Energy and CO_2 emission data uncertainties

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There can be substantial differences in the estimates of global and national primary energy statistics and CO_2 emission inventories that are published annually by organizations that are independent of the International Panel on Climate Change. This review analyzes the sources of discrepancies from reports published by international organizations, government agencies and private companies that are commonly referenced in analyses of primary energy statistics and CO_2 emissions. National and global estimates of CO_2 emissions from fossil fuel combustion are based directly on estimates of primary energy use, which varied by 9.2% (43 EJ) globally for the year 2007. The resulting CO_2 emissions from fossil fuel combustion varied by 2.7% (786 $MtCO_2$) for the same year. Depending on which data sources are used, national trends in energy intensity and carbon intensity may appear to be increasing or decreasing. This review identifies and compares the assumptions of the major energy statistics and CO_2 emissions estimates to facilitate more comprehensive and consistent comparisons and analyses of the most recent published data.

Every year, nations collect and publish information related to their domestic energy use and their associated GHG emissions. This information is also submitted to international organizations, such as the UN, the International Energy Agency (IEA), and the International Panel on Climate Change (IPCC), which utilize these data to report estimates of national and global energy usage and GHG emissions. Private organizations, such as BP, along with national governmental organizations, such as the US Department of Energy, also collect and publish international energy and emission data. Recently, GHG emission inventories have become important in domestic and international policy settings owing to IPCC negotiations, and many states have enacted policies designed to reduce national energy usage and GHG emissions, since it is usually the main GHG contributor and statistics from this sector are readily available with a comparatively low level of uncertainty [1]. Non-IPCC reports provide an opportunity for independent verification of the data considered in climate negotiations and climate projections. However, the methods and reported data from these sources differ in important ways from IPCC standards as well as among different datasets. These differences are often not acknowledged; however, assuming that the data reported are fungible could lead to misleading comparisons of energy use as well as contradictory results between datasets. These unmentioned uncertainties have the potential to undermine policy goals and scientific study conclusions if uncertainties and differences are not adequately taken into consideration. This review will identify and analyze differences in energy and carbon reports to improve the use of energy and emissions data.

Methods

In this review, data were collected from four prominent international energy statistics datasets (Table 1), referred to throughout this article as BP (2010) [2], US Energy Information Administration (EIA) (2010) [101], IEA (2010) [3,4] and UN (2010) [5,6]. For carbon emission inventories, five datasets that make use of these energy reports are considered (Table 2), referred to throughout this review as EIA (2010) [101], the Carbon Dioxide Information Analysis Center

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Table 1. Overview of energy-reporting organizations and publications.

Organization	Dataset code	Publications	Time period	Refs
BP	BP (2010)	BP Statistical Review of World Energy	1965–2009	[2]
International Energy Agency	IEA (2010)	Energy Balances of Non-OECD Countries Energy Balances of OECD Countries	1971–2007 1960–2008	[3,4]
UN	UN (2010)	Energy Statistics Yearbook Energy Statistics Database	1950–2007	[5,6]
US Energy Information Administration	EIA (2010)	International Energy Statistics	1980–2008	[101]

OECD: Organization for Economic Co-operation and Development.

(CDIAC) (2010) [7,8], the emissions database for global atmospheric research system (EDGAR) (2010) [102], IEA-R and IEA-S [9]. These reports were selected owing to their frequent use in academic and policy studies. Data were not altered except for unit conversions.

The energy data statistics considered here refer to **primary energy** consumption. Primary energy is the energy embodied in fossil fuels and biomass before undergoing manmade transformations, such as to electricity [10]. Primary energy 'consumption,' (and the IEA equivalent total primary energy supply), is determined using the concept of **apparent consumption**.

CO_2 emissions include emissions from fuel combustion (also termed energy-related emissions), as well as emissions from the flaring of natural gas, cement production and land-use change.

Data were collected from the most recent published reports and consolidated into a harmonization database [103]. The publicly available harmonization database provides the capability of utilizing consistent conversion assumptions across datasets to facilitate meaningful comparisons. Assumptions that may be altered relate to **primary energy equivalences**, boundary conditions, data sources for nonfuel combustion sources of carbon emissions, and units.

Comparability challenges

Comparisons among organizations are complicated by differences in the energy and carbon emission categories published. Considering fossil fuels, UN (2010) reports aggregated fossil fuel energy consumption in terms of solids, liquids and gases, whereas BP (2010), EIA (2010), and IEA (2010) aggregate fossil fuels in terms of coal, petroleum and natural gas. For this review, the solids, liquids and gases of UN (2010) are considered equivalent to the coal, petroleum and natural gas categories, respectively, of the other organizations. This categorization scheme means that some solid petroleum-based products (i.e., shale oil) and gas-based liquids (i.e., natural gas liquids) are categorized differently. While these definitional differences do not necessarily lead to differences between total national and global data, the differences in fuel disaggregation complicate direct comparisons of data and affect carbon emission calculations.

Organizations also tabulate and organize published data in different fuel categories. IEA (2010) publishes emissions according to the specific fuel category (e.g., coking coal, natural gas liquids and petroleum coke) and in addition gives a grand total. EIA (2010) aggregates emissions into coal, petroleum, and natural

Table 2. Overview of carbon emission-reporting organizations and publications.

Organization	Dataset code	Publications	Energy data used	Time period	Refs
Carbon Dioxide Information Analysis Center	CDIAC (2010)	Global, Regional, and National Fossil-Fuel CO_2 Emissions Carbon Flux to the Atmosphere from Land-Use Changes	UN (2010)	1751–2007 1850–2005	[7,8]
European Commission, Joint Research Centre/Netherlands Environmental Assessment Agency	EDGAR (2010)	Emissions Database for Global Atmospheric Research	IEA (2010)	1970–2005	[102]
International Energy Agency	IEA-R (2010)	CO_2 Emissions from Fuel Combustion-Reference Approach	IEA (2010)	1960–2007	[9]
International Energy Agency	IEA-S (2010)	CO_2 Emissions from Fuel Combustion-Sectoral Approach	IEA (2010)	1960–2007	[9]
US Energy Information Administration	EIA (2010)	International Energy Statistics	EIA (2010)	1980–2008	[101]

EDGAR: Emissions database for global atmospheric research.

gas categories. CDIAC (2010), utilizing UN (2010) data, reports aggregated energy emissions into solids, liquids and gases. This review equates solids, liquids and gases categories with coal, petroleum and natural gas categories, while acknowledging the discrepancies discussed with energy statistics above. EDGAR (2010) aggregates emissions according to the IPCC sector emission categories, which differentiate emissions according to their source category (such as transportation or energy production) and not by their fuel-type, making fuel-specific comparisons between EDGAR (2010) and the other organizations nearly impossible [11].

Differences in energy data statistics

Despite methodological differences among reporting organizations, unadjusted aggregate global totals of primary energy use do not always appear to differ greatly (Figure 1A). Unadjusted EIA (2010) and IEA (2010) estimates of total global primary energy use in 2007 differ by less than 1%, or 5 EJ. UN (2010) and BP (2010) values are 5% (26 EJ) and 9% (43 EJ) lower, respectively, than EIA (2010). However, the similarities between data sources should not be taken at face value. Real differences in global and national data between organizations are hidden beneath the aggregated published datasets. Using consistent assumptions across agencies highlights the discrepancies in reported primary energy use (Figure 1B). Data have been harmonized by considering energy only from coal, petroleum and natural gas, as well as electricity from hydroelectric and nuclear sources using a consistent primary energy equivalent efficiency [12]. IEA (2010) values preharmonization were 8% (38 EJ) greater than BP (2010) data; however, postharmonization, the two datasets' total values are nearly identical. These values are 2% (7 EJ) and 6% (28 EJ) less than global primary energy consumption of UN (2010) and EIA (2010), respectively. BP (2010) and IEA (2010) aggregated similarities mask further fuel-specific differences: IEA (2010) reports petroleum consumption that is 5 EJ greater than BP (2010), yet this is offset by BP (2010) reporting 5 EJ more natural gas consumption than IEA (2010). The apparent similarities and revealed discrepancies among datasets are due to the different assumptions employed by each reporting organization. Important assumption differences include differences in raw data inputs, boundary conditions, fossil fuel calorific contents and electricity conversion factors.

The raw data used to compile energy use data may often be different among energy statistics reports [13–15,104]. UN (2010) and IEA (2010) send annual surveys to member states as the primary method of collecting data, with the IEA using UN survey results for non-IEA member nations. By contrast, BP (2010) and EIA (2010) rely primarily on national reports and information from regional agencies. Differences in surveys and in collection sources can lead to disparities in the values of reported physical quantities of fuels (such as tonnes of coal or m^3 of natural gas). For example, although BP and the EIA use similar methods to obtain natural gas consumption data, EIA (2010) reports 2008 world natural gas consumption to be 119 billion m^3, or 4% greater than BP (2010). Since the EIA began collecting data in 1980, the differences between these two organizations' values have been as high as 8%. EIA (2010) estimates total crude petroleum production (in barrels) to be 1.2% greater than BP (2010) crude production in 2007. Differences between UN (2010)

Key terms

Primary energy: Energy embodied in natural resources prior to undergoing any human-made conversions or transformations. Examples include coal, crude oil, sunlight, wind, running rivers, vegetation and uranium.

Apparent consumption: Equal to: production + imports - exports - bunkers ± stock changes. A top-down energy accounting 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.

Primary energy equivalence: For fuels that produce electricity and have no obvious calorific content (e.g., nuclear, hydroelectric, wind and solar), as there is with fossil fuels and biomass, a primary energy equivalence must be assigned to each unit of electric output. Substitution equivalence and direct equivalence are two methods of assigning primary energy equivalences.

