**World Resources Institute**

# CAIT: INDICATOR FRAMEWORK PAPER

January 2009

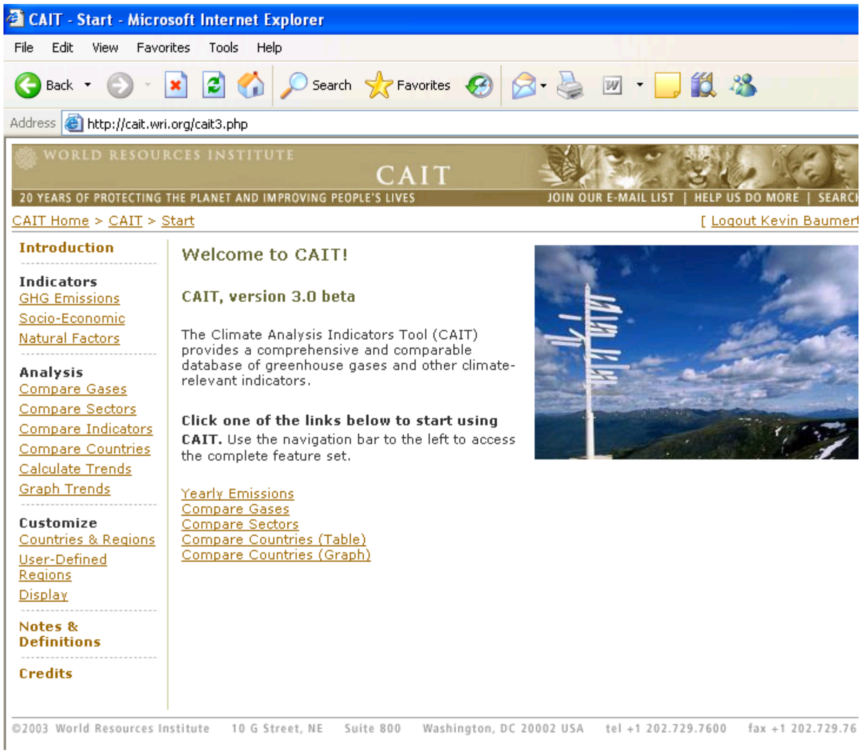
**Note: This document accompanies the Climate Analysis Indicators Tool (CAIT), version 6.0**.

## About this Document

This document provides information about the indicators included in CAIT, including background information, methodologies, and—in the case of *non-emissions-related data*—information about original data sources that were used to construct the indicators (information on greenhouse gas data sources can be found in **Greenhouse Gas Sources and Methods**, available on the CAIT website).

## Acknowledgements

The World Resources Institute is grateful for the input and contributions to this paper provided by Odile Blanchard and Niklas Höhne.



Welcome to CAIT!

**CAIT, version 3.0 beta**

The Climate Analysis Indicators Tool (CAIT) provides a comprehensive and comparable database of greenhouse gases and other climate-relevant indicators.

**Click one of the links below to start using CAIT.** Use the navigation bar to the left to access the complete feature set.

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## List of Acronyms

| | |
|---|---|
| CDIAC | Carbon Dioxide Information Analysis Center (of the U.S. Dept. of Energy) |
| CDD | Cooling Degree Day |
| $CH_4$ | Methane |
| $CO_2$ | Carbon Dioxide |
| FAO | Food and Agricultural Organization |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| GWP | Global Warming Potential |
| HDD | Heating Degree Day |
| HDI | Human Development Index |
| HFC | Hydrofluorocarbon |
| IEA | International Energy Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| KWh | Kilowatt hour |
| $N_2O$ | Nitrous Oxide |
| NOAA | National Oceanic and Atmospheric Administration |
| OECD | Organization for Economic Co-operation and Development |
| PFC | Perfluorocarbon |
| PPP | Purchasing Power Parity |
| SBSTA | Subsidiary Body for Scientific and Technological Advice |
| $SF_6$ | Sulfur Hexafluoride |
| UN | United Nations |
| UNDP | United Nations Development Programme |
| UNESCO | United Nations Educational, Scientific, and Cultural Organization |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WEC | World Energy Council |
| WRI | World Resources Institute |

# 1. Introduction

In the next few years, governments will need to make important decisions with respect to a wide range of issues under the UN Climate Change Convention (UNFCCC). To effectively address issues that are important to all Parties to the Convention, data and information are needed to support decision-making. With this need in mind, World Resources Institute (WRI) aims to provide an information and analysis tool—the Climate Analysis Indicators Tool (CAIT)—to build capacity and help support future policy decisions made under the Climate Convention and in other fora.

