmonized assumptions include considering only commercial fuels and considering commercial fuels plus IEA-reported wastes and traditional fuel use. Market exchange rates from World Development Indicators (WDI) are used for GDP.

Figure 7 shows that, according to IEA published data that includes traditional fuels, the energy intensity of Indonesia has decreased by about 10% over the past 16 years. According to EIA, which does not report traditional fuel use, energy intensity increased by nearly 30%. All reports show a sharp rise in energy intensity from 1997-1999, but in the years surrounding this period IEA shows a clear decline and EIA shows a relatively flat trend. IEA values remain absolutely higher (because they include additional sources of energy), but the trends between the two organizations are contradictory. When assumptions are harmonized to the WEC convention and exclude combustible renewables, both organizations report a slight increase in energy intensity. When assumptions are harmonized to the WEC convention and include combustible renewables, all organizations show a slight decrease in the energy intensity of Indonesia. Similar analyses can be made for other developing countries with large amounts of traditional fuel usage, such as China and India. Energy intensity analyses or targets for these nations are very sensitive to data source.

The discrepancies in methods among organizations do not have any direct international policy implications, but they are important for a number of reasons. First, although each agency describes its methods in its reports, these methodological differences are not readily understood nor clearly identified in articles referencing these values. As IEA world energy consumption may vary by over 30 Exajoules (greater than the entire primary energy consumption of Russia) depending on which primary energy equivalence convention is being used, it becomes crucial that investigators and politicians understand what is being included in these reports. Second, these reports are all widely cited and generally considered to be accurate. Assuming that data reported from these organizations are equivalent could lead to invalid comparisons of energy use or to contradictory analyses, as suggested by Indonesian energy intensity above. For these reasons and for the implications energy data has for carbon dioxide analyses, energy use data would be greatly improved by the standardization of methods, categories, and energy data conventions by energy reporting organizations.

3 Carbon Dioxide Emission Reports

This section compares the methodological assumptions employed by the major international carbon dioxide reporting organizations as well as the discrepancies in their reported data and in data after harmonizing assumptions. As with energy consumption reports, organizations employ different methods when calculating carbon dioxide emissions on national and global scales. Given the large number of referenced organizations that publish emissions data, it becomes essential to understand the methodological assumptions behind these reports. Although each organization ostensibly publishes the same energy use data, different assumptions and methods lead to sometimes significant discrepancies between organizations. Sources of discrepancies between carbon dioxide data published by reporting organizations result from utilizing different data inputs, categorizing emissions sources differently, utilizing emission factors, and from reporting data in different units. Figure 8 outlines the major sources of discrepancies in carbon dioxide emissions data, which are covered in more detail below.

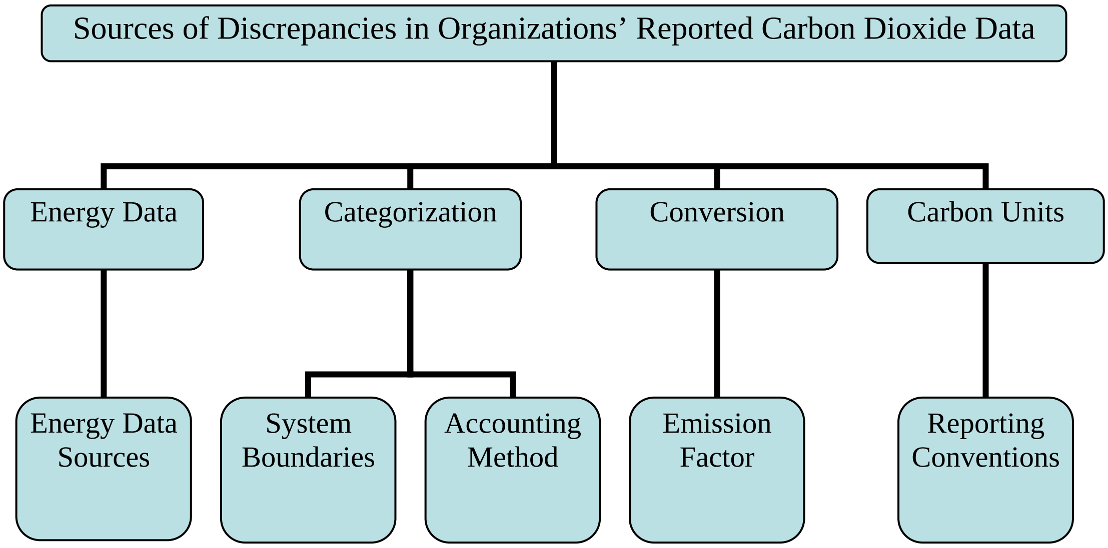


Figure 8: Schematic diagram of sources of discrepancies of carbon dioxide emissions data reported by organizations.

3.1 Sources of discrepancies in carbon dioxide emission data

This section addresses the assumptions of four carbon dioxide reporting organizations, covering a total of five datasets: IEA *Sectoral* Approach (IEA-S) and *Reference* Approach (IEA-R), EIA, CDIAC, and EDGAR. These organizations are summarized in Table 7.

Table 7. Overview of carbon dioxide emissions data reporting organizations

Organization	Code	Publications	Energy Source
International Energy Agency (Reference Approach)	**IEA-R**	CO_2 Emissions from Fuel Combustion-Reference Approach	IEA
International Energy Agency (Sectoral Approach)	**IEA-S**	CO_2 Emissions from Fuel Combustion-Sectoral Approach	IEA
Energy Information Administration	**EIA**	International Energy Annual	EIA
Carbon Dioxide Information Analysis Center	**CDIAC**	Global, Regional, and National Fossil-Fuel CO_2 Emissions Carbon Flux to the Atmosphere from Land-Use Changes	UN
Emissions Database for Global Atmospheric Research	**EDGAR**	Emission Database for Global Atmospheric Research (EDGAR), release version 4.0.	IEA

As noted in Section II, the IEA is an international organization and the EIA is an independent statistical agency of the US Department of Energy. The two different IEA methods refer to different methods of accounting for greenhouse gas emissions. CDIAC, like EIA, is also part of the US Department of Energy, although CDIAC is based in the Oak Ridge National Laboratory in Tennessee. It utilizes UN energy data to calculate emissions according to the methods developed by Marland and Rotty (1984). EDGAR is a joint project of the European Commission Joint Research Centre and the Netherlands Environment Assessment Agency, based in Ispra, Italy. It utilizes IEA energy data to calculate emissions. Each agency publishes data annually, with the exception of the less frequent EDGAR, and is widely cited in policy and academic papers. Although each agency ostensibly produces a report of anthropogenic carbon dioxide emissions, their reports are not always directly comparable and utilize different methods. These different assumptions and methods can lead to strikingly different absolute values and trends in carbon emissions.

3.1.1 Energy Data: Energy Data Sources

The choice of energy data sources is an extremely important methodological decision in determining carbon dioxide emissions. Anthropogenic sources of carbon dioxide, especially those regulated nationally and internationally, result primarily from the use of energy. As is described in Section II, energy reporting organizations can report vastly different physical quantities of fossil fuels that comprise a nation's and the world's total primary energy supply. Table 7 indicates sources of energy data for the carbon dioxide emission reporting organizations. Note how three of the methods considered utilize IEA data, and no organizations utilize BP energy data. The choice of energy data is important not only due to the physical quantities of fuels reported by energy organizations, but also due to the calorific values ascribed to fossil fuels. Additionally, analyses of carbon intensity are based on both carbon dioxide emissions and energy use data, making the choices of energy system boundaries and primary energy equivalences important for these analyses. The choice of energy data sources for carbon dioxide emission reporting organizations has important implications that persist throughout all other sources of discrepancies between organizations.

3.1.1.1 Categorization: System Boundaries

In addition to direct emissions from fossil fuel combustion, there are a number of other categories of emission sources that are either included or omitted by reporting organizations. Other anthropogenic sources of carbon dioxide that are published include emissions from natural gas flaring, cement production, municipal wastes, biomass combustion, and land-use changes. These other categories have the potential to augment emissions that result simply from fossil energy use by as much as 50%. Table 8 summarizes organizations' inclusion of these various sources of emissions, along with providing the organizations' source of data.

Table 8. Summary of data sources for other emission sources.

	Gas Flaring Sources	Cement Sources	Wastes Sources	Biomass Sources	Land-Use Sources
IEA-R	N/A	N/A	IEA	N/A	N/A
IEA-S	N/A	N/A	IEA	N/A	N/A
EIA	National data, Cedigaz, IEA	N/A	N/A	N/A	N/A
CDIAC	UN	USGS	N/A	N/A	FAO (Houghton 2003,)
EDGAR	CDIAC	USGS	FAO	FAO	FAO

Emissions from Natural Gas Flaring

The flaring of natural gas currently makes up less than 1% of energy-related carbon dioxide emissions, yet is still an important source of emissions for certain countries. All organizations addressed here report emissions from natural gas flaring except IEA. While IEA collects and publishes data on gas flaring from OECD countries, it does not include these values in its calculations of carbon dioxide emissions. EIA obtains its natural gas flaring data from this IEA source, from government agency reports, and from Cedigaz, a natural gas information organization founded in 1961. CDIAC obtains its gas flaring data primarily from the UN energy data, supplemented with historical data from EIA and others. EDGAR reports that it obtains its gas flaring data directly from CDIAC, supplemented with data from EIA and the United Nations Framework Convention on Climate Change (UNFCCC), yet there are significant trend differences between EDGAR and CDIAC natural gas flaring data. Figure 9 shows natural gas flaring emissions as they are reported by EIA, CDIAC, and EDGAR. Note the different trends between the carbon dioxide reports and the recent rise in CDIAC data. Cumulatively, gas flaring emissions range from 1980-2005 range from 4.3 Pg CO_2 (CDIAC) to 5.1 Pg CO_2 (EDGAR), a 20% discrepancy that does not affect total emissions substantially. Global totals of gas flaring in 2005 as reported by EIA and CDIAC differed by more than 9%.

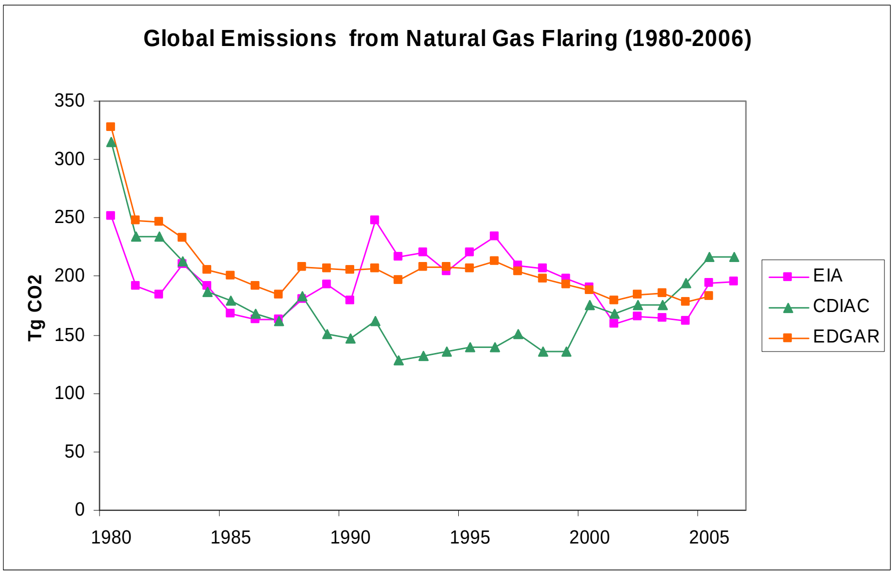


Figure 9: Global emissions from the flaring of natural gas, 1980-2006. EIA gas flaring data are not directly reported and must be calculated by subtracting data from table H.3CO$_2$ from table H.3conCO$_2$. EDGAR emissions are taken from category 1B2. CDIAC natural gas flaring emissions are directly reported.

Emissions from Cement Production

Carbon dioxide emissions from cement production are roughly six times greater than gas flaring carbon dioxide emissions, and comprise roughly 4% of energy-related emissions. Despite this greater share of emissions, only CDIAC and EDGAR report emissions from cement. However, only CDIAC reports emissions explicitly from cement. EDGAR reports an aggregated value, "production of minerals," which includes cement and "lime, carbides, soda ash, dolomite and limestone use" (EDGAR 2009). Both organizations obtain cement production data from the United States

Geological Survey (USGS), which itself collects data primarily from country reports and from in-country specialists (Busse 2007). EDGAR's other minerals data are from [CRF/UNFCCC (2008)]. Figure 10 shows global cement emissions as they are reported by EDGAR and CDIAC. Note that EDGAR emissions also include other minerals. While the absolute difference between the two datasets in 2005 is roughly 300 Tg CO_2 (more than total natural gas flaring emissions), trend data is very similar. This is likely due to both organizations using USGS raw data.