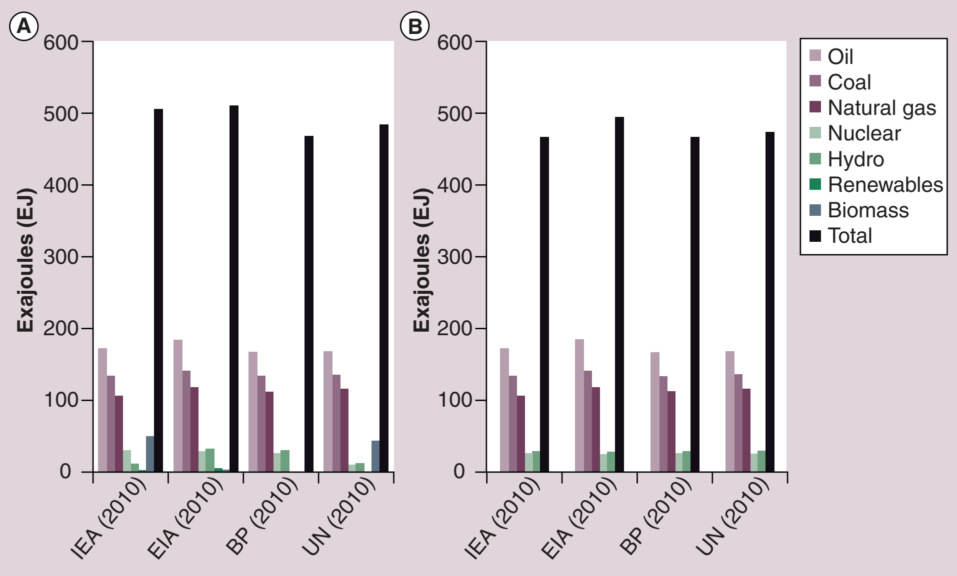

Figure 1. 2005 global primary energy use. (A) As reported and, **(B)** with harmonized assumptions, including only commercial energy and utilizing a primary energy equivalence of 38.6%.
EIA: US Energy Information Administration; IEA: International Energy Agency.

Key terms

Calorific value (heat content): The energy released as heat when a compound undergoes complete combustion with oxygen under standard conditions. Gross calorific value assumes all vapor produced during the combustion process is fully condensed, whereas net calorific value assumes the water leaves with the combustion products without being fully condensed.

Substitution equivalence method: The primary energy equivalence of electricity generation represents the amount of energy that would be necessary to generate an identical amount of electricity in conventional thermal power plants. The primary energy equivalent is calculated using an average generating efficiency of these plants, approximately 30–40%, leading to primary energy values approximately three-times as large as direct equivalence values.

Direct equivalence (physical energy content) method: The primary energy equivalence of electricity generation represents the physical energy content of the electricity generated in the plant, which amounts to assuming an efficiency of 100%.

Energy intensity: A macroeconomic measure of the energy required per unit of economic output. It is commonly expressed as units of energy per unit of gross domestic product.

and IEA (2010) crude production data (in tonnes, since they do not report barrels) are less than 1% in 2007. Estimates of 2007 coal production (in tonnes) are within 0.5% for all datasets.

To convert estimates of physical quantities of fuels consumed (such as tonnes of coal or m^3 of natural gas) into energy values (in joules, for example), reporting organizations utilize a conversion factor termed a **calorific value**. The calorific value of a fuel is the total amount of energy released during combustion for a specified unit of mass (or volume) of a particular product derived from coal, natural gas or petroleum. Reporting organizations calculate energy consumption based on the gross calorific value (GCV) or the net calorific value (NCV) of fuels. In general, EIA (2010) uses GCV, the UN (2010) and IEA (2010) use NCV, and BP (2010) uses a combination of the two. Calorific values utilized by reporting organizations are country- and region-specific. However, the energy content of a fuel, such as coal, is often not uniform within any particular country; different coal deposits have coal resources of varying qualities, for example. Country-specific calorific values often differ among energy statistics reports, which has the effect of creating apparent differences in energy consumption in countries where the reported value of physical quantities of fuels consumed are identical. In 2007, differences in coal production (in tonnes) between EIA (2010), which utilizes GCV, and BP (2010), which utilizes NCV, is less than 0.3%; however, the reported energy differences for this value differ by more than 7.4%, or 10 EJ. Considering two organizations that both utilize NCV, there can also be differences: IEA (2010) 2007 petroleum consumption is approximately 2.5% (4 EJ) greater than that of UN (2010), even though UN (2010) reports its physical units to be 0.7% greater.

Table 3. Summary of primary energy equivalence assumptions for 2007 data.

	IEA (2010)†	EIA (2010)‡	BP (2010)§	UN (2010)¶
Nuclear (%)	33.0	28.0–35.1	38.6	100 (Direct)#
Hydro (%)	100 (Direct)	34.5	38.6	100 (Direct)
Renewables (%)	100 (Direct)	34.4	N/A	100 (Direct)
Geothermal (%)	10.0	16.2	N/A	100 (Direct)††

N/A: Not applicable.
†Data from [3,4].
‡Data from [101].
§Data from [2].
¶Data from [5,6].
#UN claims a nuclear efficiency of 33% (UN, 2008). However, calculations reveal use of 100% efficiency.
††UN claims a geothermal efficiency of 10% (UN, 2008). However, calculations reveal use of 100% efficiency.

Further conversion differences are seen among energy statistics when electricity generation from sources in which there is no obvious primary energy content (e.g., nuclear, hydroelectric and modern renewables), must be converted into a primary energy value. Datasets utilize region- and country-specific conversion factors termed the primary energy equivalence of electricity for this transformation. There are two competing methods for developing the primary energy equivalence: the **substitution equivalent method** and the **direct equivalence method**. The energy reported from electricity using the substitution equivalent method, which assumes these sources to have efficiencies comparable to an average fossil power plant (30–40%), can be three-times higher than the energy reported using the direct equivalence method, which assumes 100% energy-to-electricity conversion. All of the energy statistics reports calculate the primary energy equivalence of electricity differently, which can lead to significant differences in reported energy consumption **(Table 3)**. For example, in 2007, UN (2010) reported 168 TWh more (5.6%) of global hydroelectric generation than EIA (2010), yet the EIA (2010) energy value, which utilizes the substitution equivalent method, was 2.74-times (19.9 EJ) greater than the UN (2010) energy value, which utilizes the direct equivalence method. Similarly, IEA (2010), utilizing a substitution equivalent method, reports primary energy from global nuclear electricity generation in 2007 to be 3.1-times (20.1 EJ) greater than UN (2010), despite a 1.5% (40 TWh) difference in generation.

Beyond conversion differences, energy statistics can differ on national and global levels owing to boundary conditions related to what sources of energy are included. There is also considerable uncertainty over the nonenergy use of fossil fuels, particularly for petroleum feedstocks in the chemical industry [16,17]. Differences in system boundaries are most apparent with the inclusion or omission of international bunker fuels, modern renewable energy sources, and energy from biomass and wastes. According to IEA (2010), in 2007, nearly 9% of total global petroleum consumption was from bunker fuels, consumed in international ports, airports or during international transport. EIA (2010) and BP (2010) include bunker fuels in individual national energy consumption totals as well as in aggregated global energy consumption totals. IEA (2010) includes bunker fuels in aggregated global energy consumption totals, but does not attribute any bunker fuel consumption to a particular nation. UN (2010) does report bunker fuel consumption on a national and global level, but these data are reported in a separate category that does not contribute to total energy consumption values. Owing to this, for countries with high traffic international ports, such as Singapore and The Netherlands, EIA (2010) and BP (2010) report much higher petroleum consumption values than IEA (2010) and UN (2010). For 2007, EIA (2010) reports petroleum consumption values for The Netherlands that are 31% (0.5 EJ) greater than UN (2010). Estimates of bunker fuels can also vary greatly. For the USA in 2007, bunker fuel estimates ranged from 1.3 EJ (IEA) to 1.9 EJ (UN).

Although modern renewable energy sources (e.g., solar photovoltaics, wind energy, geothermal and tidal power) comprise less than 1% of current total global primary energy use, their installed capacity has been rapidly increasing and could play a larger role in the future energy mix. IEA (2010), EIA (2010), and UN (2010) report electricity generated (in multiples of watt-hours and associated primary energy equivalent) from these sources, in addition to heat generated from geothermal plants, whereas BP only includes installed capacity from these sources.

All organizations report consumption of biomass fuels and wastes to some degree, yet there is great variation in where these values are counted and what is included in these categories. All organizations include liquid biofuels (such as corn- or sugar-based ethanol) in their global and national totals of energy use, but they are included in different categories. IEA (2010) accounts for these fuels in its 'Combustible Renewables and Wastes' category and EIA (2010) accounts for these fuels in its 'Wood and Wastes' category [3,101]. By contrast, UN (2010) and BP (2010) add biofuels to their 'Liquids' and 'Oil' categories, respectively, thus it is often in the same category as petroleum. In 2007, UN (2010) and IEA (2010) reported global biofuels consumption to be approximately 1.5 EJ, approximately 1% of global petroleum consumption. Other than biofuels, EIA (2010) only includes energy from the Wood and Wastes category if it produces electricity.