This Indicator Framework paper supports CAIT. It provides a description and sources of the data included in CAIT (with the exception of greenhouse gas data sources[1]), as well as a conceptual framework for classifying indicators that are relevant for climate protection.

## 1.1. CAIT Products

CAIT is not a single tool, but a set of tools, each with its own specialized purpose. Each is available free of charge from the CAIT website (http://cait.wri.org). The principal CAIT products are briefly described below.

- → **CAIT** (online) operates through a web-based interface. CAIT includes a wide variety of climate-relevant data and indicators that can be viewed through an interactive and customizable interface. For GHG emissions-related indicators, CAIT's interface allows the user in most instances to choose particular years, sectors, gases, and countries to display. CAIT includes numerous analysis features that allow for a range of comparisons across gases, sectors, countries, and years (including with graphing and charting tools). Three additional modules accompany CAIT that incorporate different data and indicators:
    - **CAIT-UNFCCC** is a basic interface for viewing and analyzing official GHG emissions data submitted by UNFCCC Parties to the Convention Secretariat.
    - **CAIT-U.S.** is an interface for viewing data, indicators, and policy development pertaining to U.S. *states*.
    - **CAIT-V&A** is an interface for viewing data and indicators related to countries' vulnerability and adaptive capacity (V&A).

This Indicator Framework paper pertains to the principal CAIT product described above. CAIT-UNFCCC, CAIT-U.S., and CAIT-V&A, however, do not include the indicators described in this paper (with minor exceptions).

## 1.2. Indicators in CAIT

The indicators presented in CAIT are grouped into three categories: Greenhouse Gas (GHG) Emissions, Socio-Economic, and Natural Factors. These categories are loosely mapped to the

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[1] *See* **CAIT: Greenhouse Gas Sources & Methods**, available online at http://cait.wri.org/downloads.php.

Convention principles of responsibility, capability, and "specific needs and special circumstances." Table 1 shows the indicators included in CAIT.

**Table 1. Summary of Indicators**

| Category | Indicator (s) | Units |
|---|---|---|
| **GHG Emissions** | Yearly Emissions | Tonnes of $CO_2$ equivalent (national and per person) |
| | Cumulative Indicators:<br>- Cumulative Emissions<br>- Concentrations<br>- Temperature Increase | <br>- Tonnes of $CO_2$ equivalent (national and per person)<br>- National share (percentage) and per person (index)<br>- National share (percentage) and per person (index) |
| | Emission Intensities<br>- GHG Intensity of the Economy<br>- Carbon Intensity of Energy Use<br>- Carbon Intensity of Electricity Production | <br>- GHG emissions per unit GDP<br>- $CO_2$ emissions per unit energy consumption<br>- $CO_2$ emissions per kilowatt hour (electricity) |
| **Socio-Economic** | Health | Life expectancy, in years |
| | Education | Index value: combination of (1) literacy rates and (2) school enrollment rates |
| | Income and Economy | (1) Income per capita: GDP per capita<br>(2) Size of economy: total GDP |
| | Energy Use | Tonnes of oil equivalent (total and per capita) |
| | Governance | Index value covering six areas of governance |
| **Natural Factors** | Climatic Conditions | (1) Heating needs (heating degree days)<br>(2) Cooling needs (cooling degree days) |
| | Natural Resource Endowments | (1) Fossil fuel reserves (coal, oil, and gas); by tonnes of oil equivalent (total and per capita) and carbon intensity of reserves<br>(2) Energy use mix; by carbon intensity (carbon per unit of electricity production) |
| | Geography | Total land area impacted by human activity (proxy for transport requirements) (total and per capita) |
| | Population | Total number of people |

Section 2 of this paper describes the GHG Emission Indicators included in CAIT. GHG Emission Indicators are framed broadly to include (1) annual emissions, (2) historical indicators (e.g., cumulative emissions), and (3) emissions intensity indicators (e.g., emissions per unit of GDP). This section provides background information and a conceptual rationale for inclusion (or lack of inclusion) of GHG-related indicators in CAIT. However, this section does not include information about underlying GHG data and sources used to construct the various indicators. This information can be found in a separate document, entitled: **CAIT: Greenhouse Gas Sources & Methods**, available online from the CAIT website (http://cait.wri.org/downloads.php).