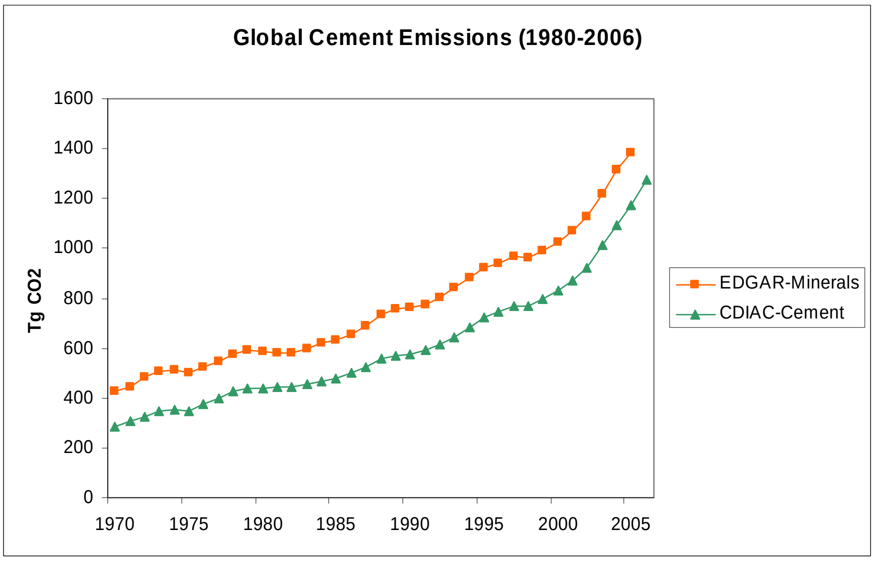


Figure 10: Global emissions from the production of cement, 1970-2006. EDGAR data stops in 2005. EDGAR data includes the production of other minerals in addition to cement.

Emissions from Municipal Wastes

Inorganic carbon emissions from municipal and industrial wastes, which result primarily from incineration of plastics, make up less than one percent of emissions from energy sources. IEA and EDGAR report waste emissions, yet use slightly different categories. IEA has two categories: industrial waste and non-renewable municipal waste. Organic wastes are deliberately excluded from carbon dioxide accounts as these sources are assumed to add no net emissions. EDGAR reports emissions from incineration of inorganic wastes, but includes other wastes involved in industrial processes in industry-specific categories. The wastes are not disaggregated from industrial production as a whole. EDGAR also includes waste emissions from organic sources in a separate category. The differences in categories and values reported make it difficult to distinguish the level of overlap in reporting for wastes and to make an appropriate comparison. In 2005, IEA-S and IEA-R reported emissions from industrial and municipal wastes to be 103 and 104 Tg CO_2, respectively, while EDGAR estimates emissions from waste incineration to be 30 Tg CO_2.

Emissions from Biomass and Combustible Renewables

Combustible renewables include liquids produced from biomass (such as ethanol), as well as any solid biomass that is used directly as fuel or converted into other forms before combustion. Of the organizations considered here, only EDGAR reports emissions from these sources. IEA does report energy consumption from combustible renewables, but does not include emissions resulting from their consumption. EIA reports energy usage of combustible renewables that go into electricity production, but again does not include resulting emissions.

Emissions from Land-Use Changes

Emissions from land-use changes could represent a large fraction of total anthropogenic carbon dioxide emissions, and have been thoroughly addressed in other studies. A comprehensive review of land-use emissions is out of the scope of this paper; instead this analysis only attempts to put these emissions in context of all other anthropogenic carbon dioxide emission sources. Land-use changes resulting in emissions include forest and grassland fires as well as savanna burning. Emissions from these sources are estimated by EDGAR and CDIAC only, using data from the FAO and from Houghton (2003) CDIAC includes one general land-use change category while EDGAR separates these into three separate categories: Agricultural Wastes and Savanna Burning, Biofuels and Wastes, and Forest Fires. The latter category is assumed to be equivalent to the CDIAC category and the IPCC land-use category. There is great uncertainty in these data, especially with regard to the degree to which these are "net" or "gross" emissions, (where net emissions contribute to atmospheric CO_2 concentration increases and gross emissions are presumably partially offset each year by sink sequestration and storage), yet EDGAR estimates on a global scale they could be half as large as emissions from energy sources. As many of these land-use changes may be long-lasting, they are a crucial component of future estimations of carbon dioxide emissions, especially given the magnitude of emissions by developing countries. Figure 9 compares non-fossil sources of carbon dioxide as reported by EDGAR and CDIAC in 2005 with IEA-S fossil energy emissions. Note how large land-use emissions can be compared with fossil energy emissions, especially for EDGAR. EDGAR land-use emission sources include forest fires, savanna burning, and emissions from agricultural crops used for energy purposes. EDGAR land-use emissions thus represent gross emissions, not accounting for the yearly re-growth or re-planting of agricultural crops. Still, the annual contributions of non-fossil sources is quite significant, and if re-planting does not occur, the gross emissions contribute to net emissions, and these emissions are seldom accounted for.

While there is uncertainty as to how much of the land-use emissions are gross or net emissions, emissions from industrial sources are certainly net emissions. Industrial emissions from CDIAC only represent emissions from cement production. Industrial emissions from EDGAR, however, include the production of minerals described above, the production of metals, and inorganic waste combustion. As seen from Figure 11, there is a substantial amount of industrial emissions that are not accounted for by CDIAC. It should be noted that EDGAR industrial emissions may be overestimated by as much as 1 Pg, yet this still represents a significant percentage of total emissions from energy sources (van Aardenne, personal communication).

In terms of net carbon accounting as it is conducted by the IPCC, Figure 12 compares global land-use emissions from CDIAC with those of forest fires from EDGAR, categories which are intended to be equivalent to the IPCC SRES land use emissions. Whereas absolute values do not differ much in 2004 and 2005, note the vast differences in trends: CDIAC shows smooth, gradual trends whereas EDGAR data are variable year to year. For 2005, EDGAR and CDIAC data are remarkably similar, although history shows how different these sources can be. Cumulative emissions from CDIAC from 1970-2005 are 14% larger than EDGAR emissions, corresponding to 23.9 Pg CO_2, or roughly 80% of global fossil energy emissions in 2005.From 1990-2005, cumulative emissions reported by CDIAC are just 4.6% larger, corresponding to 4.2 Pg.

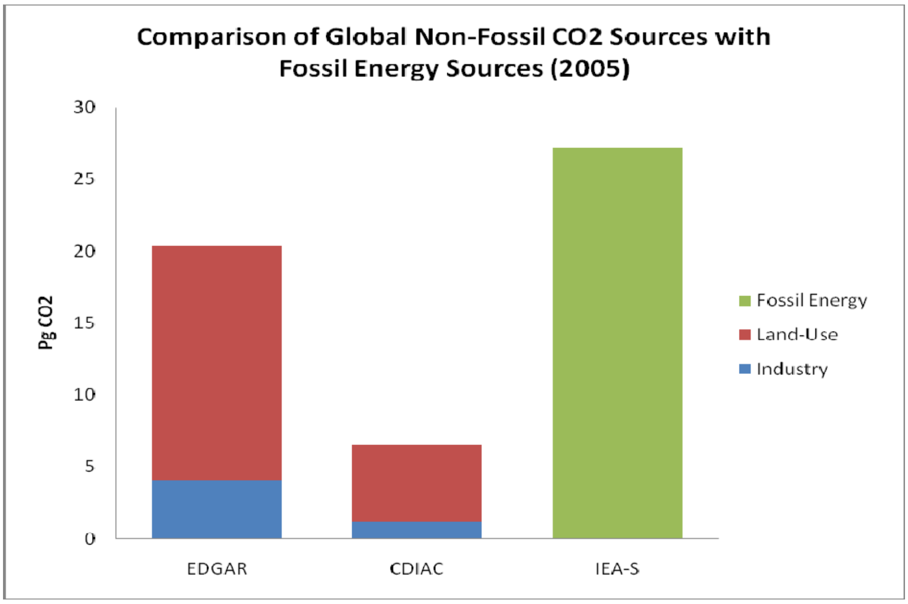


Figure 11: Comparison of global emissions from non-fossil sources and IEA-S energy-only emissions, 2005. EDGAR land-use data includes sources from forest fires, agricultural wastes, and savanna burning. EDGAR industry data includes emissions from mineral, metals, and inorganic wastes. CDIAC land-use emissions are as reported. CDIAC industry emissions include only cement emissions.

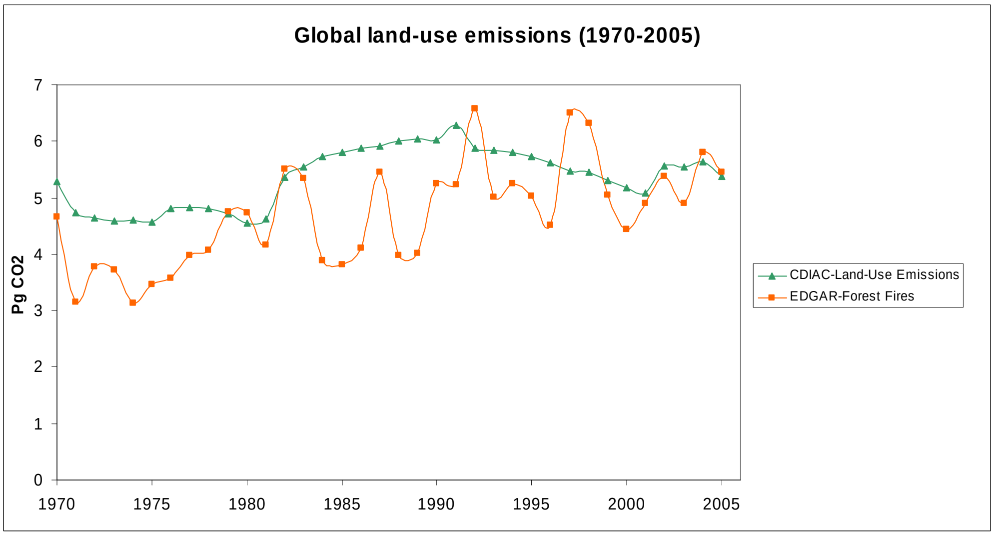


Figure 12: Global emissions from land-use changes, 1970-2005. EDGAR emissions come from the category of Forest Fires.

Figure 13 shows EDGAR emissions from all organic sources. According to EDGAR, the largest share of emissions from organic sources comes from the combustion of agricultural wastes and savanna burning. Biofuels and other wastes have steadily been increasing, but still make up the smallest category. These two categories are largely only gross contributors to atmospheric CO_2 concentrations, but are still substantial. The degree of uncertainty is large and the amount of double-counting, (i.e. including emissions from a forest fire and the emissions that result from salvaging some wood to use at fuel wood) is unknown. However, improving estimates of these natural and anthropogenic sources of CO_2 from year to year will help improve emission inventories, carbon cycle and climate models as well as the understanding of the relationship between yearly emissions and atmospheric concentrations.

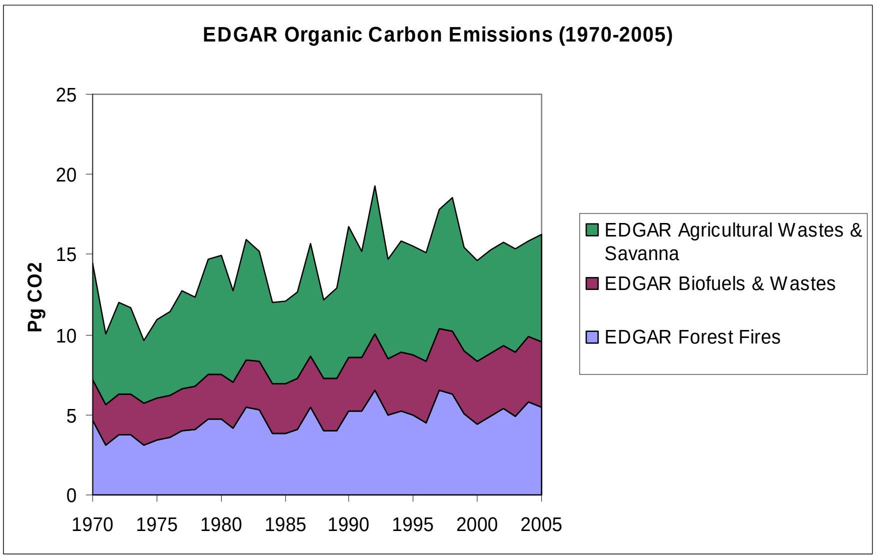


Figure 13: Global emissions from land-use changes as reported by EDGAR, 1970-2005.