Only UN (2010) and IEA (2010) provide data for traditional, noncommercial sources of biomass energy, termed 'traditional fuels' for this review. UN (2010) defines these traditional fuels as being composed of fuelwood, bagasse, charcoal, animal wastes, vegetal wastes, municipal wastes, industrial wastes and other wastes. IEA (2010) refers to these energy sources as 'combustible renewables and wastes', and are categorized as biogas, liquid biomass, industrial waste, municipal waste and solid biomass. For both organizations, only the amounts specifically used for energy purposes are included in energy statistics. As noted above, IEA (2010) combustible renewables liquid biomass category includes biofuels (e.g., biodiesel and ethanol produced from biomass), yet UN (2010) considers these in its 'Alcohol' and 'Biodiesel' sub-categories of its 'Liquids' category. Similarly, biogas, production of which UN (2010) reports as 0.5 EJ, or 0.4% of natural gas production in 2007, is treated in the 'Gases' category of UN (2010) and the 'Combustible Renewables' category of IEA (2010). Estimates of traditional fuels represent a significant percentage of total energy consumption reported by IEA (2010) and UN (2010) in 2007, (10 and 9%, respectively), and there are considerable differences between values reported by these organizations (Figure 2).

Energy intensity

Energy trend analyses, such as the **energy intensity** of the economy can be affected by the choice of the dataset. Although there may be exceptions and there is a high dependency on the level of development, as nations develop and transition from manufacturing economies to service-based economies, their energy intensity of the economy decreases [18,19]. Including different factors such as traditional biomass can severely alter trends in energy intensity, especially for developing nations, since

Figure 2. Global primary energy supply of traditional fuels and wastes from 1971–2007 as reported by IEA (2010) in the 'Combustible Renewables and Wastes' category [3,4] and UN (2010) in the 'Traditional Fuels' category [5,6].

IEA: International Energy Agency.

they replace fuelwood consumption with more modern, cleaner fuels, such as natural gas [20]. For example, depending on which data source is used, Indonesian data shows a net increase or a net decrease in energy intensity for the period 1980–2007 (Figure 3). Using IEA (2010) data that includes traditional fuels, the energy intensity of Indonesia has decreased by approximately 16% over the past three decades. According to EIA (2010), which does not report traditional fuel use, energy intensity increased by nearly 6%. Assessments of the 'progress' a country is making can be greatly affected by the choice of datasets, and conflicting narratives can be constructed based upon the results of these analyses.

Differences in carbon emission data statistics

CO_2 emission inventories from fuel combustion are calculated directly from reported energy data statistics. However, even sources citing the same energy data source provide different estimates of the resulting GHG emissions. Understanding differences in energy statistics is imperative to understanding differences in CO_2 emission inventory analyses.

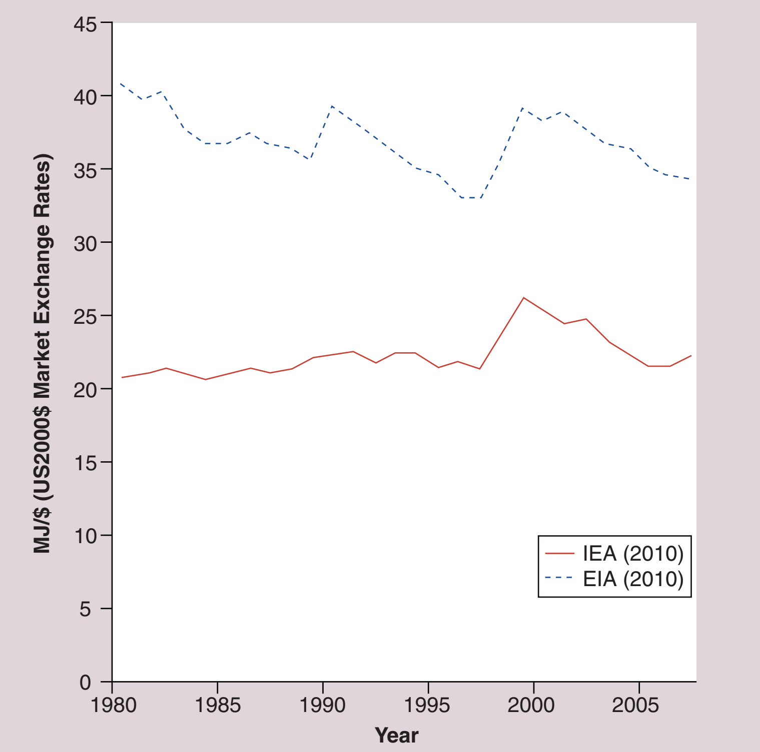

Figure 3. Energy intensity of Indonesia, 1990–2006, from energy data as reported by IEA (2010) [3,4] **and EIA (2010)** [101]**.** Market exchange rates from World Development Indicators are used for GDP [12]. The World Energy Council's primary energy equivalency recommendation of 38.6% is used for the harmonized cases.
EIA: US Energy Information Administration; IEA: International Energy Agency.

Considering unadjusted total CO_2 emissions, (including industrial emissions from EDGAR [2010] but not land-use change emissions), CDIAC (2010) shows the highest reported emissions in 2005, 29,200 $MtCO_2$ (Figure 4A). IEA-S (2010) reports the lowest global CO_2 emissions, at 27,100 $MtCO_2$. From 1971 to 2007, CDIAC (2010) reports of global emissions are, on average, 7% higher than emissions reported from the IEA-S (2010) method. When only emissions from fuel combustion are considered, CDIAC (2010) is on average 3% higher than IEA-S (2010) each year from 1971 to 2007 (Figure 4B). Fuel combustion emissions from EIA (2010) are, on average, 2% higher than IEA-S (2010). EDGAR (2010) energy-only emissions, utilizing IPCC sector-based emission factors, are consistently lower than other reported values.

Disaggregating global emission inventories into fossil fuel-specific emissions makes the differences between datasets more apparent. For coal (solids), CDIAC (2010) consistently reported the highest emissions until the late 1990s, when EIA (2010) began reporting higher emissions (Figure 5). Conversely, EIA (2010) consistently reported higher petroleum (liquids) emissions until the early 1990s, when CDIAC (2010) overtook it (Figure 6). EIA (2010) has consistently reported higher emissions from natural gas (gases), and since 1999 has generally reported the highest overall emissions from fossil fuels (Figure 7).

Differences on a global level may mask larger differences on a national level for certain countries. Of the 26 top carbon-emitting nations in 2007, representing 80% of global fuel combustion emissions, seven show differences of greater than 10% between EIA (2010) data and IEA-S (2010) data. For Canadian fuel combustion emissions from 1990 to 2008, EIA (2010) data are on average 8.5% greater than IEA-S (2009) data, partly because EIA (2010) includes emissions resulting from bunker fuels consumption (Figure 8). However, the disparity is not only due to bunker fuels, which represents only 5% of the total amount of petroleum consumed in Canada from 1990 to 2007 (IEA 2010). It is worthy of note that from 1993 to 1994 and from 1997 to 1999, CDIAC (2010) data uniquely shows a decline in emissions. From 2003 to 2004, EIA (2010) and IEA-S (2009) show increases in emissions, whereas other datasets show declines. From 2006–2007, both IEA-R (2009) and IEA-S (2009) show increases in emissions, whereas EIA (2010) shows a decline. While short-term trend discrepancies are not as important as long-term trajectories, these differences do highlight the hazards of using just one dataset to examine short-term emission trends. Sources of discrepancies for CO_2 emission inventory data in Canada, as well as for other countries and global totals, result from differences in

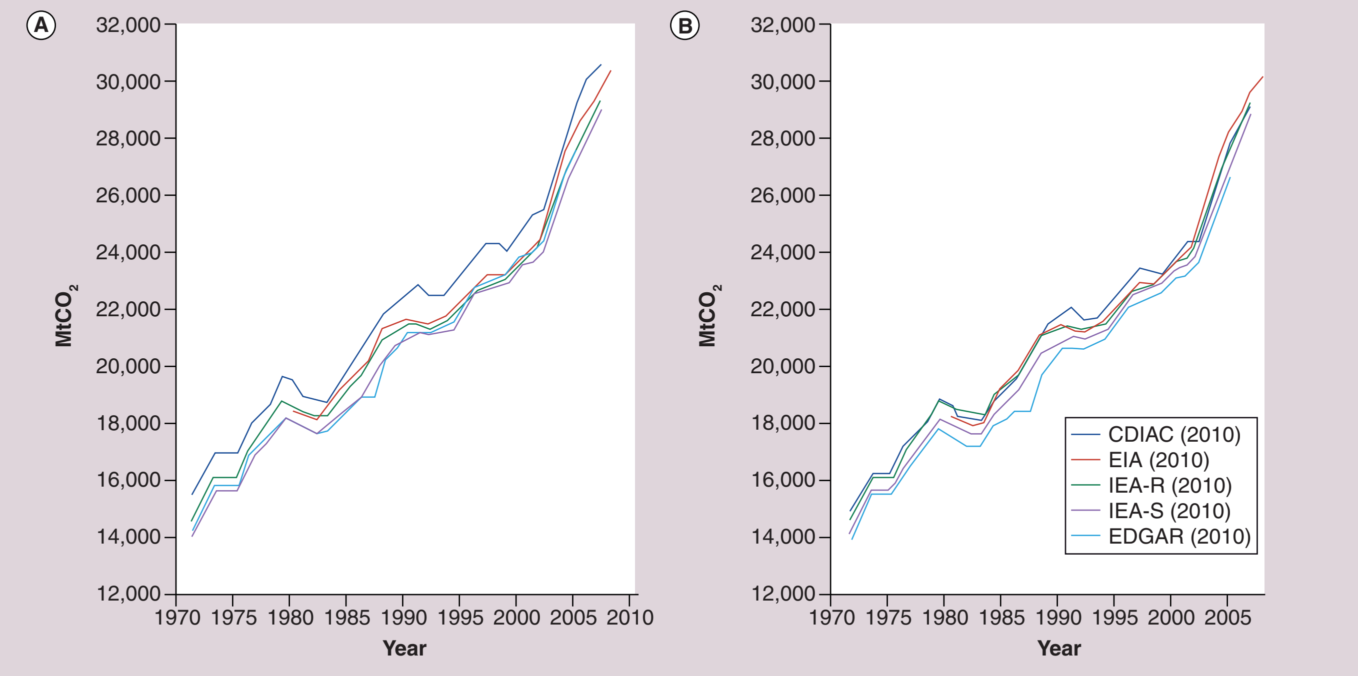

Figure 4. Global emissions from (A) energy and industrial sources and (B) from fuel combustion only, as reported by institutions, 1971–2008. EIA (2010) data begin in 1980 [101]. EDGAR (2010) data stop in 2005 and industrial sources include cement emissions [102]. CDIAC (2010) data stop in 2007 and industrial data include gas flaring and cement emissions [7,8]. IEA-S (2010) and IEA-R (2010) data stop in 2007 and industrial data include municipal waste emissions [9].