Section 3 describes the second category of indicators: Socio-Economic Indicators. Socio-Economic Indicators are also framed broadly and include numerous indicators that relate to the *capabilities* and *opportunities* countries may have to protect the climate system.

Section 4 describes the final category of indicators: Natural Factor Indicators. Natural Factor Indicators represent those factors that tend to lie largely beyond the reach of public policy (like climatic conditions and geography), but which nevertheless may significantly influence GHG emissions. To some extent, these factors reflect certain unchangeable *national circumstances* that countries face.

Section 5 describes the *Indexing* feature included in CAIT.

### 1.3. Data and Indicator Caveats

When considering the indicators presented in CAIT, users should keep several points in mind. First, no indicator or set of indicators can be entirely representative of Convention principles, such as responsibility or capability, or any specific factor. Indicators simplify and summarize often large amounts of information in order to facilitate communication and understanding. They are not exact representations; interpretations over what the indicators actually mean in any given policy context can vary substantially. Thus, this Indicator Framework paper examines what indicators might serve as *reasonable proxies* for various factors related to principles embodied in the Climate Convention. No single indicator or group of indicators should be understood as "quantifying" any single factor or principle. Likewise, indicator values or rankings in CAIT are not intended to be suggestive of any specific commitments that Parties should take on (or rights they should acquire).

Second, the list of indicators presented in CAIT is not complete. In some cases, data constraints prevented particular indicators from being selected. In other cases, indicators are included, despite a lack of complete global geographic coverage. Finally, some data that underpins many of the indicators may be subject to substantial *uncertainties* and gaps. This applies especially to $CO_2$ emissions from land use change and some non-$CO_2$ gases. For more information about these data sources, and associated uncertainties, see **CAIT: Greenhouse Gas Sources & Methods**, available online from the CAIT website (http://cait.wri.org/downloads.php).

## 2. GHG Emission Indicators

This section describes the greenhouse gas-related indicators in CAIT (as well as some others that are not included). These include (1) annual emissions, (2) historical indicators (e.g., cumulative emissions), and (3) emissions intensity indicators (e.g., emissions per unit of GDP).

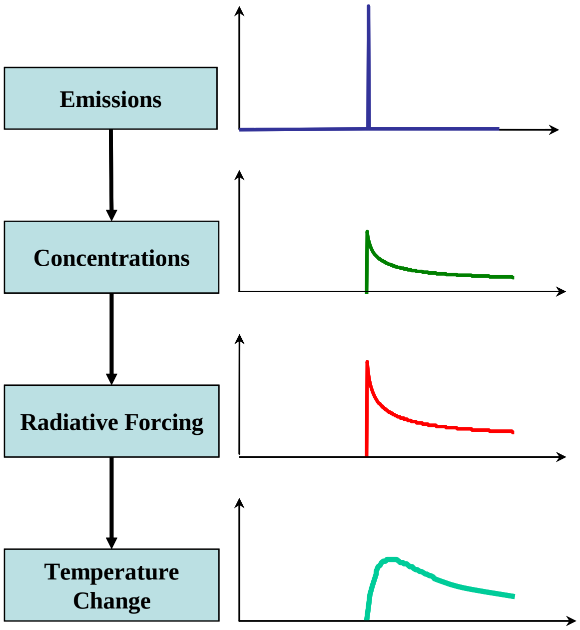
The Preamble of the Convention acknowledges the first two of these categories in referring to "historical and current global emissions" and the need for "due consideration of the relative contributions to the enhancement of the greenhouse effect." Emission *intensity* indicators (Section 2.4) are included in CAIT due to their relevant policy applications.

For information about the *underlying GHG data* used to construct GHG indicators in CAIT, see **CAIT: Greenhouse Gas Sources & Methods**, available online at http://cait.wri.org/downloads.php. Because intensity indicators (Section 2.4) include non-GHG data (e.g., GDP), information on those data sources is discussed below.