3.1.1.2 Categorization: Accounting Methods

An important component of comparing emission reports is to examine by what means data are collected and how they are accounted. There are two distinct accounting methods employed in the five methods analyzed here. The first method is termed the reference approach. The reference approach determines emissions based on the top-down determined apparent consumption of energy. Using such a method can be beneficial in countries with few or unreliable data. IEA-R and CDIAC employ the reference approach method. In the CDIAC method, a probable oxidation percentage, determined by average US data, and a mass-based emission factor are multiplied by the apparent consumption value (Marland and Rotty, 1984).

A second approach to carbon accounting is termed the sectoral approach. In this method, reports of energy consumption from each individual sector are summed to give a more detailed picture of how much energy has been consumed, and in what form. This approach requires greater precision and trust in a larger number of data sources, but offers a more accurate account of actual emissions produced if quality data are available. The IEA Sectoral Approach and the EIA utilize this approach. EDGAR's approach goes one step into further detail, utilizing the Sectoral approach but using technology-based (as opposed to average fuel-based) emission factors. Thus the emissions for a particular energy process are not only dependent upon the quantity of fuel but also the specific technologies combusting that fuel.

Organizations publish data in different categories. In this case, each organization has a different method for publishing specific components of carbon emissions. IEA for both approaches publishes emissions according to the specific fuel category (such as coking coal, natural gas liquids, petroleum coke, etc.) and additionally gives a grand total. EIA and CDIAC, in contrast, aggregate emissions into three basic categories for solid, liquid, and gaseous fuels. EDGAR aggregates emissions according to the IPCC Sector Emission Categories, where emissions are tabulated according to their end-use (such as transportation or energy production) and not by their fuel-type, making fuel-specific comparisons between EDGAR and the other organizations nearly impossible. Although it is useful to categorize emissions into these categories, the EDGAR dataset could be improved by also publishing emissions by fuel category; this would also aid in cross-organization comparisons. Table 9 summarizes both the accounting methods and energy emission categories employed by organizations.

Table 9. Overview of agency accounting methods.

Agency	Accounting Method	Energy Emission Categories
IEA-R	Reference Approach.	45 IEA Energy Categories
IEA-S	IPCC Tier 1 Sectoral Approach (Average fuel-based emission factor)	45 IEA Energy Categories
EIA	Sectoral Approach	Coal Petroleum Natural Gas
CDIAC	Reference Approach	Solids Liquids Gases
EDGAR	IPCC Tier 2 Sectoral Approach (Country-specific and technology-based emission factor)	13 IPCC Sector Emissions Categories (IPCC Category 1)

3.1.1.3 Conversion: Emission Factors

Carbon emission factors, with the exception of those used by CDIAC, are based on the energy content of particular fuels, not on the physical quantities of fuels. As is described in Section II, all energy reporting organizations utilize different calorific values for fossil fuels. Theoretically, the NCV or GCV used for energy use should not matter if corresponding different (NCV vs. GCV) emission factors are used. Table 10 shows a range of emission factors, including those used by the IPCC. Note how emission factors for GCV are lower than emission factors for NCV.

In practice, IPCC and proportional emission factors are not used by the carbon dioxide emission reporting organizations. Although energy organizations may report nearly identical quantities of barrels of oil or tonnes of coal consumed, their different calorific values lead to significant differences in the total amount of energy consumed. These calorific differences are not compensated by proportional differences in emission factors, which lead to significant differences in carbon dioxide emitted from energy sources. EIA’s use of GCV and IEA’s use of NCV led to large differences in reported energy quantities, and because of emission factor choices these differences persist in analyses of carbon emissions.

Table 10. Overview of emission factors for fossil fuels (kg CO_2/GJ) adapted from Nakicenovic *et al.*, (1996).

		IPCC 1995	Literature Low	Literature High
COAL (BITUMINOUS)	GCV		87.6	89.8
	NCV	94.6	92.0	94.6
NATURAL GAS	GCV		49.9	51.3
	NCV	56.1	55.0	56.5
CRUDE OIL	GCV		69.7	74.4
	NCV	73.3	73.3	78.5

Table 11 displays aggregated global emissions from fossil fuels for the year 2005[10]. In addition, the table shows the aggregated energy consumption values from which these numbers were originally derived and corresponding average implied emission factors for the various fuels. Implied emission factors are derived from these aggregated data, not from the emission factors reported for individual coal products (such as anthracite, lignite, peat, etc.) or for individual petroleum products (crude oil, jet fuel, kerosene, etc.). Given that organizations categorize coal and petroleum products differently in energy publications, the corresponding carbon emissions data are also based on different categories. For example, IEA and UN have ten (albeit different) categories for coal products, whereas EIA only uses four categories. Thus IEA and CDIAC utilize ten different emission factors for coal products, whereas EIA utilizes just four. These different categorization techniques lead to different energy and carbon emissions values, while also making emission factors derived from particular aggregated fossil fuel categories (i.e., "coal") somewhat artificial. The implied emission factors are not intended to represent actual emission factors utilized by these agencies, but rather offer a basis for comparison of the calorific content and emission factors used by these organizations. Percent differences are calculated using IEA-S as standard. Note for coal emissions that although IEA uses NCV and EIA uses GCV for calculating coal's energy content, IEA-S and EIA have roughly equivalent implied average emission factors. Both aggregated values are closer to the GCV emission factor range. However, given the different calorific values used to calculate energy use, these emission factors should differ. This inconsistency leads to discrepancies of 4.5% for emissions from coal, equating to 450 Tg of CO_2, roughly the total fossil fuel emissions of Mexico. Here the discrepancies in energy reports persist in emission reports due to emission factor choices. The UN reports the least amount of oil energy consumption, though CDIAC, which uses UN energy data, reports the highest oil CO_2 emissions. Additionally, although the UN purports to use NCV for natural gas energy data, the implied emission factor and quantity of natural gas consumed suggests that GCV is used. It appears that the IEA-S method and the EIA method provide the lower and upper bounds, respectively, for emissions from individual fossil fuels, with a total difference of just under 5%. Considering all fossil fuel emissions from EDGAR, which reports lower fossil fuel consumption emissions than IEA-S but does not disaggregate emissions by fuel, the difference between low and high values for fossil fuel emissions rises to just over 6%.

[10] EDGAR data are not included because EDGAR emission categories do not correspond to fossil fuel categories.

Table 11. Summary of global CO_2 emissions and primary energy use from coal, oil, and natural gas.

	Agency	Energy Consumption (EJ)	CO_2 Emissions (Pg CO_2)	Implied Emission Factor (kg CO_2/GJ)	% Difference Emissions	% Difference Energy	% Difference Emission Factor
COAL	IEA-S	121.1	11.0	90.8	--	--	--
	IEA-R	121.1	11.3	93.3	2.7%	0.0%	2.7%
	EIA	127.6	11.5	90.1	4.5%	5.4%	-0.8%
	CDIAC/UN	119.3	11.1	93.0	0.9%	-1.5%	2.4%
OIL	IEA-S	167.7	10.7	63.8	--	--	--
	IEA-R	167.7	10.8	64.4	0.9%	0.0%	0.9%
	EIA	179.2	11.1	61.9	3.7%	6.9%	-2.9%
	CDIAC/UN[11]	166.6	11.3	67.8	5.6%	-0.7%	6.3%
GAS	IEA-S	98.9	5.3	53.6	--	--	--
	IEA-R	98.9	5.4	54.6	1.9%	0.0%	1.9%
	EIA	112.9	5.7	50.5	7.5%	14.2%	-5.8%
	CDIAC/UN	109.5	5.4	49.3	1.9%	10.7%	-8.0%
TOTAL	IEA-S	387.7	27.0		--	--	
	IEA-R	387.7	27.5		1.9%	0.0%	
	EIA	419.7	28.3		4.8%	8.3%	
	CDIAC/UN	395.4	27.8		3.0%	2.0%	
	EDGAR	387.7	26.7		-2.9%	0.0%	

[11] UN oil primary energy values are taken from summing commercial liquids, aviation and marine bunker fuels, and unallocated sources.

3.1.1.4 Carbon Units: Reporting Conventions

Much as energy data discrepancies are masked by differences in units, carbon dioxide emission data are reported in different units, which require data manipulation to compare different data sources. All reporting organizations publish data in terms of carbon dioxide except CDIAC, which uses carbon. Table 12 summarizes the reporting conventions used by carbon dioxide emission reporting organizations.

Table 12. Reporting conventions for carbon dioxide emission reporting organizations.

Organization	Carbon Unit Published
IEA-R	Million Metric Tonnes CO_2 (Tg CO_2)
IEA-S	Million Metric Tonnes CO_2 (Tg CO_2)
EIA	Million Metric Tonnes CO_2 (Tg CO_2)
CDIAC	Thousand Metric Tonnes C (Gg C)
EDGAR	Thousand Metric Tonnes CO_2 (Gg CO_2)

3.1.2 Discussion of discrepancies in carbon dioxide emission data

Carbon reporting organizations' methodological assumptions significantly affect their annual data output. Differences from choices of energy data and corresponding emission factors, choices of accounting approach, and inclusion of non-fossil energy emission sources have important consequences for particular years and for trend data. Like energy reports, it is helpful to examine reports of emissions as-published as well as after harmonizing assumptions to determine appropriate levels of discrepancy. Examining data as reported, EDGAR's report of "Emissions excluding organic carbon" is consistently the highest with its emissions from energy and industry, followed by CDIAC. Figure 14 shows emissions from energy and industrial practices as reported by institutions as well as energy-only emissions.

The difference between these two organizations and the others is their including industrial factors such as cement production in their reports. CDIAC reports of global emissions are on average 7% higher than emissions reported from the IEA-S method. When only emissions from energy sources are addressed (i.e. removing cement and natural gas flaring emissions from CDIAC, natural gas flaring from EIA, wastes from IEA-R and IEA-S, and all industry from EDGAR), CDIAC still is on average 3% higher than IEA-S each year for the designated period. Energy-only emissions from EIA are on average only 2% higher than IEA-S after harmonization (from1980-2006). EDGAR energy-only emissions are consistently lower than other reported values. Differences from energy-only emissions are less than differences from reports as-published, yet still indicate significant data uncertainties.