CDIAC: Carbon Dioxide Information Analysis Center; EDGAR: Emissions database for global atmospheric research system; EIA: US Energy Information Administration; IEA: International Energy Agency.

energy data inputs, corresponding CO_2 emission factors, inclusion of nonfuel combustion emission sources, and accounting methods.

For most countries, nationally and internationally regulated anthropogenic sources of CO_2 result primarily from direct combustion of energy. The choice of energy data has implications not only owing to the physical quantities of fuels reported in energy statistics, which may differ substantially, but also owing to the calorific values ascribed to those fossil fuels.

CO_2 emission factors, with the exception of those used by CDIAC (2010), are based on the energy content of particular fuels and are thus directly affected by calorific values of energy data. CDIAC (2010) utilizes the carbon content of the fuel to determine CO_2 emission factors [21]. Theoretically, the choice of NCV or GCV for energy consumption accounting is immaterial for CO_2 emissions accounting if corresponding (NCV or GCV) CO_2 emission factors are used; consumption of a barrel of petroleum should lead to the same CO_2 emissions across all datasets, regardless of whether NCV or GCV was chosen. However, in 2007, EIA (2010) reported emissions from global coal combustion to be 3.5% (420 $MtCO_2$) greater than CDIAC (2010) emissions, despite the physical quantities of coal

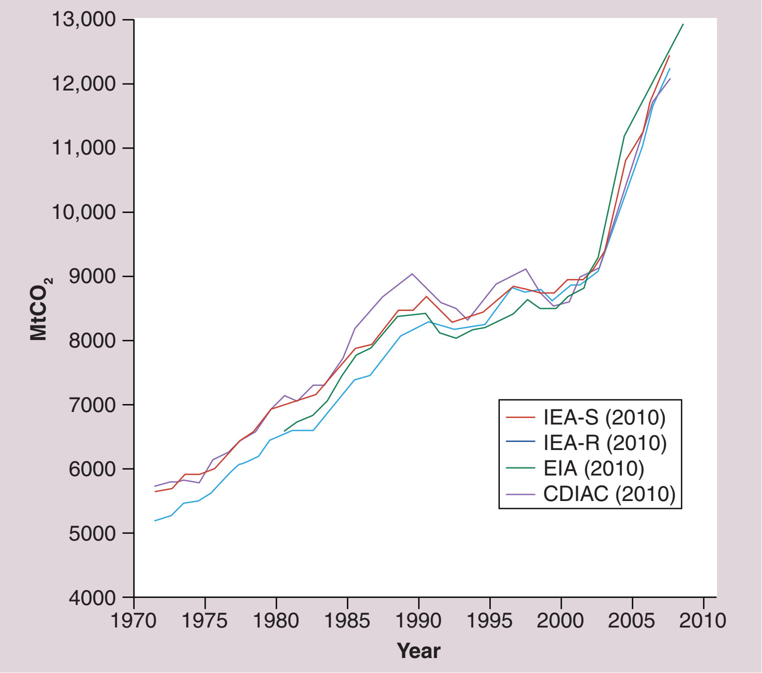

Figure 5. Global emissions from the consumption of coal. CDIAC (2010) reports consumption of solids as opposed to coal [7,8].

CDIAC: Carbon Dioxide Information Analysis Center.

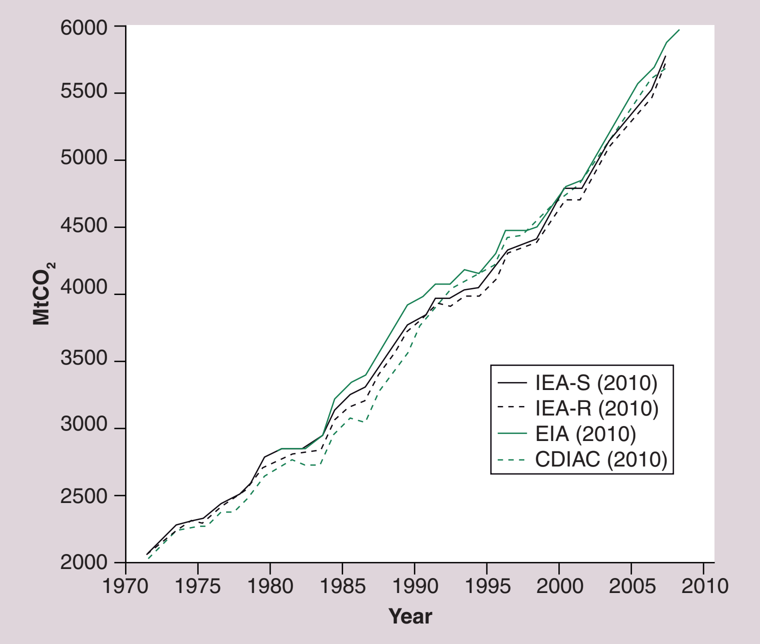

Figure 6. Global emissions from the consumption of natural gas. CDIAC (2010) reports consumption of gases as opposed to natural gas [7,8]. CDIAC: Carbon Dioxide Information Analysis Center.

contributing to these calculations differing by less than 0.5%. CDIAC (2010) global petroleum emissions were 3.9% (420 $MtCO_2$) greater than IEA (2010) petroleum emissions in 2007, despite IEA (2010) reporting slightly higher (0.7%) physical units. These discrepancies highlight the implied differences in calorific values for fossil fuels (and sub-categories of fuels) and corresponding CO_2 emission factors.

Further differences in carbon emission data from similar energy data result from the energy accounting methods utilized. There are two distinct carbon accounting methods employed in the five emission inventory estimates analyzed here: the top-down **Reference Approach** and the bottom-up **Sectoral Approach**. The Reference Approach considers a nation's aggregated energy supply, whereas the Sectoral Approach considers energy use in specific sectors to calculate emissions. IEA-R (2010) and CDIAC (2010) employ the Reference Approach. IEA-S (2010) and EIA (2010) utilize the Sectoral Approach, with IEA-S (2010) explicitly using the Tier 1 Sectoral Approach using 1996 IPCC guidelines [9]. The EDGAR (2010) Sectoral Approach utilizes the Tier 2 approach, using combustion technology-based (as opposed to average fuel-based) emission factors.

Both the Sectoral and Reference Approaches should give identical results, given sufficient quality data [9]. In practice, there are disparities that result from the methods employed, and the accounting method should therefore always be noted. Comparing the two IEA carbon accounting approaches, which utilize the same energy data inputs, lead to total global differences in CO_2 emissions in 2007 of less than 2%, or 400 $MtCO_2$. However, certain countries have vast differences between Sectoral and Reference Approaches. South Africa's difference in 2007 amounts to 26% (89 $MtCO_2$), and the Organization for Economic Co-operation and Development countries such as Canada, Mexico, and Australia demonstrate differences greater than 5% in 2007 **(Figure 9)**.

Differences are also apparent between IEA-S (2010) and EDGAR (2010) data, which both utilize IEA energy data inputs and use a Sectoral Approach. The difference between the agency methods relates to the categorization of emissions and the accounting method. Furthermore, EDGAR uses technology-based emission factors, whereas IEA-S uses average fuel emission factors. IEA-S (2010) reported that global emissions from fossil fuel consumption are consistently higher than EDGAR (2010) emissions from 1971 to the present. While annual emissions differ only by approximately 2% each year (or 0.440 $MtCO_2$ in 2005), it highlights the variation that is possible from using different levels of detail in the Sectoral Approach **(Figure 10)**.