### 2.1. Emissions and the Concept of Responsibility

The Subsidiary Body for Scientific and Technological Advice (SBSTA), an organ of the Climate Convention, is undertaking scientific and methodological work regarding attributing responsibility for climate change. This work has evolved out of the 1997 Brazilian Proposal.[2] After the Kyoto Protocol was adopted in 1997, work on the Brazilian Proposal was referred to SBSTA for further scientific and methodological work. It continues to be assessed by an expert working group (UNFCCC, 2002).[3]

**Figure 1**: Simplified Cause-Effect Chain from Emissions to Climate Change Impacts



However, it is important to point out that responsibility for *causing* climate change need not necessarily be proportional to responsibilities to take *action* to limit emissions. The concept of responsibility, examined in this section, is done independently of any particular policy question related to mitigating greenhouse gas emissions or adapting to the physical effects of climate change. It is equally important to note that, while the original Brazilian Proposal focused on *temperature increase*, there are other possibilities for defining and measuring relative responsibility for causing climate change on the basis of current and historical emissions.

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[2] During the 1997 Kyoto Protocol negotiations, the Brazilian delegation proposed to allocate greenhouse gas emission targets to industrialized countries on the basis of their relative responsibility for temperature increase (UNFCCC 1997). Although the proposal was not adopted in Kyoto, it had a significant influence on the negotiation process (La Rovere et al. 2002) and has been the subject of significant study (see e.g., Elzen et al. 1999).

[3] For more information, see http://unfccc.int/methods_and_science/other_methodological_issues/items/1038.php, which contains all relevant documents and information about the state of the expert assessment of contributions to climate change.

Climate change's simplified "chain of causality" helps to illustrate the range of possibilities (see Figure 1, left side). The chain of causality begins with the societal actions that produce or prevent *emissions* of greenhouse gases. Greenhouse gas emissions, in turn, affect the *concentration* of greenhouse gases in the atmosphere. Each greenhouse gas has its own particular concentration in the atmosphere at a given point in time.

Accordingly, each gas has its own particular *radiative forcing*; that is, an imposed perturbation in the radiative energy budget of the Earth's climate system.[4] Unlike concentrations, radiative forcings of different gases can be added together, allowing the combined effects of all gases to be represented in a single measure. The single value of the radiative forcing over time is the primary determinant of increases in global average surface temperatures. This warming (both the absolute value and the rate of change) then leads to the eventual physical impacts that affect human society, such as sea level rise, changes to rain patterns and the earth's hydrological systems, increased extreme weather events, and migration or extinction of species.

Consideration of delays, non-linear effects and feedbacks, and the start date for evaluation, are particularly important in understanding the "chain of causality" (Figure 1) and the concept of historical responsibility. These three considerations are explored below.

### *i. Delays*

There is some degree of delay between the steps shown in Figure 1. These time delays are illustrated on the right side of the figure. The top frame shows a hypothetical "pulse" of emissions at a given point in time (with *no* emission before or after this pulse). This emission pulse leads to an immediate increase in atmospheric concentrations (second frame), which declines over time as the gas is slowly removed from the atmosphere (e.g., through uptake). This process takes a few centuries for $CO_2$, but only a few decades for methane. Like concentrations, radiative forcing increases and then slowly declines. Finally, the temperature change (bottom frame) resulting from the pulse increases first, reaches a maximum, and finally declines again. The amount of the delay between the pulse emission and the maximum in temperature change is dependent on the removal process of the greenhouse gas in the atmosphere and therefore different for the greenhouse gases. For $CO_2$ the delay is several decades, while for methane it is only several years, due to its faster removal from the atmosphere.

For an increase in $CO_2$ concentrations (e.g., twice the pre-industrial level), there is equally a significant time delay between radiative forcing and when a new temperature equilibrium is reached. Only about half of the temperature increase caused by increased greenhouse gas concentrations occurs within the first several years after the change in concentrations (den Elzen et al., 1999). The rest of the effect is delayed decades to centuries, mostly due to the time it takes for the temperature of the deep oceans to equilibrate.

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[4] *Radiative forcing* is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism. It is expressed in Watts per square meter ($W/m^2$). IPCC 2001a: 5.

The delay between the various steps in the cause-effect chain has an important impact on any assessment of responsibility. When accounting for responsibility for *past* emissions, one needs to consider also the *future* effects.