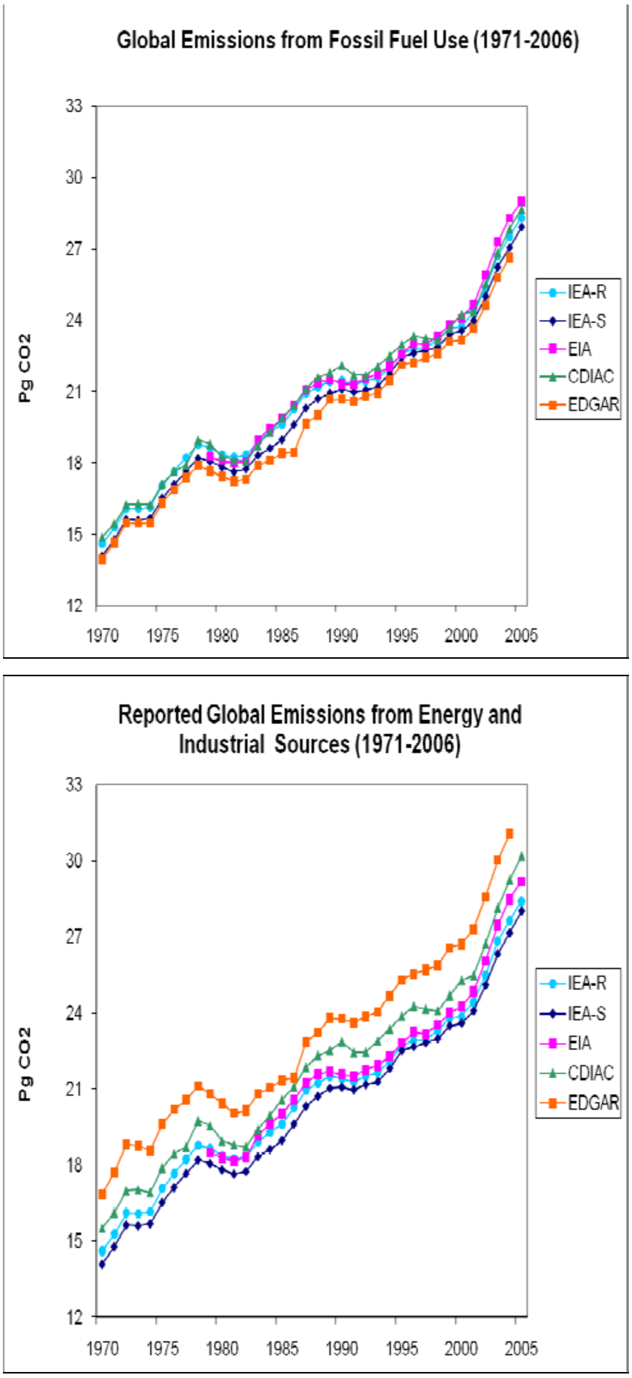


Figure 14: Global emissions from energy and industrial sources (bottom) and energy-only (top), as reported by institutions, 1971-2006. EDGAR data stop in 2005. EIA data begin in 1980. Note how EDGAR emissions that include industrial emission sources are the highest, though EDGAR energy-only emissions are the lowest.

Emissions resulting from energy usage provide the basis from which other comparisons of data and uncertainty can be made. While the inclusion of other factors can be readily transferred from one dataset to the next or subtracted from a dataset, emissions from energy usage are more difficult to rectify due to the wide variety of heating values and emission factors used for numerous categories of fuels, which themselves are different agency by agency and year to year. It is unreasonable to expect researchers to identify and analyze these differences; instead reporting organizations should utilize consistent methods and report uncertainty ranges that arise from using different methods or different energy sources.

Considering fossil fuels individually, Figure 15 shows global emissions by fossil fuel from 1970-2006 for IEA-S, IEA-R, EIA, and CDIAC. For coal, CDIAC consistently reports higher emissions until the late 1990s, when EIA begins reporting higher. Conversely, EIA consistently reports higher petroleum emissions until the early 1990s, when CDIAC overtakes it. EIA has consistently reported higher emissions from natural gas, and since 1999 has generally reported the highest overall emissions from fossil fuels.

2005 Global emission differences resulting from commercial fossil fuels are under 6%, yet this global aggregation masks larger differences on national scales. Indeed, of the 26 highest emitters of CO_2 from commercial fuels in 2005 (representing 80% of global energy-related emissions), 13 countries have discrepancies of greater than 10% when comparing IEA-S and EIA emissions. It is important to note that EIA attributes international bunker fuel emissions to each nation, whereas other organizations exclude these values from national totals. Figure 16 compares EIA and CDIAC emissions from just fossil fuels for the Netherlands from 1980-2006. In 2006, EIA values are 55% greater than CDIAC values, and EIA values show a rising trend as opposed to the flatter trend of CDIAC.

As a further example of national differences, Canada shows great disparities among all organizations, both in terms of trends and absolute amounts. Cumulative emission differences between IEA-S and EIA from 1990-2006 are 9.8%, or 0.8 Pg CO_2. Figure 17 shows Canadian emissions from fossil fuels only from 1990-2006, including EDGAR data, as fuel aggregation is possible. Such a large disparity between organizations for absolute quantities and cumulative amounts since 1990 is not only due to the inclusion of bunker fuels and should cause concern for policymakers and researchers analyzing carbon emissions.

Both the Sectoral and Reference methods should give identical results, given sufficient quality data. In reality, there are disparities that result from the methods employed. The most striking example of this is a comparison of the two IEA approaches, which utilize the same energy data. While total global differences between the two organizations in 2005 only amount to approximately 2% (corresponding to 0.5 Pg CO_2), certain countries have vast differences. South Africa’s difference amounts to 23% (.075 Pg CO_2) and Mexico’s difference is over 9% (.036 Pg CO_2). Figure 18 shows Mexico’s emissions from 1990-2006 as reported by IEA-R and IEA-S. Distinct trend differences can be seen from 1998-2001 as well as in 2006. Given that these two different approaches by the same agency using the same raw data give such different results for an OECD country, the different methods utilized should always be noted.

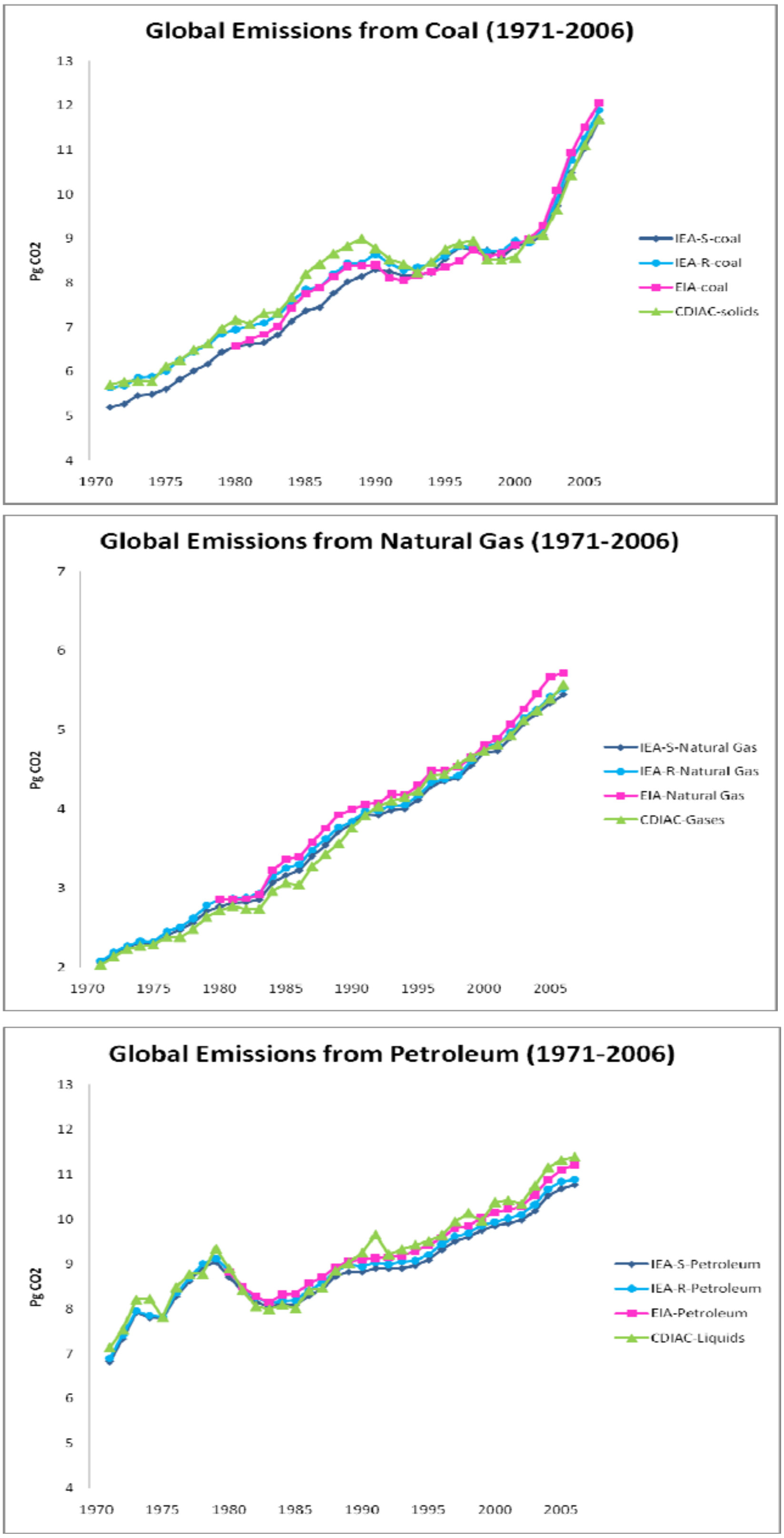


Figure 15: Global emissions from coal (top), natural gas (middle), and petroleum (bottom) sources, 1971-2006. EIA data begin in 1980.

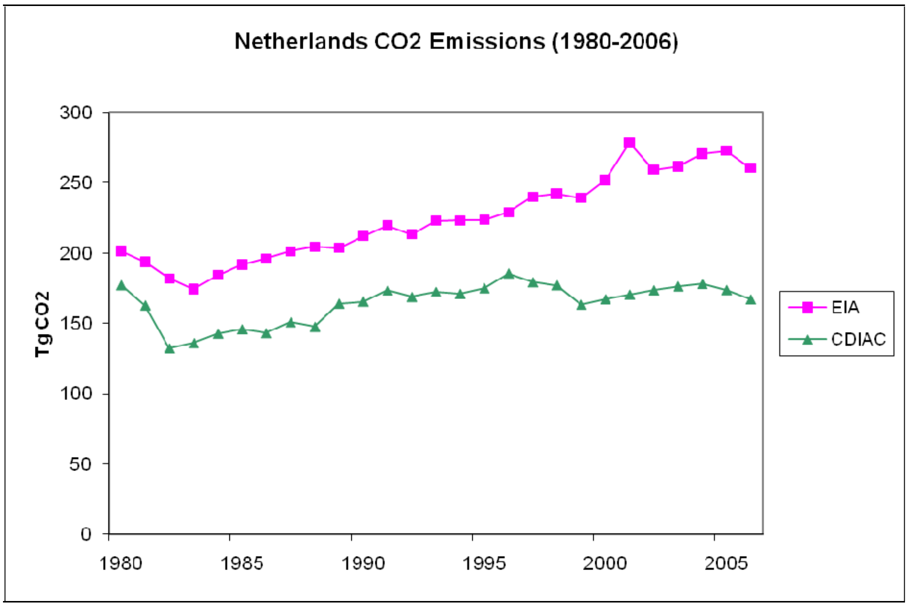


Figure 16: Emissions from energy usage only as reported by EIA and CDIAC, 1980-2006. EIA includes international bunker fuels in its national inventories whereas CDIAC excludes them.

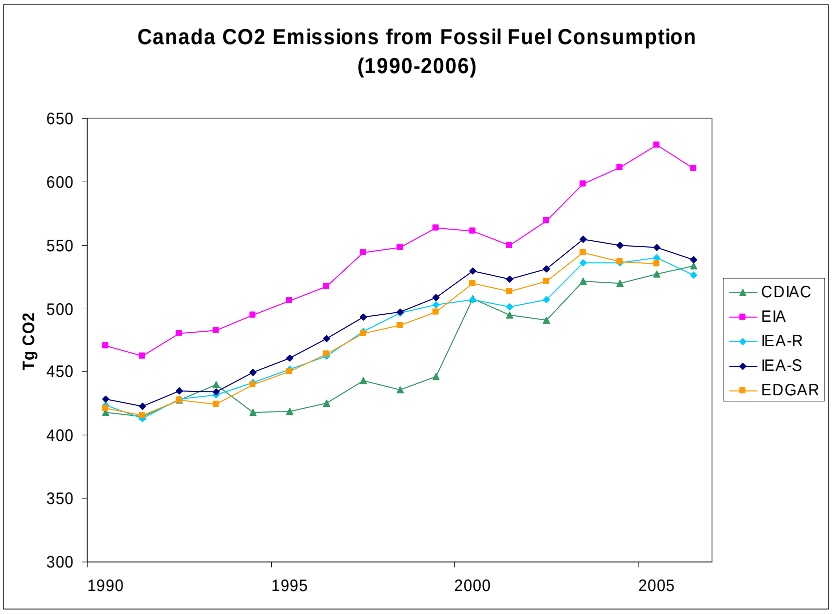


Figure 17: Canadian energy emissions as reported by institutions, 1990-2006. EDGAR data stop in 2005. Note the vast trend differences between organizations, especially CDIAC. EIA includes international bunker fuels in its inventory.