In addition to direct emissions from fossil fuel combustion, there are a number of other categories of emission sources that can affect national and global emission inventories **(Table 4)**. Other anthropogenic sources of CO_2 that are published by certain datasets include

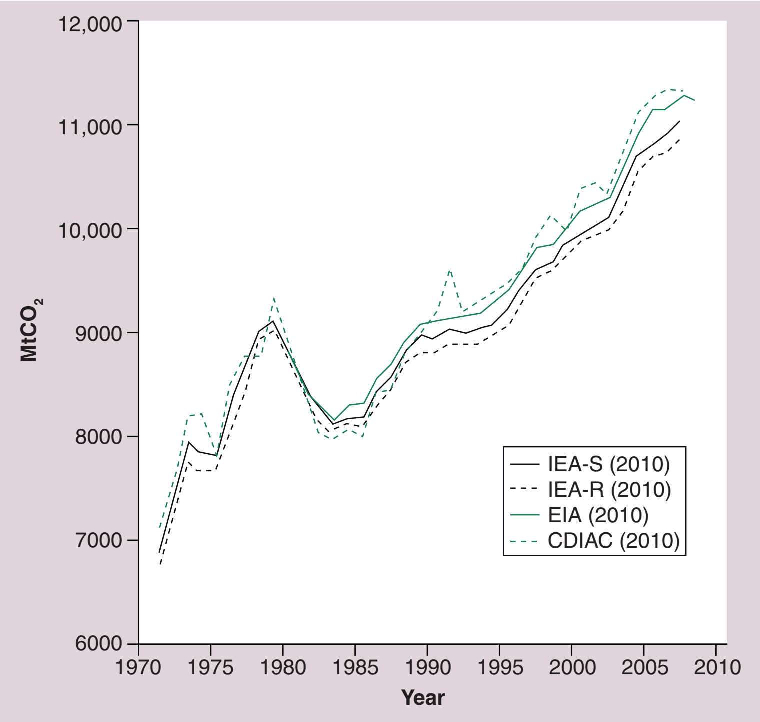

Figure 7. Global emissions from the consumption of petroleum. CDIAC (2010) reports consumption of liquids as opposed to petroleum [7,8].

emissions from the production of cement, natural gas flaring, municipal wastes, biomass combustion and land-use changes. These other categories combined have the potential to augment emissions that result simply from fossil combustion by as much as 50%, or 12,000 $MtCO_2$ (EDGAR, 2010).

The production of cement results in process-related CO_2 emissions that occur through the calcination of limestone [22]. Cement production is also energy intensive and may require significant inputs of fossil fuels, yet these fossil fuel emissions are considered fuel combustion emissions, not cement-related emissions. Cement production emissions are approximately 4.8% (1300 $MtCO_2$) of fuel combustion emissions (CDIAC, 2010). CDIAC (2010) and EDGAR (2010) report emissions from cement. Both organizations obtain cement production data from the US Geological Survey, which itself collects data primarily from country reports and from in-country specialists [23]. However, EDGAR (2010) utilizes an explicit accounting for the share of blended cement in total cement production and thus for the fraction of cement clinker in total cement production per country, resulting in estimates of cement production that are 22% (200 $MtCO_2$) less than CDIAC (2010) **(Figure 11)** [105].

The inclusion or omission of emissions from cement production from CO_2 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 show how emissions reported by EIA (2010) (which does not include cement emissions) showed a slight decrease in China's carbon intensity from 1980 to 2004 [20]. However, CDIAC (2010) (which does include cement emissions) for the same time period shows a relatively constant carbon intensity. This is due to the cement production process in China becoming more energy intensive and, due to China's high dependency on coal, more carbon intensive.

Table 4. Summary of nonfuel combustion emission sources.

	Gas flaring	Cement	Wastes	Land-use change	Refs
IEA-R (2010)	No	No	Yes	No	[9]
IEA-S (2010)	No	No	Yes	No	[9]
EIA (2010)	Yes	No	No	No	[101]
CDIAC (2010)	Yes	Yes	No	Yes	[7,8]
EDGAR (2010)	Yes	Yes	Yes	Yes	[102]

CDIAC: Carbon Dioxide Information Analysis Center; EDGAR: Emissions database for global atmospheric research system; EIA: US Energy Information Administration; IEA: International Energy Agency.

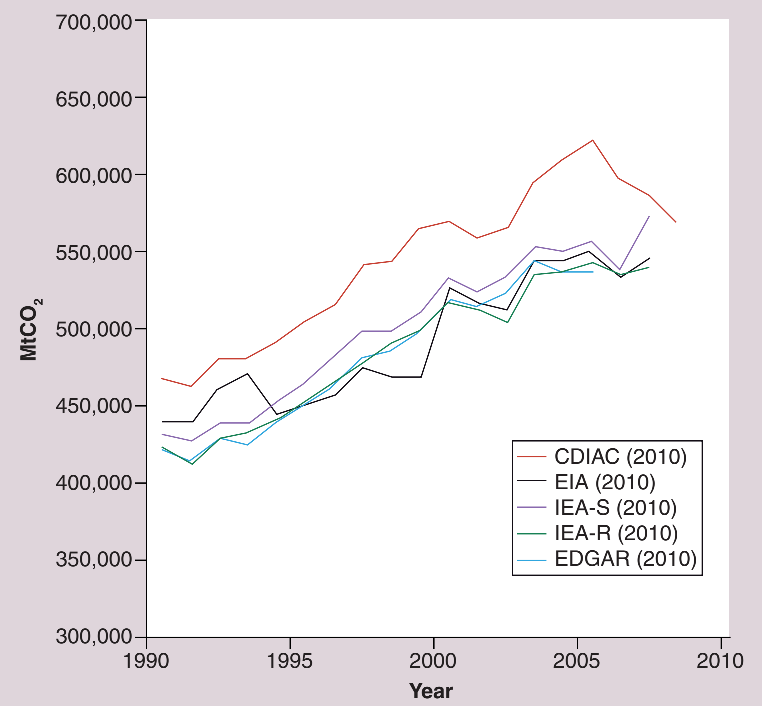

Figure 8. Canadian fuel combustion emissions as reported by institutions, 1990–2008 EDGAR (2010) data stop in 2005 [102], CDIAC (2010) in 2007 [7,8], and IEA-S (2010) and IEA-R (2010) in 2007 [9]. EIA (2010) includes international bunker fuels in its values [101]. In 1990, data begin to highlight the more recent variations in data.

CDIAC: Carbon Dioxide Information Analysis Center; EDGAR: Emissions database for global atmospheric research system; EIA: US Energy Information Administration; IEA: International Energy Agency.

The flaring of natural gas currently makes up less than 1% of global fuel combustion CO_2 emissions, yet it is still an important source of emissions for certain countries such as Iran and Algeria, where emissions from natural gas flaring represent 7 and 5% of energy-related emissions in 2007, respectively, according to CDIAC (2010). All organizations addressed here report emissions from natural gas flaring except IEA (2010). Although IEA (2010) collects and publishes energy data on gas flaring quantities from the Organization for Economic Co-operation and Development countries, it does not include these values in its calculations of CO_2 emissions. There can be great variation in national-level gas flaring emissions data. EIA (2010)

Key terms

Reference Approach: A top-down approach to determining CO_2 emissions using the apparent consumption of energy. This approach can be applied on the basis of relatively easily available energy supply statistics, and can serve as an upper limit for Sectoral Approach emissions.

Sectoral Approach: A bottom-up approach to determining CO_2 emissions. For energy included in the International Panel on Climate Change category '1A Fuel Combustion,' energy consumption data 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 availability of disaggregated and sector-specific activity data and emission factors.

Carbon intensity: A measure of the amount of carbon contained in various energy forms. It is commonly expressed as units of carbon emitted per unit of energy (e.g., in tonnes CO_2 per MJ)

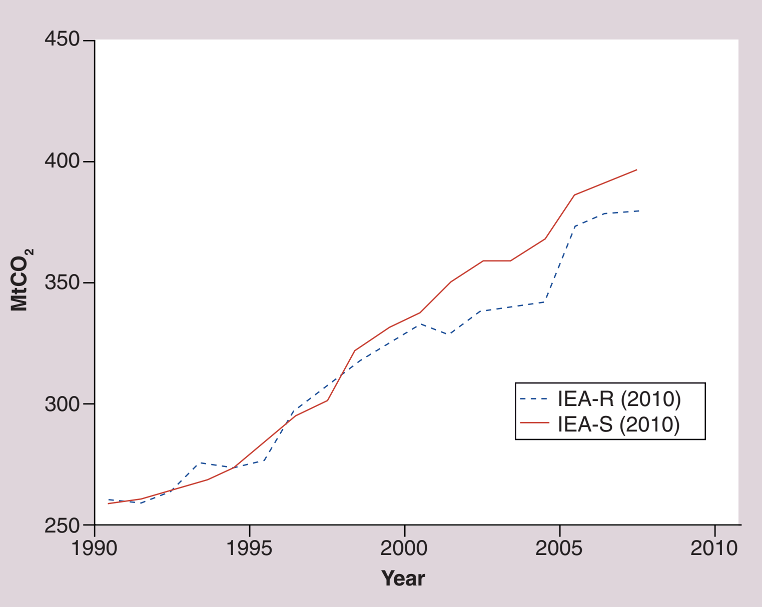

Figure 9. Australia fuel combustion emissions as reported by IEA-R (2010) and IEA-S (2010) 1990–2007 [9]. Both methods use the same energy data but use different methods of accounting. In 1990 data begin to highlight the most recent data discrepancies.
IEA: International Energy Agency.