### *ii. Non-linear Effects and Feedbacks*

Each step in the "chain of causality" (Figure 1) includes some degree of non-linear effects. In other words, it is not necessarily the case that a doubling of concentrations leads to a doubling of radiative forcing, and so on. For example, due to a "saturation effect" the amount of radiative forcing caused by greenhouse gas emissions tends to *decrease* as greenhouse gas concentrations in the atmosphere increase (IPCC, 1995). Accordingly, due to higher concentrations, the radiative forcing from an increase in concentration of 1 ppmv today is about 25 percent less than the same increase at the beginning of industrialization.

In addition, feedbacks between the factors exist. For example, temperature increase will influence the carbon cycle and therefore the speed at which carbon is removed from the atmosphere.

As a consequence of the non-linear effects and feedbacks, the effect of emissions of individual sources may depend on the date of emissions and on emissions from other sources. For example, the contribution of one country to warming is a function of another's. Likewise, the contribution of some gases (e.g., $CO_2$) is a function of the emissions of other gases, including non-GHGs (e.g., aerosols). In addition, the total temperature change may not be equal to the sum of effects of individual countries or regions. Either these non-linearities and feedbacks are neglected (as in the first version of CAIT) or a method to attribute the responsibility under these conditions has to be selected (UNFCCC, 2002: 12).

### *iii. Start Date*

For most indicators of responsibility, a start date is needed that specifies from which year historical emissions should be considered. Two considerations are especially important when choosing the start date.

First, uncertainty of the data increases the further one looks into the past (UNFCCC, 2002: 14). Stretching back only a decade, emissions data—especially for non-$CO_2$ gases and $CO_2$ from land-use change and forestry—are not reliable at the country level. Uncertainty, with respect to data availability, may also be geographically biased. Earlier data are generally available for industrialized countries, but not for developing countries (which, it should be noted, emitted far smaller quantities in distant periods). CDIAC's database has $CO_2$ emissions for only 20 countries available in 1850 compared to 148 in 1950 and 184 in 2005. This consideration may influence the choice of an appropriate start date (Marland et al., 2008).

Second, a key issue is whether, or to what degree, the current generation should be held responsible for the actions and decisions of previous generations. The IPCC (1996b: 109) identifies several criticisms of the view that historical responsibility should stretch back to previous generations.

- Past generations were not aware of the harmful nature of GHG emissions and had no incentive to limit them.

- It is not always clear who benefited, or benefits today, from historical emissions, given shifting patterns of production, trade, consumption, and migration. Whether to attribute past emissions to colonial powers might also be relevant here.
- Country boundaries have also changed remarkably over the past century, particularly during the early 1990s and the years following World Wars I and II. Some countries are relatively recently formed.

Following on such criticisms, one plausible starting year might be 1990, when the IPCC published its First Assessment Report warning that GHG emissions could have been contributing to global warming (La Rovere et al., 2002).

On the other hand, some of the above arguments are open to challenge. Many countries have laws and regulations embracing the legal principle of "objective responsibility"; for example, in the United States and Brazil, a polluter cannot escape a penalty by claiming unawareness of the environmental damages caused (La Rovere et al., 2002: 169). Along an ethical line of reasoning, the IPCC (1996b: 109; citing Bhaskar, 1993) states that "the current generation [in developed countries] are the prime beneficiaries of resource transfers from previous generations…If the current generation accepts assets from their parents, then it is incumbent upon them to also accept the corresponding liabilities."

In CAIT, a start date can be specified by the user (e.g., 1900). Due to data limitations, 1850 is the earliest possible start date that can be selected. Overall, as discussed above, there are ethical or fairness considerations with respect to choosing a starting date for attributing responsibility. One useful exercise would be a sensitivity analysis showing the difference in results under various indicators. This can be done with CAIT.

### *iv. Discussion*[5]

As explained above, emission and responsibility indicators exist throughout the chain of causality. Experts participating in the UNFCCC assessments of "contributions to climate change" have identified indicators of responsibility that are located at various steps shown in Figure 1. (UNFCCC, 2002: 7.) Table 2 shows seven such indicators and evaluates them against three criteria. The suggestion by UNFCCC (2002), adopted here, is that indicators of responsibility are more appropriate to the extent that they are (1) closer to impacts, (2) more understandable, and (3) more scientifically certain.