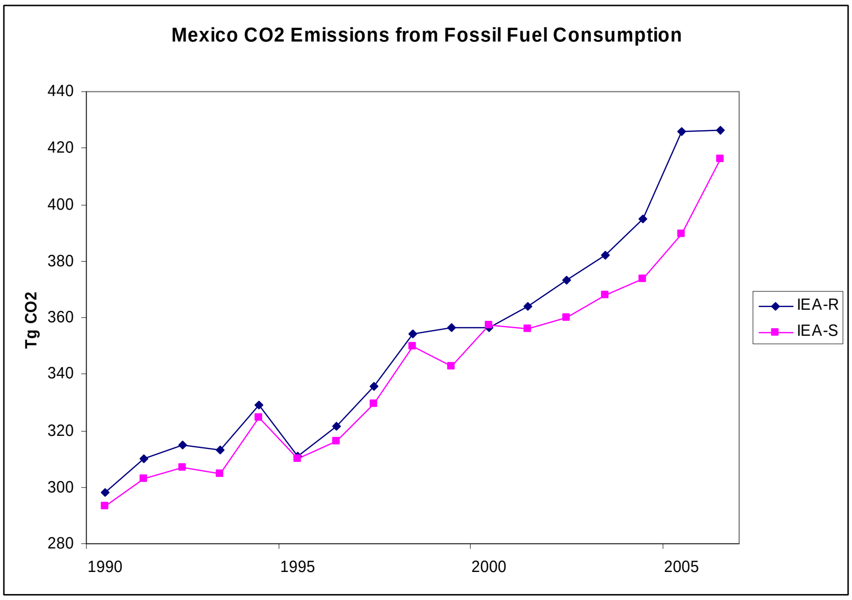


Figure 18: Mexican energy emissions as reported by IEA-R and IEA-S, 1990-2006. Both methods use the same energy data but use different methods of accounting.

Differences are also apparent between IEA-S and EDGAR, which both utilize IEA energy data and use a sectoral approach. The difference between the agency methods relates to the categorization of emissions. IEA-S utilizes IEA energy categories, whereas EDGAR uses IPCC emission categories. Furthermore, EDGAR uses technology-based emission factors, whereas IEA-S uses average fuel emission factors. IEA-S reported global emissions from fossil fuel consumption are consistently higher than EDGAR emissions from 1971 to the present. While cumulative emissions during this period differ only by about 2%, it highlights the variation that is possible even within two organizations using the same energy data and the sectoral approach. Figure 19 highlights these differences for energy-only emissions.

No two organizations include the same non-energy emission sources. Even when organizations ostensibly are including the same emission sources, such as emissions from wastes and cement production, they use different definitional categories for these emissions and their values are not readily comparable. Such definitional differences could lead to problems when comparing data between different agency reports.

Different sources of information for these other categories can lead to very different values. The differences for the US and Russia highlight this issue for natural gas flaring. EIA reports US natural gas flaring emissions to be 24.3 million metric tonnes CO_2 for 2005, whereas CDIAC reports emissions to be 6.5 million metric tonnes CO_2. For Russia, EIA reports no emissions from natural gas flaring, whereas CDIAC reports emissions to be 24.8 million metric tonnes CO_2. These values come close to cancelling out on the global scale, yet on a national basis they give quite different pictures.

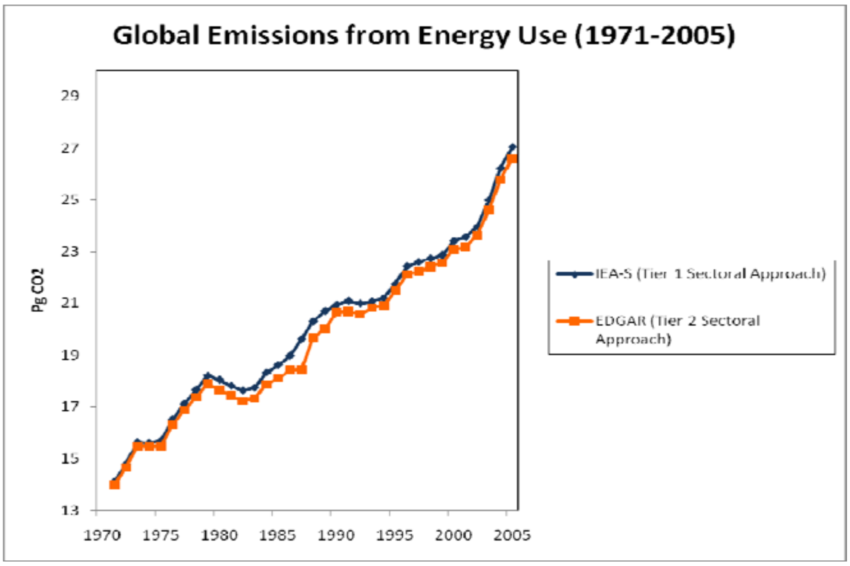


Figure 19: Global energy emissions as reported by IEA-S and EDGAR 1971-2005. Both organizations use the same energy data and both utilize a sectoral approach, but EDGAR uses technology-based emission factors whereas IEA-S uses average fuel emission factors.

The inclusion or omission of cement from emissions reports can have an impact on data trends, especially for countries that produce a large amount of cement, such as China. Considering the carbon intensity of China's energy use, Ausubel and Waggoner (2008) show how emissions reported by EIA (which does not include cement emissions) showed a slight decrease in China's carbon intensity from 1980 to 2004. However, CDIAC (which does include cement emissions) for the same time period showed no decrease in carbon intensity. This is due to the cement production process in China becoming more energy intensive and thus more carbon intensive. According to EIA data, China has been improving its carbon intensity, yet according to CDIAC, it has not. The inclusion or omission of traditional fuels in energy statistics can lead to significant trend differences in carbon intensity analyses. Considering the carbon intensity of energy for India, the differences are quite clear. IEA-S, using IEA data that includes traditional fuels, shows a lower absolute carbon intensity (as there is much energy being produced from biomass that has no corresponding emissions accounted for), but as the share of biomass decreases and the share of other fuels increase over time, carbon intensity steadily increases. For EIA data, which does not include traditional fuels, carbon intensity has stayed relatively constant since 1990 (as noted in Figure 4 in Section II the commercial fuel mix of India has stayed relatively stable even as commercial fuels make up a larger percentage of total energy use). Thus the data reported by these two institutions lead to contradictory decarbonization trends. EIA implies progress while IEA-S implies a worsening situation. However, neither agency is entirely comprehensive and there is a third possible trend. When energy usage from traditional biomass sources are included and carbon emissions from these sources are included (using an emission factor of 109.58 g CO_2/MJ), there is a steady decline in carbon intensity, highlighting the energy end-use improvements India has made. Figure 20 shows Indian carbon intensity from 1990-2006 for IEA-S and EIA, both as reported and with harmonized assumptions that incorporate IEA combustible renewable energy values and their estimated emissions. It is evident from these three contradictory interpretations of Indian carbon intensity that the choice of energy and emission sources has very important consequences for analyses. Researchers must exercise caution and should acknowledge multiple interpretations when performing carbon intensity analyses.

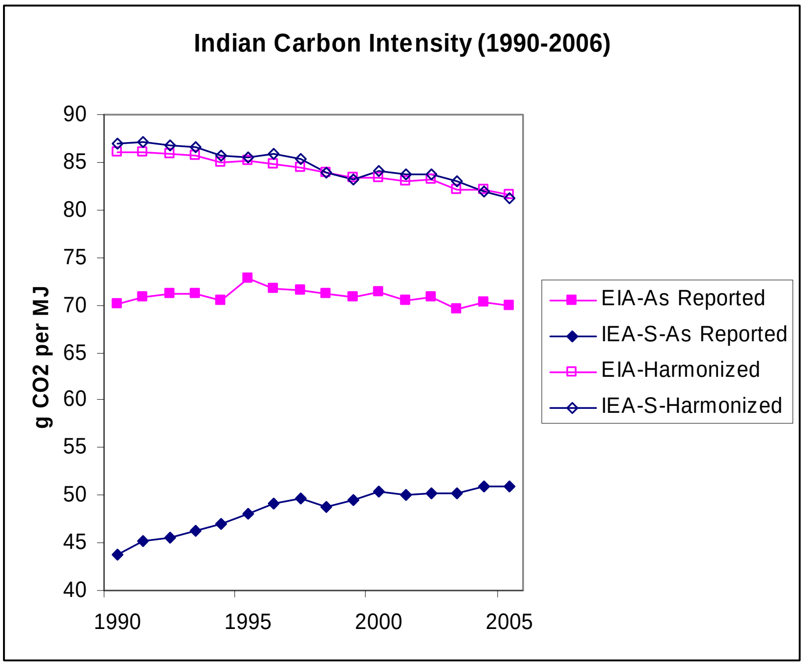


Figure 20: Indian carbon intensity, 1990-2006. IEA-S data utilize IEA energy statistics, which include traditional fuel consumption. EIA data utilize EIA energy statistics, which do not include traditional fuel consumption. Harmonized datasets include emissions from energy and from IEA-reported traditional fuel consumption. IEA-reported traditional fuel energy values were added to EIA data to make consistent with IEA energy data.

Emissions from land-use changes can significantly alter our understanding of contributions to global totals. Using EDGAR data for the year 2005, the Democratic Republic of Congo (DRC) is ranked 126th in terms of emissions from energy and industrial sectors, emitting just 2.6 Tg of CO_2, whereas the US emitted 5,974 Tg of CO_2 the same year. However, once emissions from land-use changes are included, DRC is ranked 10th, emitting a total of 1,367 Tg CO_2.Indeed, as EDGAR estimates that over 80% of emissions from Brazil and Indonesia as well as 40% from India arise from land-use changes, these emission sources must continue to be an important issue addressed at the national and international policy level.

Discrepancies are very rarely acknowledged, and yet could greatly affect climate modeling, national and international policies, and carbon markets. The inclusion of industrial and non-energy related factors can have a significant impact on our assessment of total anthropogenic impacts on the carbon cycle. As data from EDGAR suggest, industrial emissions include more sources of emissions than just from cement, though cement data are readily available and are therefore included in current policies and scientific models. Emissions from land-use changes are more difficult to measure, especially in tropical countries where many drastic changes are occurring. EDGAR notes an extremely high uncertainty value (roughly 100%) for these emissions, implying policies developed to regulate these emissions will have to address these large uncertainties (Olivier *et al.*, 1999).

If a carbon tax was implemented or credits apportioned to carbon-emitting activities, much consideration would need to be placed on what emissions would be taxed or given credits. The importance of this can be seen simply with the US cement manufacturing industry. If emissions from cement are included, this represents an additional .05 Pg of CO_2 per year that must be allocated. Depending on which source one uses for natural gas flaring, up to .02 Pg of CO_2 could potentially be regulated. By only addressing factors that are easily measurable, other important industrial sources of carbon dioxide may be ignored by policies and not adequately considered in scientific assessments. Considering emissions only from US energy use in 2005, EIA reports .25 Pg more CO_2 than CDIAC. Such discrepancies and differences in methods are much greater than is currently recognized in published literature and in policy debates, and they could influence future policies designed to regulate carbon markets.

4 Carbon Emission Data in the Context of Climate Change Negotiations

The carbon emission reports discussed here offer a unique opportunity for independent reviews of national emission inventories pursuant to UNFCCC protocols and subject to the IPCC reporting guidelines. As such they could have an important role at the 2009 Copenhagen Conference of the Parties (COP) and future negotiations that address national emission inventories and emission reduction goals.