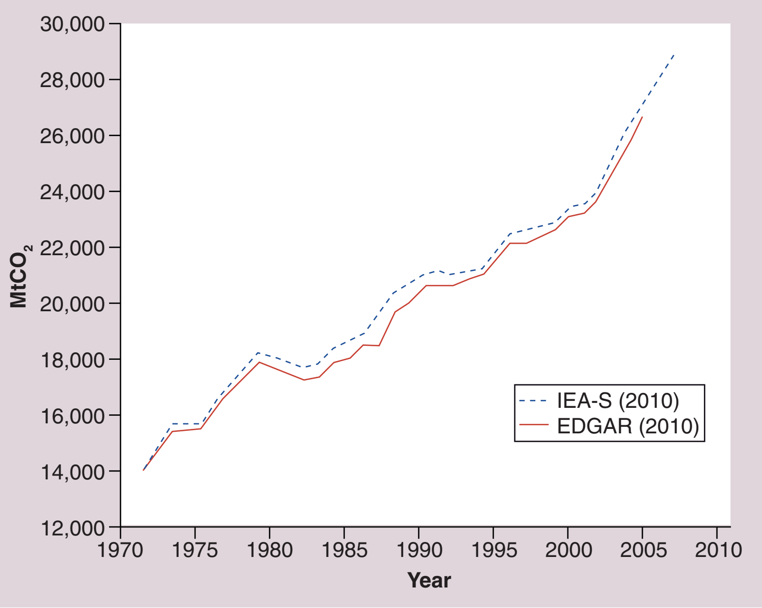

Figure 10. Global fuel combustion emissions 1971–2007 as reported by IEA-S (2010) and EDGAR (2010) [9,102]. Both organizations use the same energy data and both utilize a sectoral approach, but EDGAR (2010) uses technology-based emission factors whereas IEA-S (2010) uses average fuel emission factors. EDGAR (2010) emissions stop in 2005.
EDGAR: Emissions database for global atmospheric research system;
IEA: International Energy Agency.

reports natural gas flaring emissions in Mexico to be 13.2 MtCO$_2$ in 2007, whereas CDIAC (2010) reports emissions to be less than half of that value, 4.7 MtCO$_2$. For Russia, EIA (2010) reports 7.5 MtCO$_2$ from natural gas flaring in 2006, whereas CDIAC (2010) reports emissions to be more than three-times greater: 24.7 MtCO$_2$. EIA (2010) global estimates of natural gas flaring emissions are 5% (10.1 MtCO$_2$) in 2007, which is greater than CDIAC (2010) estimates **(Figure 12)**.

CO$_2$ emissions from municipal and industrial wastes, which result primarily from incineration of plastics, make up less than 1% of emissions from energy sources (IEA, 2010). IEA data sources and EDGAR (2010) report waste emissions, yet include different sources of waste. In 2005, the IEA-S (2010) and IEA-R (2010) reported emissions from industrial wastes to be 45 MtCO$_2$ and municipal wastes to be 46 MtCO$_2$, while EDGAR (2010) estimates emissions from municipal waste incineration of municipal wastes to be 30 MtCO$_2$.

CO$_2$ emissions are also released from land-use changes. Emissions from land-use changes could represent a large fraction of total anthropogenic CO$_2$ emissions, and have been addressed in other studies [24–26]. Emission-causing land-use changes include savannah and agricultural waste burning as well as forest and grassland fires [11]. Emissions from these sources are estimated by EDGAR (2010) and CDIAC (2010) only. CDIAC (2010) includes one general land-use change category of 'carbon flux' while EDGAR (2010) separates these into two distinct categories according to IPCC codes: "Agriculture (including savannah burning)" and "Land-use change and forestry" **(Figure 13)**.

There is great uncertainty in these data, with EDGAR (2010) reporting uncertainty estimates of 50% and CDIAC (2010) reporting uncertainty estimates of 30%. An additional complication to estimating emissions from land-use changes is determining whether releases 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). Given uncertainty ranges, EDGAR (2010) estimates on a global scale that land-use change emissions 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 CO$_2$ emissions, especially given the magnitude of emissions by developing countries. For example, using EDGAR (2010) data for the year 2005, the Democratic Republic of Congo is ranked 126th in terms of emissions from energy and industrial sectors, emitting just 2.6 MtCO$_2$, whereas the USA emitted 5974 Mt CO$_2$ the same year. However, once emissions from land-use changes are included, the Democratic Republic of

Congo is ranked 10th, emitting a total of 1,367 $MtCO_2$. Indeed, since EDGAR (2010) estimates that over 80% of emissions from Brazil and Indonesia as well as 40% from India arise from land-use changes, these emission sources will continue to be an important issue addressed at the national and international policy level.

Carbon intensity

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 use for India, a country that utilizes more traditional fuels than any other, the differences are clear **(Figure 14)**. IEA-S (2010), using IEA (2010) energy data that include traditional fuels, shows a lower absolute carbon intensity (due to energy being produced from biomass that has no corresponding calculated emissions); however, as the share of biomass decreases and the share of other fuels increases over time, carbon intensity steadily increases. For EIA (2010) data, which do not include traditional fuels, carbon intensity has stayed relatively constant since 1990. Thus, the data reported by these two institutions lead to contradictory decarbonization trends. There is also a third possible trend: when energy usage from traditional biomass sources are included and carbon emissions from these sources are also included (using the IPCC standard average emission factor of 109.6 g CO_2/MJ), there is a steady decline in carbon intensity, highlighting the energy end-use improvements India has made [27]. These three contradictory interpretations of the carbon intensity of energy use in India indicate the importance that the choice of energy and emission sources has on trend analyses.

Importance of differences in energy statistics & carbon emission inventories

Carbon emissions data uncertainty in the context of climate change negotiation

The carbon emission inventory reports discussed here offer an opportunity for independent reviews of national emission inventories pursuant to the UN Framework Convention on Climate Change (UNFCCC) protocols and subject to IPCC reporting guidelines. The UNFCCC requires Parties to the convention (i.e., nations) to regularly report their emissions following the standard methods outlined by the IPCC; however, there is still considerable uncertainty in emission reports that must be addressed and that can affect modeling analyses [28–33]. Different methods and different primary data sources can assist in identifying irregularities in national-level data, yet for effective independent verification, data collection and reporting must improve among the datasets discussed, providing values that are directly comparable to IPCC values.

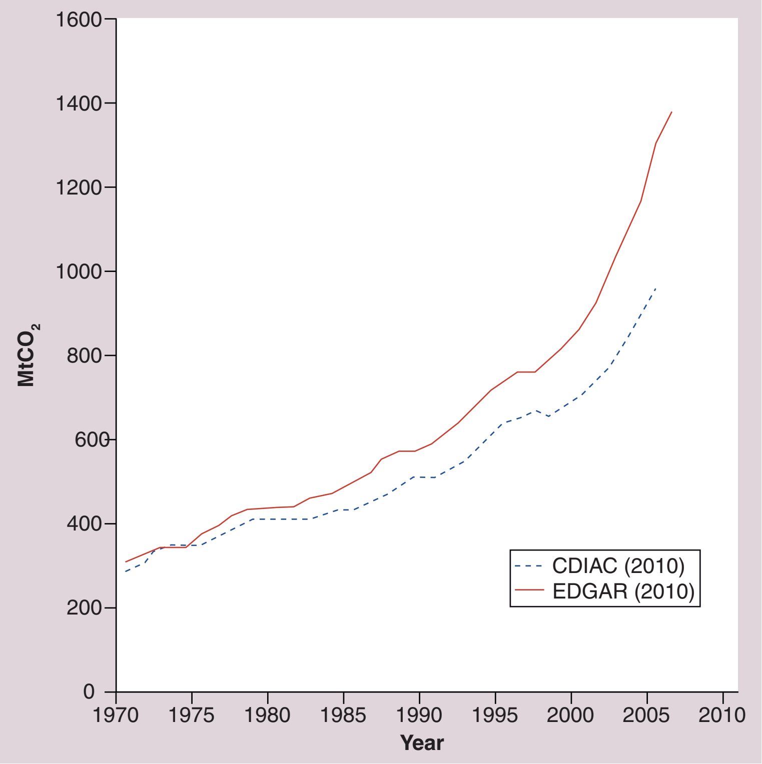

Figure 11. Global emissions from the production of cement, 1970–2006. EDGAR (2010) data stop in 2005 [102].

EDGAR: Emissions database for global atmospheric research system.

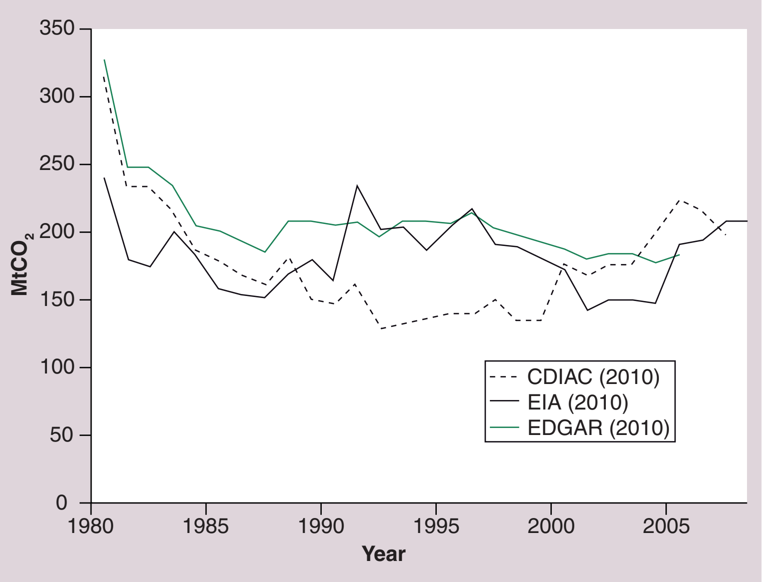

Figure 12. Global emissions from the flaring of natural gas, 1980–2008. EDGAR (2010) data stop at 2005 [102]. CDIAC (2010) data stop at 2007 [7,8].

CDIAC: Carbon Dioxide Information Analysis Center; EDGAR: Emissions database for global atmospheric research system; EIA: US Energy Information Administration.