The indicators later in the cause-effect chain (e.g., temperature increase and sea level rise) score well with respect to closeness to climate impacts; they are closer to the harmful effects the Climate Convention aims to reduce. Countries with longer average "age" of their emissions in the atmosphere will show a larger share of responsibility using indicators late in the chain—such as temperature change and sea-level rise. Those countries with more recent emissions will conversely show smaller shares of responsibility late in the chain, because their emissions take quite some time before reaching their full global warming effect.

Indicators earlier in the cause-effect chain, on the other hand, are generally more transparent to calculate, involve less uncertainty in their calculation, and are easier to understand (despite the UNFCCC's scoring; see Note in Table 2). They also capture the marginal contributions to climate

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[5] This section draws significantly on UNFCCC 2002; Höhne and Harnisch 2002; and IPCC 2001a.

change, which are most amenable to influence from policy and technological changes. Overall, the most appropriate indicators of responsibility are likely to lie between the beginning and end of the cause-effect chain.

**Table 2**. Evaluating Responsibility Indicators: Three Criteria
Scale: * = Low; **** = High; "–" = Nil

| Indicator | Close to Climate Impacts | Understandable | Certain |
|---|---|---|---|
| 1. Annual Emissions | - | **** | **** |
| 2. Cumulative Emissions | - | **** | *** |
| 3. Concentrations | * | **** | ** |
| 4. Radiative forcing | ** | **** | ** |
| 5. Weighted concentrations (future effects of historical emissions) | *** | - | ** |
| 6. Temperature Increase | **** | **** | * |
| 7. Impacts (e.g., sea level rise) | **** | **** | - |

**Source:** Adapted from UNFCCC, 2002: 10.

**Note:** The UNFCCC's scoring for the "understandable" criterion may be overstated toward the bottom of the cause-effect chain (e.g., for temperature change). It is true that the concept of global responsibility for global temperature change is easily understandable at an intuitive level. Conceptually, however, the notion of a particular *country's contribution* (or region's) to the global temperature increase is not easily understandable. This is due in part to feedbacks and non-linear effects that have an essentially global character; they are problematic to attribute to individual countries or regions (UNFCCC, 2002: 12). There are also different attributing methodologies that can be applied to countries or regions.

Other evaluation criteria may also be important. Table 3 evaluates the same responsibility indicators against the following four criteria discussed in Höhne and Harnisch (2002: 6-7):

- **Backward-looking**. The indicator takes into account historical emissions.
- **Backward-discounting**. The indicator weighs recent emissions more heavily than early emissions.
- **Forward-looking**. The indicator takes into account the effect of the emissions in the atmosphere after the point of emissions.
- **Comparability between gases**. The indicator can account for the different characteristics (e.g., lifetimes) of the different greenhouse gases.

**Table 3**. Evaluating Responsibility Indicators: Four Additional Criteria
Scale: * = Low; *** = High; "–" = Nil

| Indicator | Backward-looking | Backward-discounting | Forward-looking | Comparability between Gases |
|---|---|---|---|---|
| 1. Annual Emissions | - | - | ** † | ** † |
| 2. Cumulative Emissions | *** | - | ** ‡ | ** ‡ |
| 3. Concentrations | *** | *** | - | - |
| 4. Radiative forcing | *** | *** | - | *** |
| 5. Weighted concentrations (future effects of historical emissions) | *** | *** | *** | *** |
| 6. Temperature Increase | *** | **$^+$ | -$^x$ | *** |
| 7. Impacts (e.g., sea level rise) | *** | ** | -$^x$ | *** |

**Source:** UNFCCC, 2002: 10; Höhne and Harnisch, 2002; and authors' interpretations.

**Notes:**

† Multiplying the emissions of the gases by their respective global warming potentials (GWPs) make this indicator *forward-looking* and *comparable*.

‡ Multiplying the summed gases by their respective GWPs could make this indicator *forward-looking* and *comparable*.

$^+$ Discounts also very recent emissions due to the delays.

$^x$ Temperature increase and impacts occur with a delay after the emission. The rating assumes an approach whereby contributions to *current* warming or impacts (e.g., in 2002) are assessed. If contributions to *future* temperature increase and impacts were assessed, the ratings would be ***.

These specific indicators are discussed in more depth below in sections 2.2 and 2.3. Yearly emissions as well as three historical indicators—cumulative emissions, concentrations, and temperature increase—are included in CAIT. Explanations for why other historical indicators are *not* included in CAIT are provided in Section 2.3 below.