The UNFCCC requires Parties to the convention (i.e. nations) to regularly report their emissions following the standard methods outlined by the IPCC. The IPCC describes three primary Tiers of detail for the accounting methods that nations may use in calculating emissions. Nations must use one of these three Sectoral methods, unless there is a dire lack of data. In the case of a lack of data, the Reference approach may be used. Tier 1 methodologies are the least specific, relying on average fuel-based emission factors applied similarly to all countries. Tier 2 methodologies utilize country-specific fuel emission factors, and include technology-specific emission factors where available. Tier 3 methodologies are the most specific, relying on data at the individual power plant or other individual emission source level. Of the carbon reporting organizations considered here, EDGAR utilizes a Tier 2 (country-specific technology-based emission factor) approach, whereas IEA-S and EIA utilize a Tier 1 (average fuel-based emission factor) approach. CDIAC and IEA-R utilize the Reference approach. As is noted above, the use of these different methodologies can result in significantly different reported emissions. Whereas the United States may not have significant differences between methods, other countries' results show a high sensitivity to choice of method. Additionally, the IPCC organizes emissions according to activity data, not according to individual fuels. Activity data is defined by the IPCC as "human activity resulting in emissions or removals taking place during a given period of time" (IPCC 2006). Data on energy use and metal production are examples of activity data. Instead of being broken down by fuel category, activity data are broken down according to end-use purposes. Thus energy use is decomposed into categories such as public electricity and heat production, domestic aviation, and rail transportation. Individual fuels are aggregated together based on their end-use purpose, and are not reported individually. In total, there are thirteen subcategories for energy-related emissions, nine of which are a result of direct domestic fuel combustion, two of which relate to fugitive emissions from fuels, and two of which are related to international bunker fuels. Of the reporting organizations considered here, only EDGAR replicates the IPCC emission categories. As such, it is the only organization that publishes data that are directly comparable to IPCC national emission inventories at a disaggregated level. On aggregated national and global levels, comparisons are possible, provided assumptions of system boundaries are consistent. The online database tool described in this work allows carbon emission reporting organizations' assumptions to be modified so as to be consistent with IPCC system boundaries, facilitating comparisons of national emission inventories.

Equivalent system boundaries will not rectify all sources of discrepancies, however. Nations, in their national emission inventory reporting to the IPCC, use different calorific values and emission factors than are used by carbon emission reporting organizations. Such differences are much harder to harmonize, given the different sources and different levels of detail in the original data sources.

The combination of these different assumptions described above can lead to significantly different results of national and global carbon emissions. If a global policy such as an emission cap and trade system is developed through UNFCCC negotiations, an assumption such as the accounting method used (i.e. Reference, Tier 1, Tier 2, and Tier 3) becomes extremely important for industrialized nations. With the monetization of emissions, nations would have financial incentives to use the accounting methods most advantageous for their particular situations. Or, a nation may legitimately revise previous years' data after employing a more specific accounting method, resulting in a situation where previous years' (monetized) emissions were over- or underreported. Having one standardized accounting method would obviate such concerns, yet data quality and collection capabilities are not equal among nations, including industrialized nations, making a standardized accounting method unfeasible in the near future. If developing countries are eventually monitored and given emission allocations in such a global regime, concerns about accounting methods will be all the more important. Given that we do not know the "true" quantity of carbon emissions released annually by individual nations, the consideration of data reported by independent carbon emission reporting organizations (with their different methodologies) facilitates carbon emission monitoring. The different methods employed by the independent carbon emission reporting organizations provide a more comprehensive glimpse into what actual emissions may be. Although certain disparate assumptions may be harmonized, other assumption differences provide a class of uncertainty that goes beyond the uncertainty ranges reported by nations. Improving the quality and consistency of data in independent carbon emission reporting organizations could facilitate the development of a more robust independent verification procedure for IPCC national emission inventories. In turn, if the IPCC also required emissions to be reported by fuel categories, and not only by activity data, more effective comparisons could be made between the data that are reported to the IPCC by nations fulfilling treaty obligations and the data that are regularly published and utilized in scientific arenas.

5 Unrecognized Uncertainties in Publications

A consequence of the multitude of methods used to calculate carbon dioxide emissions is that competing conclusions that can be made by the choice of one dataset over another. As the assumptions behind emission reports are often difficult to identify and distinguish, yet all organizations are generally considered credible sources, there is a great risk of researchers unintentionally using data that is not fully comprehensive or appropriate for their analyses. The use of an alternative dataset may or may not lead to starkly different conclusions, but at the very least would provide insight into the analysis uncertainty. Unfortunately, these uncertainties are often not presented fully.

There are many examples of studies using carbon dioxide reports for analysis, yet Raupach *et al.,* in 2007 has received considerable attention. In this article, recent emission data are given from EIA and CDIAC suggesting that recent CO_2 emissions trends exceed the highest extreme emission scenario of the IPCC SRES. Since being published, authors have referenced that trend reported by Raupach *et al.*, noting the added urgency and need for immediate drastic actions to reduce emissions (Caldeira and Wood 2008, Anderson and Bows 2008, Canadell and Raupach 2008, Joos and Spahni 2008, Howden *et al.,* 2007, Canadell *et al.,* 2007). However, analysis shows that once emission uncertainty and proper assumptions are accounted for, global emissions have not surpassed the highest IPCC emission scenarios. The analysis and conclusions of Raupach *et al.,* are flawed due to (i) not using the full range or marker scenarios of the IPCC emission scenarios, (ii) not incorporating all available sources of emissions data, (iii) combining raw data with standardized emission scenarios, (iv) improperly 'normalizing' EIA data, (v) using short-term time series to make claims about long-term trends. These analytical flaws will be addressed in turn below.

Raupach *et al.,* utilize a figure, reproduced in Figure 21, to highlight their point that emissions have exceeded IPCC scenarios. A first point of concern for Figure 18 and the statement is that Raupach *et al.,* does not include all of the IPCC emission scenarios in their analysis. In particular, Raupach *et al.,* shows the A1FI scenario (the fossil fuel-intensive scenario) as being the most extreme example. However, they exclude eight individual IPCC scenarios in their analysis that show higher emissions than A1FI in 2010 (A1-AIM, A1-ASF, A1-IMAGE, A1C-AIM, A1G-AIM, A2-AIM, B1-ASF, and B2-ASF). Furthermore, Raupach *et al.,* construct an average of the emission scenario families, ignoring the published IPCC marker scenarios, which further limits and lowers the range of the IPCC scenarios used in their analysis (van Vuuren and Riahi, 2008). Thus their figure does not give a comprehensive account of the IPCC scenarios; including the full scenario range would be appropriate if claims are made that world emissions have exceeded the highest IPCC scenario.

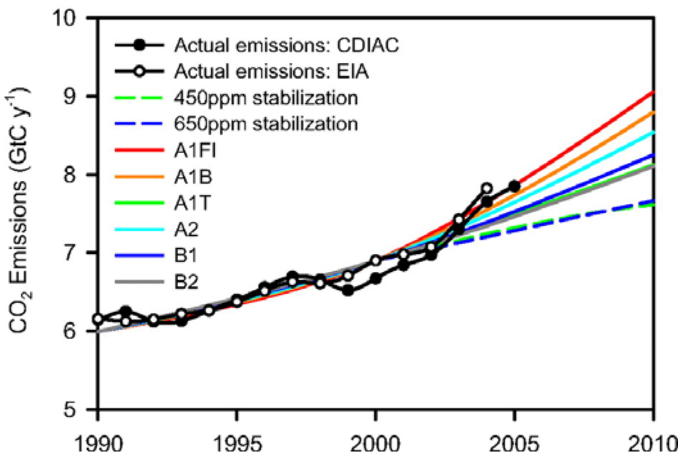


Figure 21: Raupach *et al.*, figure as published. Note how EIA emissions exceed the A1FI emissions scenario.

Raupach *et al.*, also only includes emissions data from EIA and CDIAC, the two organizations as noted in Section III that consistently report the highest emissions levels. By not including emissions from IEA-R, IEA-S, or EDGAR, they are excluding international agency estimates that follow IPCC protocols. The analysis of Raupach *et al.*, could be improved by including emissions from these data sources along with estimated emissions using average emission factors for BP energy data to observe most recent developments.

Also note that Raupach *et al.*, utilize standardized[12] emission scenarios that all have equivalent emissions for the years 1990 and 2000, yet the EIA and CDIAC data have not been similarly standardized and both are higher than the standardized value in 1990. As such these raw data should be compared with the emission scenarios using raw data. The standardized emissions scenarios mask the uncertainties inherent in the different modeling approaches to the SRES emission scenarios.

To account for EIA's lack of cement data, Raupach *et al.*, normalizes EIA average values to CDIAC data for the years 1990-1999. Data were normalized multiplying EIA data by a constant factor to make the ten-year average the same. However, considering emissions that resulted only from commercial energy sources, EIA was on average 1.5% lower than CDIAC for this ten-year period. From 2000-2006 EIA commercial energy emissions were on average 1% greater than those of CDIAC. Thus by normalizing mean values for the time period when EIA was reporting smaller emissions from commercial energy, the values from EIA from 2000-2006 are slightly exaggerated in Raupach *et al.*, Figure 21. Published average emissions (i.e. using inconsistent assumptions) differences between the two organizations went from 4% from 1990-1999 to 2.8% from 2000-2006. While an overestimation of 1-2% of EIA data may not critical, as EIA data is portrayed in Figure 21 as exceeding IPCC estimates, a more conservative (and likely more accurate) approach would have been to simply add CDIAC cement emissions to the EIA data.

[12] SRES emission scenarios were standardized by the IPCC to have equivalent emissions for1990 and 2000 to avoid addressing initial raw uncertainties in emissions considered by the SRES modeling teams.

Figure 22 displays the full range of the standardized IPCC SRES emission scenarios along with data from EIA, CDIAC, IEA-R, IEA-S, EDGAR, and estimates from BP energy data. Emission values for BP have been included using average fuel emission factors[13]. Natural gas flaring emissions in 2007 and 2008 were derived from the most recent natural gas production data from Cedigaz and BP. Cement production emissions from 2007 and 2008were estimated from the most recent USGS cement production statistics. Both IEA methods, EDGAR, and BP data show lower emissions than EIA and CDIAC. Note that all organizations' data, even CDIAC and EIA, fall within the range of the SRES emission scenarios, and that the most recent estimated emissions from BP in 2008 indicate a path within the emission scenarios.

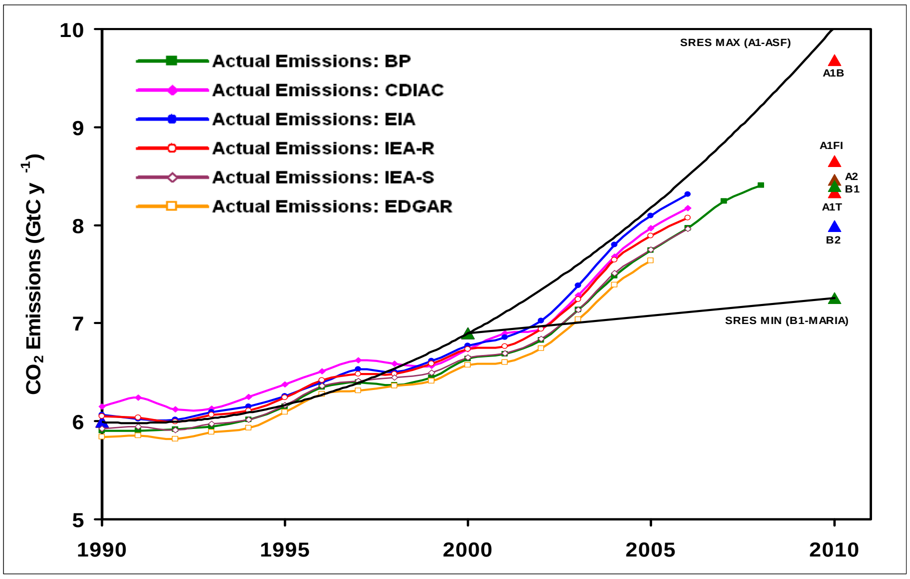


Figure 22: Global emissions from energy and cement sources compared with standardized IPCC SRES emission scenarios, 1990-2008. EDGAR data stops in2005. BP data is the only data source extending to 2008. All other data sources stop in 2006. Note how all six organizations report emissions within the most extreme IPCC emission scenarios. Triangles on right side of graph represent IPCC SRES marker scenario estimates for 2010.

Figure 23 shows how emissions from energy, cement production, and gas flaring for EIA, CDIAC, IEA-R, IEA-S, EDGAR, and estimated BP emissions compare with the full range of the raw IPCC emission scenarios. There is considerable variability in the emission scenarios baseline data for 1990 and 2000, much more than the variability in the published reports. All agency values clearly fall within the maximum and minimum IPCC raw emission scenarios.

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[13] Per analysis in Section II, NCV emission factor of 73.33 gCO2/MJ was used for Petroleum. GCV emission factors were used for coal (89.71 gCO2/MJ) and natural gas (50.24 gCO2/MJ). Emission factors are from IPCC.