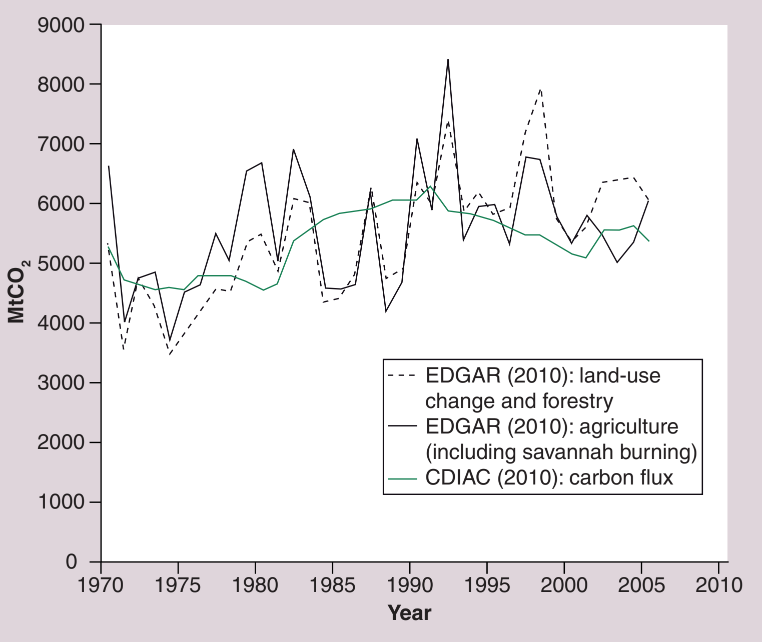

Figure 13. Global emissions from land-use changes, 1970–2005.
Data from [7,8,102].
CDIAC: Carbon Dioxide Information Analysis Center; EDGAR: Emissions database for global atmospheric research system.

The combination of different energy statistics and carbon emission inventory calculation methods can lead to significantly different results of national and global carbon emissions; greater transparency of data is needed to ensure comparisons between datasets are considering consistent assumptions and boundary conditions. While many discrepancies among datasets could be avoided through the use of one standardized accounting method across organizations, barriers such as access to available data, questions regarding data quality, and availability of monetary resources may prevent this from occurring. At the very least, energy statistics and carbon emission inventory reporting organizations could utilize consistent boundary conditions, utilize consistent categorization schemes within fuel categories, organize data according to IPCC categories, and perform sensitivity analyses associated with ranges of fuel calorific values and CO_2 emission factors.

Given that we do not know the 'true' quantity of all 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 and may assist in addressing uncertainty when developing national and international policies [34]. The different methods employed by the independent carbon emission reporting organizations can provide a more comprehensive glimpse into what actual emissions may be, yet these data must be presented in a format that is comparable with other datasets in order to be useful. Improving the quality and consistency of data in carbon emission reporting organizations could facilitate the development of a more robust independent verification procedure for IPCC national emission inventories.

Unrecognized uncertainties in publications

A consequence of the multitude of methods used to calculate CO_2 emissions is that competing conclusions can be made by the choice of one dataset over another, as seen earlier in this article from the carbon intensity analyses from energy use in India. Thus, in any analysis of CO_2 emissions it is critical to provide alternative datasets so as to provide a better assessment of the uncertainty in values associated with different CO_2 accounting methods. Many studies have used CO_2 reports for analyses, yet Raupach *et al.* has received considerable attention for its

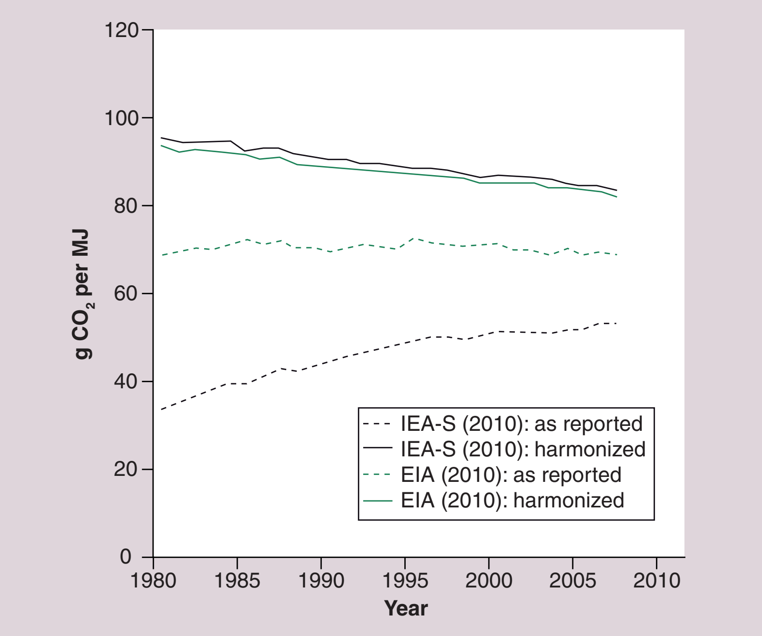

Figure 14. Conflicting trends of the carbon intensity of India, 1980–2007. IEA-S (2010) data utilize IEA (2010) energy statistics, which include traditional fuel consumption [3,4,9]. EIA (2010) carbon data utilize EIA (2010) energy statistics, which do not include traditional fuel consumption [101]. Harmonized datasets include emissions from fuel combustion and from IEA (2010)-reported traditional fuel consumption. IEA (2010)-reported traditional fuel energy values were added to EIA (2010) data to make them consistent with IEA (2010) energy data.
EIA: US Energy Information Administration;
IEA: International Energy Agency.

conclusions taken from recent data, namely that recent CO_2 emissions trends exceed the highest extreme emission scenario of the IPCC's Special Report on Emission Scenarios (SRES) [35]. Since being published, several authors have referenced that conclusion, noting the added urgency to reduce emissions [36–41].

However, as has been observed, Raupach *et al.* excludes individual IPCC scenarios, constructs an average of the emission scenario families and ignores certain IPCC illustrative marker scenarios [42,43]. It is worth noting that Raupach *et al.* only includes emissions data from EIA (2010) and CDIAC (2010), the two organizations as noted earlier that consistently report the highest emissions levels from fuel combustion. By excluding emissions from IEA-R (2010), IEA-S (2010) and EDGAR (2010), Raupach *et al.* are excluding data with lower levels of reported CO_2 emissions.

Figure 15 displays the full range of the IPCC SRES emission scenarios along with data from EIA (2010), CDIAC (2010), IEA-R (2010), IEA-S (2010), EDGAR (2010) and BP (2010) estimates of CO_2. Emission values for BP (2010) have been included in the most recent BP report. Emissions from BP (2010) utilize average fuel emission factors applied to the aggregated fuel categories of oil, coal and natural gas. BP (2010) values are consistently higher than other datasets, due to the use of IPCC-suggested emission factors, which are higher than the implied emission factors when fuel types are disaggregated and more specific emission factors are used. While BP (2010) estimates are not appropriate for analyzing absolute values, they can be useful in indicating recent trends [44]. Natural gas flaring emissions and cement emissions from 2008 and 2009 were calculated exogenously and added to BP (2010) values to provide consistency with other data. Natural gas flaring data were derived by utilizing a ratio of historical natural gas emissions to gas flaring emissions data from CDIAC (2010) and EIA (2010) from the last 10 years. Cement production emissions were estimated from the most recent US Geological Survey cement production statistics, based on 10 years of historical data of cement production compared with CDIAC (2010)-reported cement emissions [45].

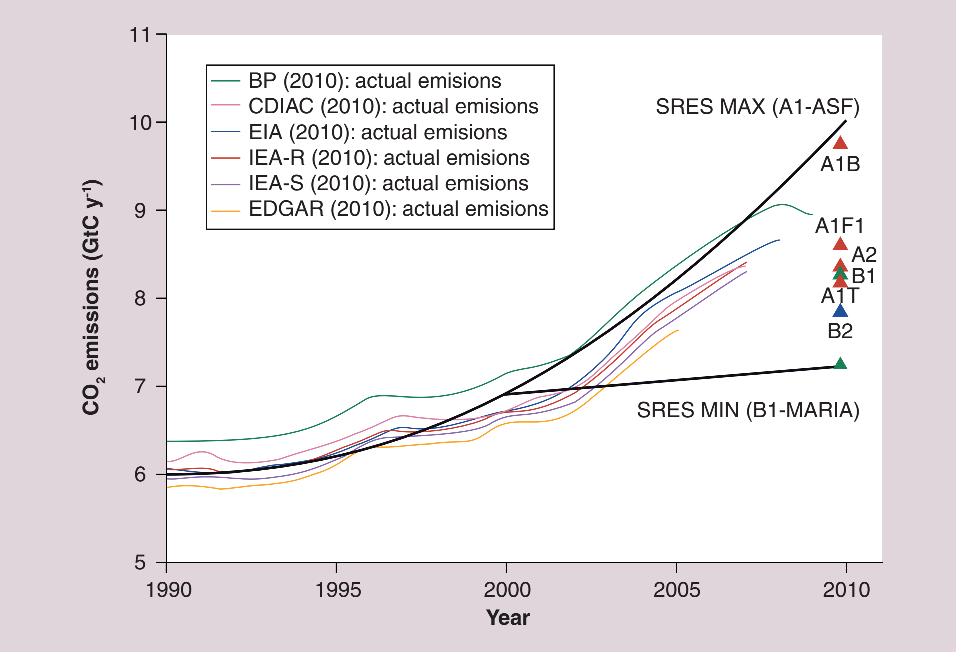

Figure 15. Global emissions from energy and cement sources compared with the International Panel on Climate Change's Special Report on Emission Scenarios raw data, 1990–2009. EDGAR (2010) data stops in 2005 [102], CDIAC (2010) [7,8], IEA-S (2010) and IEA-R (2010) [9] stop in 2007, and EIA (2010) stops in 2008 [101]. Triangles represent the six illustrative Special Report on Emission Scenarios marker scenarios. Emissions are reported in terms of carbon, not CO_2, to be consistent with previous discussions of this issue.
CDIAC: Carbon Dioxide Information Analysis Center; EDGAR: Emissions database for global atmospheric research system; EIA: US Energy Information Administration; IEA: International Energy Agency.