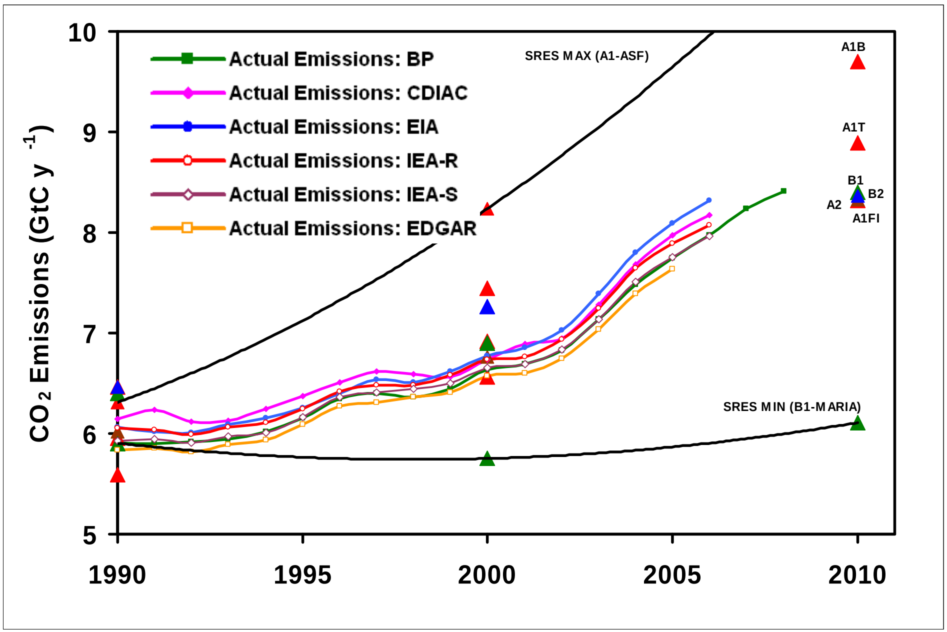

Figure 23: Global emissions from energy and cement sources compared with raw IPCC SRES emission scenarios, 1990-2008. EDGAR data stops in 2005. BP data is the only data source extending to 2008. All other data sources stop in 2006. Note how all six organizations report emissions within the most extreme IPCC emission scenarios. Triangles represent IPCC SRES marker scenario estimates for 2010.

It is important to point out that Raupach *et al.*, use short-term data to come to their conclusions. The period of 2000-2005 was a period where emission increases from fossil fuels were increasing. van Vuuren and Riahi (2008) note how short-term CO_2 developments reported by Raupach *et al.*, do not indicate a significant long-term trend reversal. Indeed, as the most current data from BP shows for the year 2008, energy usage and corresponding carbon emissions increased at a much slower rate. Global emissions by 2010 are on track to fall in the middle of the IPCC SRES scenarios, e.g. in between the B2 and A1T scenarios. There is no indication that emissions are exceeding the highest IPCC scenario projection[14].

Raupach *et al.*, also point to a trend reversal with regard to regional and global carbon intensities. Again, this claim relies on recent trends, ignoring longer-term patterns. Figure 24 shows world carbon intensity from 1971-2006, including BP estimates with average emission factors for 2007 and 2008. Following the convention of Raupach *et al.*,1990 serves as the base year for all organizations. CDIAC emission data are based on UN energy data. While there is an obvious increase from 2000-2006, latest BP data show that this increase may be leveling out. Other temporary increases can be seen in the early 1970s and the mid 1990s. However, it is still too early to tell whether or not there is a disruption in the long-term trend of decarbonization.

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[14] On a final note about the Raupach *et al.* published figure, emission scenario graphs are spline fits of calculations for certain selected years and do not represent exact trajectories of emissions. Thus temporarily exceeding a smoothed line does not necessarily mean long-term targets are in jeopardy.

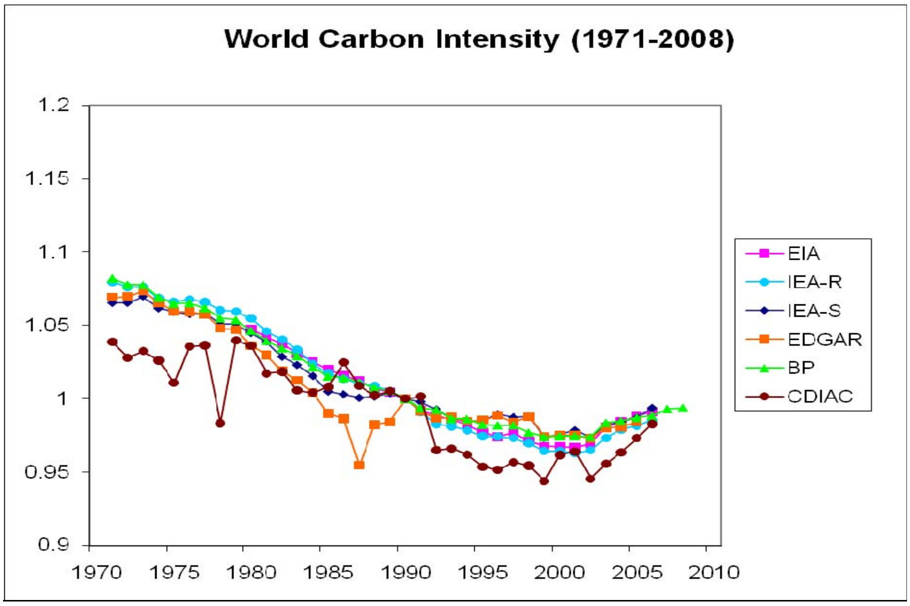

Figure 24: World Carbon intensity 1971-2008. Emissions from energy sources only divided by GDP-MER as reported by the World Development Indicators. EDGAR data stops in 2005. BP data is the only data source extending to 2008. All other data sources stop in 2006. 1990 is the reference year and equals 1 for all organizations.

The methods employed by Raupach *et al.*, to reach the conclusions that there has been a global trend reversal and that total global CO_2 emissions have exceeded the most extreme IPCC scenario are flawed. Such assumptions have led to faulty conclusions that not only undermine the validity of the IPCC SRES scenarios, but also minimize the uncertainty inherent in the development of the IPCC models. A broader perspective must be taken when assessing the degree to which the world is within the bounds of the IPCC emission scenarios by including full uncertainties inherent in the emission reports as well as full uncertainties inherent in the emission scenarios. The importance of using and comparing consistent data is of the utmost importance for legitimate scientific articles and the policy proposals that are based on those studies. However, as noted above, organizations use different calorific values and other assumptions that can lead to vastly different results. Often researchers and policymakers are unaware of methodological assumptions inherent in these reports. For these reasons, it is vital to have a tool that explicitly notes what assumptions lie behind data. Furthermore, as uncertainty between reports is unlikely to go away, it becomes essential to be able to quickly compare reported values among organizations.

6 Online Database Tool

Given the difficulty of identifying and rectifying discrepancies between agency methods and assumptions, researchers and policymakers often overlook these differences. The online database tool offers a temporary solution to certain hidden assumptions and data discrepancies by harmonizing disparate assumptions.

The database has multiple functions. First, the database displays different organizations' reported energy and carbon emission values side-by-side for select countries and for the global total. The database converts all reported energy and carbon dioxide emission quantities into consistent International System of Units (SI) values, allowing for direct comparison between reports. This allows researchers to compare the unmodified reports. Figure 25 shows a screenshot of an example output of the database.

Carbon Emissions (Harmonized Assumptions)

These data utilize the following harmonized assumptions:

Carbon Units	Tg Carbon Dioxide (Million Metric Tonnes)
Carbon Sources-Cement Production (from CDIAC)	Yes
Carbon Sources-Gas Flaring (from CDIAC and EIA)	Yes
Carbon Sources-Wastes (from IEA-Sectoral)	No
Carbon Sources-Combustible Renewables (from IEA	No

Row	Tg Carbon Dioxide (Million Metric Tonnes)	Source	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
115	Taiwan	IEA-S	123.0397	132.2268	141.8281	153.8561	162.4831	169.8722	177.7832	187.9558	199.4951	207.3398	223.718	231.6829	241.0685	255.5051	264.8946	271.1923
116	Thailand	BP	95.78288	106.6983	117.6717	134.294	149.7175	170.3777	189.1641	194.4068	173.2944	181.3626	181.0888	188.061	202.8835	213.8685	233.454	246.7728
117	Thailand	CDIAC	95.75565	116.0603	126.7459	142.459	158.1685	181.3351	202.5706	209.9178	186.2418	196.8211	201.4163	216.9462	230.4863	246.0089	267.97	270.9272
118	Thailand	EIA	92.88166	101.853	111.595	127.9463	142.8637	162.5036	189.5094	195.2383	173.7777	184.1168	174.5713	186.0782	202.955	222.0811	243.4121	261.552
119	Thailand	IEA-R	90.34187	98.81622	109.2197	124.3999	138.2696	160.8515	180.9716	184.1181	162.9831	173.605	174.7783	188.5102	203.2064	216.5515	238.5942	245.5456
120	Thailand	IEA-S	87.60187	96.80622	106.7897	122.1899	136.7896	158.6615	178.0516	180.8081	159.9231	170.165	170.5583	180.9602	195.2864	204.6115	224.8042	233.1656
121	Turkey	BP	149.7949	151.6624	166.3427	178.0433	170.1022	182.2711	201.5911	212.3778	219.6546	215.9297	236.6262	219.0444	223.113	234.4382	242.9226	263.1663
122	Turkey	CDIAC	141.4769	144.7859	146.5265	159.7882	156.4792	170.9281	188.1986	198.045	202.0722	199.8186	221.9372	200.1411	208.3348	220.4641	226.0524	247.9035
123	Turkey	EIA	141.6592	150.2714	152.3602	160.1869	154.7203	169.808	186.6691	200.3377	203.3978	198.8515	220.2375	199.4995	211.1718	224.0666	230.4199	252.5571
124	Turkey	IEA-R	150.3499	148.6615	153.0784	158.9702	158.1681	173.783	190.909	201.6495	204.0668	200.0727	221.4905	199.0769	208.4808	220.8131	229.1373	239.8071
125	Turkey	IEA-S	140.8099	144.6915	152.0984	158.2702	156.0181	171.953	189.219	198.5495	201.1968	198.2927	220.3905	199.2269	210.3808	221.2531	229.1873	240.1471
126	Ukraine	BP	709.5663	633.2645	571.4986	466.0212	390.0236	360.0481	322.4888	324.3677	311.6983	320.8546	319.6523	320.2723	315.9463	317.0346	329.5384	323.9724
127	Ukraine	CDIAC	Not Avail	Not Avail	600.141	514.6788	422.2065	428.7879	396.559	327.3047	313.6546	316.9196	304.2516	305.241	311.6245	337.1657	328.5872	327.1691
128	Ukraine	EIA	Not Avail	Not Avail	545.9595	504.3684	420.9402	427.7701	368.8365	346.6401	336.0174	330.4887	329.4774	321.5335	330.1502	361.8492	351.8841	355.9198
129	Ukraine	IEA-R	690.04	673.63	594.7286	515.2255	426.2699	424.549	368.2592	352.2195	336.345	333.8059	328.4557	328.5812	334.2582	359.434	344.7241	341.212
130	Ukraine	IEA-S	680.88	623.44	546.4186	472.5755	392.4799	380.609	335.5792	319.1495	300.195	296.8159	288.4357	293.4312	297.0082	319.604	307.4641	302.892
131	United Kingdom	BP	605.3896	611.4238	598.8968	590.1563	579.3595	574.023	591.3228	570.0387	570.8443	561.8886	574.6837	580.923	564.8696	577.5854	584.0476	580.8157
132	United Kingdom	CDIAC	569.2388	576.7948	565.8272	548.7179	547.4903	551.1364	566.4758	541.1141	545.4821	535.9876	546.0208	555.1123	538.8019	549.4617	554.3025	546.4825
133	United Kingdom	EIA	612.2938	619.2783	585.3087	590.7903	580.9009	568.3445	597.491	575.1142	570.2751	565.4802	567.5607	581.1014	569.5043	580.9762	588.1371	590.3699
134	United Kingdom	IEA-R	573.5752	584.227	570.1657	559.6245	559.1848	552.3063	567.0196	541.6457	544.803	543.6772	557.7092	560.3026	538.9195	550.4054	550.3948	541.6165
135	United Kingdom	IEA-S	564.6952	571.837	556.4157	544.8145	539.7648	537.2063	553.7496	530.1757	534.303	528.9572	532.8392	550.3626	533.5695	547.4454	547.2948	531.6565
136	United States of America	BP	5301.42	5256.892	5357.695	5479.67	5578.14	5641.364	5838.914	5924.346	5964.087	6043.874	6209.745	6086.929	6132.12	6183.81	6313.748	6335.839
137	United States of America	CDIAC	4798.09	4812.843	4829.275	5128.191	5201.103	5201.359	5305.909	5441.824	5392.101	5467.409	5646.959	5589.461	5648.114	5636.365	5730.912	5777.135
138	United States of America	EIA	5064.039	5015.767	5114.856	5226.535	5306.549	5362.999	5551.773	5633.667	5662.277	5726.006	5904.983	5807.409	5869.285	5924.743	6018.626	6044.574
139	United States of America	IEA-R	4884.907	4872.58	4942.275	5095.023	5172.616	5171.615	5321.445	5456.368	5472.161	5560.038	5740.786	5680.477	5738.845	5739.208	5846.107	5891.523
140	United States of America	IEA-S	4875.917	4839.09	4904.905	5057.563	5131.546	5134.795	5318.645	5462.808	5505.031	5546.098	5712.876	5641.877	5670.475	5732.148	5817.557	5846.213
141	WORLD Total	BP	22516.05	22510.95	22566.33	22654.29	22933.17	23445.07	24185.51	24394.66	24283.75	24588.51	25310.07	25503.49	26025.05	27170.22	28491.75	29446.18
142	WORLD Total	CDIAC	22528	22861.21	22432.22	22454.2	22886.84	23352.48	23862.14	24254.45	24137.13	24063.78	24676.07	25262.72	25457.01	26696.29	28133.55	29204.17
143	WORLD Total	EIA	22226.75	22061.44	22033.88	22318.33	22544.64	22913.82	23446.62	23938.66	23835.91	24245.65	24805.78	25108.57	25734.48	27068.33	28581.2	29657.59
144	WORLD Total	IEA-R	22183.97	22116.43	21967.61	22224.38	22380.61	22879.03	23518.79	23743.25	23756.5	24133.75	24676.9	24771.53	25423.22	26552.16	28016.69	28906.36
145	WORLD Total	IEA-S	21706.88	21779.05	21644.3	21886.08	22034.07	22585.62	23321.83	23492.42	23629.12	23808.63	24380.42	24522.3	25057.98	26162.4	27511.29	28410.45
146	WORLD Total	EDGAR	21392.75	21442.94	21327.66	21590.94	21741.62	22321.46	22998.38	23134.63	23313.34	23493.77	24079.94	24194.45	24714.19	25796.18	27084.18	27984.05