IEA-S (2009), IEA-R (2009), and EDGAR (2010) data show lower emissions than EIA (2010) and CDIAC (2010). It is worthy of note that all organizations' data, with the exception of BP (2010) data (which is only included for trend analysis), fall within the range of the SRES emission scenarios. Estimates from BP (2010) for 2009 indicate a decline in global emissions, further confining emissions within the range of the IPCC scenarios. Furthermore, EDGAR (2010) data, which utilizes the most specific detailed methodology, indicates the lowest level of emissions and is well within the IPCC scenario limits. While there are uncertainties and problems associated with each of the methodologies employed by these organizations, including them gives a better understanding of the uncertainties inherent in estimating global emission trends.

Raupach *et al.* also point to a trend reversal with regard to regional and global carbon intensities [35]. While there is an obvious increase in carbon intensity values from 2000 to 2006, most recent BP (2010) data show that this increase may be leveling out **(Figure 16)**. However, it is still too early to definitively conclude

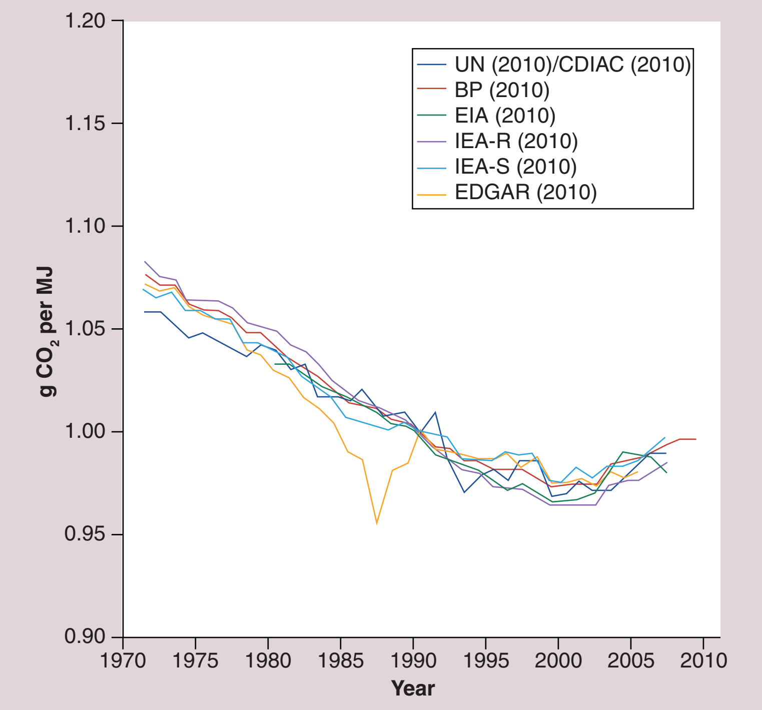

Figure 16. World carbon intensity 1971–2009. Emissions from fuel combustion divided by commercial energy only. EDGAR (2010) data stop in 2005 [102]. BP (2010) data stop in 2009 [2]. All other data sources stop in 2007. 1990 is the reference year and equals 1 for all organizations.

whether or not there is a disruption in the long-term trend of decarbonization. More years of data are required, especially since the declines in energy usage were not uniform among developing and industrialized countries [46]. Interestingly, the decline in carbon emissions in **Figure 15** is greater than the decline in carbon intensity in **Figure 16**, suggesting that while total emissions have decreased, this is probably due to a decrease in total energy consumed owing to a global economic recession and not owing to efficiency or technology improvements in the energy sector. An economic (and energy) recovery without efficiency or technology improvements in the energy sector would probably have the effect of bringing CO_2 emissions to previous levels. However, if economic recovery occurs alongside with energy efficiency and decarbonization measures, CO_2 emission may not increase as much.

Online energy-carbon harmonization database

Given the difficulty of identifying and rectifying discrepancies among multiple agency methods and assumptions for energy and carbon data, important assumption differences may not always be adequately addressed by scholars and policy makers. Unless all organizations begin utilizing consistent methods, this problem will persist. An online harmonizing database of energy and carbon emission data, first described by Macknick, offers a temporary solution to certain assumption and data discrepancies [47,103].

The database consolidates data from different sources and displays different organizations' reported energy and carbon emission values side-by-side for select countries and for the global total, while converting all reported energy consumption and CO_2 emission totals into consistent International System of Units values to allow for direct comparisons. In addition, the database has the ability to harmonize assumptions to be applied consistently across all data. Energy assumptions that can be harmonized include: the primary energy equivalence assumptions applied to electricity from hydroelectric, nuclear and renewable sources; the inclusion of traditional fuels; and the inclusion of electricity from modern renewable energy sources (e.g., wind, solar, geothermal and ocean) For CO_2 emissions, assumptions that can be altered are: emissions from cement sources; emissions from natural gas flaring; emissions from traditional fuels; emissions from the combustion of municipal and industrial wastes; and emissions from land-use changes. The database is updated with each new agency report.

Future perspective

Data discrepancies in energy statistics and CO_2 inventories can greatly affect climate modeling inputs as well as national and international policies that depend on accurate estimates of emissions, if not fully understood. Intranational and international carbon emissions trading programs (such as the US Regional GHG Initiative and the EU Emissions Trading System) could have substantially different allocations of carbon emissions, and thus financial outcomes for individual member parties, depending on which datasets and methodologies are used to calculate emissions. Whereas the uncertainty regarding emissions from fuel combustion has been well-documented in many cases, the inclusion of nonfuel combustion emissions, such as emissions from cement production and land-use change, could add greater uncertainty to our assessments of total anthropogenic impacts on the carbon cycle and carbon policy decisions. If new national carbon taxes were implemented in particular countries or credits apportioned to carbon-emitting activities, much consideration would be needed regarding what emissions (e.g., fuel combustion-related as well as nonfuel combustion-related emissions) would be taxed or given credits in addition to how to collect, monitor and assess the uncertainty of those data.

The harmonizing database described here may facilitate consistent comparisons among datasets, but it should only be seen as a partial strategy to address the current existing disparities among reporting organizations' data. Further action could be taken by both reporting organizations and researchers to reduce the chance that data are unintentionally used out of context in political, economic or scientific activities.

To ensure more consistent data comparisons in the future, reporting organizations could use a consistent reporting format with comparable fuel categories to the IPCC, which clearly presents how emissions should be categorized and estimated. Deviations from this standard format should be transparently communicated.

Organizations may not come to a consensus regarding choices of national fuel calorific content values for fossil fuels in energy reports, or the corresponding carbon emission factors for the CO_2 emission inventory reports, yet performing sensitivity analyses with these assumptions would provide a better estimate of the uncertainty associated with fuel composition in particular nations. This would lead to insights regarding why organizations reporting identical values of petroleum barrel or coal tonnage consumption report different associated emissions.

Organizations could also make an effort to report uncertainties inherent in their own data. While data may come from national reports that may 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 policy makers utilizing these data, multiple data sources should be consulted and included in analyses to give a comprehensive view of discrepancies. All data sources considered here can meaningfully contribute to emission analyses, provided that the assumptions of each are clearly explained.

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 energy-carbon 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.

Given the potential severe climatic consequences and massive potential economic implications of efforts to reduce CO_2 emissions, we should make special efforts to improve our awareness of the full discrepancies of published emission data.

Executive summary

Energy data discrepancies

- Reporting organizations collect data using different methods, leading to different reported physical quantities of primary energy consumption data.
- Average calorific values of fossil fuels differ from report to report, compounding differences in physical quantities.
- Methods for converting the electricity generated from nuclear, hydroelectric and modern renewable sources into a primary energy equivalent differ, leading to primary energy values that may differ by a factor of three, despite general agreement in the amount of electricity generated.
- Traditional, combustible biomass fuels are a significant part of many countries' primary energy use, and are not captured by all organizations.
- Many national and global energy statistics differences associated with primary energy equivalences, calorific values and traditional fuels are masked by aggregated data.
- Analyses of energy intensity show conflicting trends, depending on which data sources are used.

Carbon emission inventory data discrepancies

- CO_2 emission inventory data from fuel combustion are based directly on energy use reports.
- Reporting organizations include different sources of carbon emissions in addition to energy consumption, with some reporting emissions from the production of cement, natural gas flaring, waste combustion and land-use changes.
- Certain organizations use a top-down method of accounting for carbon emissions based on apparent consumption, whereas other organizations use a bottom-up method of accounting based on data from individual economic sectors.
- Organizations report emissions in different categories that are not always directly comparable.
- Organizations utilize different emission factors for fossil fuels that are not entirely explained by differences in the calorific value of the fuel when calculating energy statistics.
- Analyses of carbon intensity show conflicting trends, depending on which data sources are used.

Implications of energy & CO_2 data discrepancies

- Analyses of CO_2 emissions and trends are becoming increasingly important and will probably impact future energy and climate policy decisions.
- Data sources can be manipulated to show conflicting trends that could be used to support or negate policy proposals.
- Existing publications of energy statistics and CO_2 emissions do not adequately convey statistical uncertainties in reported data.
- A publicly available online tool has been developed to harmonize certain energy and CO_2 emission assumptions to facilitate consistent and timely comparisons of data.

Financial & competing interests disclosure

The author has no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

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