Introduction | Assumptions | Output-Primary Energy | Output-Carbon | Output-Energy Intensity | Output-Carbon Intensity | Unadjusted-Energy

Figure 25: Screenshot of carbon emissions output tab in online database.

The second major function of the database is the ability to select consistent assumptions to be applied across all agency data. This modifies reported data to provide an impression of discrepancies resulting from raw data collection methods. For energy reports, assumptions that can be altered include: primary energy equivalences to be applied to hydroelectric, nuclear, and renewable sources; the inclusion of traditional (non-commercial) biomass consumption (from the UN or from IEA); and the inclusion of modern renewable energy consumption (as reported by IEA). For carbon dioxide emission reports, assumptions that can be altered or included are: emissions from cement sources (taken from CDIAC); emissions from natural gas flaring (taken from EIA, CDIAC, and EDGAR); emissions from traditional biomass consumption (taken from IEA or UN energy data); emissions from the combustion of municipal wastes (taken from IEA); and emissions from various types of land-uses (taken from EDGAR and CDIAC). Discrepancies from differences in physical units and fossil fuel calorific values are currently not addressed by the online database. Figure 26 shows a screenshot of the options available for selecting assumptions for energy and carbon reports.

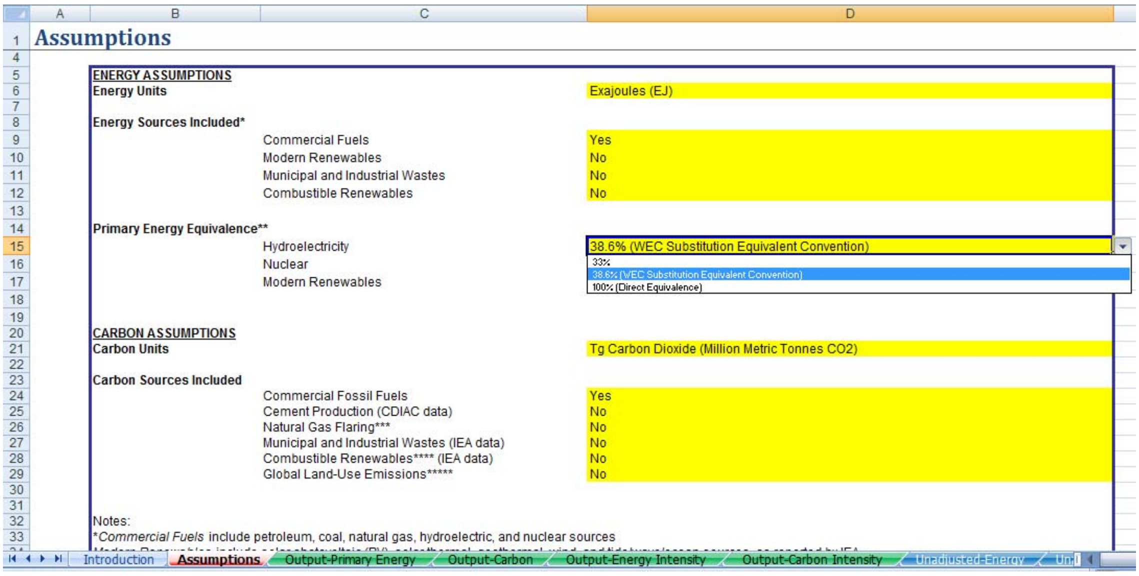

Figure 26: Screenshot of assumptions tab in online database.

The third major function of this database is to display energy intensities (energy consumed per unit of GDP) and carbon intensities (carbon emitted per unit of energy consumption) for the various combinations of energy and carbon emission assumptions. Thus one may see the variety of absolute values and trends that are possible depending on which assumptions are selected. Such a feature is meant to highlight the importance of exercising caution when analyzing reports of energy usage and emissions.

This tool serves many purposes for researchers and policymakers. By providing all agency reports side-by-side in consistent units, researchers will have a better understanding of the uncertainties between reports, not only within reports. Furthermore, by being able to change the assumptions of the data, researchers may readily respond to other published articles with data that has used the same assumptions. Additionally, researchers may also use the database to showcase the variety of interpretations that are possible using different assumptions to contradict or uphold previous conclusions.

Organizations revise previous years' data with each new report, with higher degrees of accuracy, and thus it becomes crucial to have the most recent reports, even when analyzing historic data (Marland *et al.*, 2009). The database is updated with each new agency report and can be found at the following link: http://www.iiasa.ac.at/Research/TNT/WEB/Publications/Energy_Carbon_DataBase/.

7 Recommendations

While the database tool described in Section V may readily rectify certain misinterpretations of data and lead to improved consistency and better reporting of discrepancies in energy and carbon emission reports, it should only be seen as a temporary solution to the current existing disparities among reporting organizations' data. Further action must be taken by both reporting organizations and researchers to ensure that data are not used inappropriately for political, economic, or scientific purposes.

To ensure more consistent reporting in the future, reporting organizations should use a consistent reporting format with consistent fuel categories. Currently, organizations utilize different subcategories for liquid and solid fuels, making sector-by-sector comparisons difficult. Organizations should also ensure that they include identical factors in energy and carbon reports. Primary energy equivalences for nuclear, hydropower, and renewable sources should also be consistent. The deceptive similarities of IEA and EIA aggregated world primary energy consumption data are a manifestation of these inconsistencies.

Consensus among organizations should also be reached regarding choices of heating values for energy reports and corresponding carbon emission factors for the carbon reports. Choosing consistent heating values and emission factors would avoid the current problem of organizations reporting identical values of petroleum barrel consumption but different accompanying emissions.

In addition, organizations should explicitly state assumptions and methods they are using to obtain and process their data. While organizations do report certain assumptions, often these different assumptions are contained in separate documents or are otherwise difficult to discern. Having greater clarity in the methodological assumptions employed by each agency would improve researchers' abilities to evaluate data.

Organizations should also make an effort to report uncertainties inherent in data. While much data may come from national reports that do not report uncertainties, publishing data that may have high unrecognized uncertainties could lead to wide irregularities in data that may be mistaken for trend changes.
For researchers and policymakers utilizing these data, multiple data sources should be consulted and included in analyses to give a comprehensive view of discrepancies. Until there is scientific consensus on the most appropriate calculation methods (unlikely in the near future given national data reliability concerns in many countries), all data sources considered here can legitimately contribute to analyses of data discrepancies.

Researchers should also be explicit about which assumptions are inherent in the data sources they are using. While this may often already be performed when discussing carbon emissions from energy and certain industry sources, other factors not addressed are the underlying heating values and emission factors used, which can be a significant determinant of reported emissions.
Researchers utilizing the database tool will be able to take advantage of side-by-side comparisons of the various data sources along with an explanation of the assumptions going into each unmodified report.

8 Conclusions

Global and national policies on limiting carbon dioxide emissions will continue to develop as more data accumulate. While emissions from energy use are only one part of the global carbon cycle, they are the part that we know to the greatest certainty (according to the analysis in Section III it is +/- 6%) and thus also the part most susceptible to being affected by new policies. We must strive to ensure that our sources of data driving new policies are as robust as possible and that uncertainties regarding these data are well known. Organizations currently report statistics using different methods and assumptions. There currently is no scientific consensus on which approach is the best, thus all of these approaches should be considered with their uncertainties and methods clearly stated. This paper has outlined the major assumptions and methods of the prominent energy and carbon reporting organizations along with a discussion of the potential for misinterpreting data using one widely cited reference as an example. The online database tool described here is designed to facilitate an acceptable comparison between reporting organizations' data. It also highlights the various and contradictory conclusions that may be achieved depending on which assumptions and data sources are used. Given the potential severe climatic consequences and massive potential economic implications of efforts to reduce carbon dioxide emissions, we should be vigilant and diligent in ensuring we know the full discrepancies of published emission data.

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Appendix A Commonly Used Abbreviations

BP	British Petroleum
BTU	British Thermal Unit
C	Carbon
CDIAC	Carbon Dioxide Information Analysis Center
CO_2	Carbon Dioxide
CRF	Common Reporting Format
DOE	U.S. Department of Energy
EDGAR	Emissions Database for Global Atmospheric Research
EF	Emission Factor
EIA	US Energy Information Administration
EJ	Exajoules (10^{18} J)
GCV	Gross Calorific Value (= Higher Heating Value, HHV)
Gg	Gigagrams (Thousand Metric Tonnes)
IEA	International Energy Agency
IEA-R	IEA Reference Approach
IEA-S	IEA Sectoral Approach
IPCC	Intergovernmental Panel on Climate Change
ktoe	Thousand tonnes oil equivalent
Mtoe	Million tonnes oil equivalent
NCV	Net Calorific Value (= Lower Heating Value, LHV)
OECD	Organisation for Economic Co-operation and Development
Pg	Petagrams (Billion Metric Tonnes)
Quad	Quadrillion BTU (10^{15} BTU)
SRES	IPCC Special Report on Emission Scenarios
Tce	Tonnes coal equivalent
Tg	Teragrams (Million Metric Tonnes)
TJ	Terajoules (10^{12} J)
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey

Appendix B Energy and Carbon Dioxide Approximate Equivalents

Energy	
5 EJ	Annual Energy Use in Australia
10 EJ	Annual Energy Use in France
20 EJ	Annual Energy Use in Japan
70 EJ	Annual Energy Use in China
100 EJ	Annual Energy Use in the USA
500 EJ	Annual Global Energy Use
Carbon	
0.5 Pg CO_2	Annual CO_2 Emissions in the United Kingdom
1.0 Pg CO_2	Annual CO_2 Emissions in Germany
1.5 Pg CO_2	Annual CO_2 Emissions in Japan
6.0 Pg CO_2	Annual CO_2 Emissions in the USA
7.0 Pg CO_2	Annual CO_2 Emissions in China
30.0 Pg CO_2	Annual Global CO_2 Emissions