### 2.2. Yearly Emissions

The indicator that is the easiest to measure and understand is yearly, or annual, emissions of greenhouse gases. This indicator includes $CO_2$ from fossil fuels and cement (1850-2005), $CO_2$ from land use changes (1950-2000), and five non-$CO_2$ gases ($CH_4$, $N_2O$, HFCs, PFCs, and $SF_6$; 1990, 1995, 2000, and 2005 only). All sources and gases are expressed in carbon (or $CO_2$) equivalents using 100 year global warming potentials found in IPCC (1996a). As discussed above, annual emissions is not a particularly strong indicator of causal responsibility for climate change because it is not backward-looking; a single year's emissions do not account well for the historical buildup of GHG concentrations in the atmosphere and the associated effects.

While not a good measure of causal responsibility for climate change, CAIT includes this measure for two reasons. Most importantly, yearly emissions is an accurate measure of each country's *marginal* contribution to GHG buildup at a given point in time. Yearly emissions are also important because, unlike historical indicators, it is the measure that near-term policies and technological innovations can actually influence. For that reason, CAIT includes a relatively detailed sectoral breakdown of yearly greenhouse gas emissions.

### 2.3. Cumulative (Historical) Indicators

#### *i. Cumulative Emissions*

Cumulative emissions is an indicator of historical responsibility for climate change. This indicator sums each year's emissions for a given country into a single number. Thus, it is backward-looking, making it an improvement (in terms of its relationship to causal responsibility) over the *yearly emissions* indicator. Cumulative emissions weigh all historical emissions equally, regardless of when they occurred; that is, it is backward-looking but *not* backward-discounting. So, a ton of $CO_2$ emitted in 1950 has the same "value," according to this indicator, as a ton of $CO_2$ emitted in 2005. This indicator is also not forward-looking and different gases cannot be compared (see Table 3).[6]

This indicator is included in CAIT, because it is very simple to calculate and may be a decent proxy for other responsibility indicators. For reasons of data availability it includes only $CO_2$ emissions from fossil fuel and cement production (1850-2005) and from land-use change (1950-2000). CAIT allows users to make cumulative emission calculations for customized time periods (e.g., 1950 to 2005).

#### *ii. Concentrations*

The *concentrations* indicator assesses each country's share of the greenhouse gases that are presently in the atmosphere. This indicator is similar to *cumulative emissions*. However, this indicator is backward-

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[6] Today's GWPs can be applied to the summed quantity of each greenhouse gas. However, GWPs depend on the composition of the atmosphere at a particular point in time and therefore have changed over time.

discounting, as it takes into account the decay of the gases out of the atmosphere (e.g., through absorption in terrestrial and oceanic sinks over time). Calculating this indicator for each country requires applying an absorption rate function to the historical emissions of each of the GHGs to determine the stock of those emissions that are present in the atmosphere today. One complication is that the decay rate, shown below, is understood to change over time.

A more serious difficulty of this indicator is that concentrations of different GHGs cannot be aggregated, and that it does not include a forward-looking dimension. Presently, however, historical emission estimates (at the country level) are not available for any gases other than $CO_2$. Thus, this indicator is now included in CAIT for $CO_2$ only (for fossil fuels and cement, from 1850 to 2005, and land use change, from 1950-2000).

For calculating the concentrations, we have used the simple methodology that had been applied in the original Brazilian Proposal and which was recommended as the preliminary default by the UNFCCC expert group (UNFCCC, 2002). It assumes a constant decay function for $CO_2$ composed of four exponential functions. The formula is as follows:

$$\Delta\rho(t) = c\int_{0}^{t} E(t')\cdot\left[ f_0 + \sum_{S=1}^{3} f_S \cdot e^{\left(-\frac{t-t'}{\tau_S}\right)} \right] dt'$$

*with*,

| S | $f_S$ | $\tau_S$ |
|---|---|---|
| 0 | 0.152 | - |
| 1 | 0.253 | 171 years |
| 2 | 0.279 | 18 years |
| 3 | 0.316 | 2.57 years |

$\Delta\rho(t)$: Additional $CO_2$ concentration due to the emissions as a function of time in ppmv
$t$: Time in years
$c$: Constant: 0.47 ppmv/GtC
$E(t)$: Emissions of $CO_2$ as a function of time in GtC
$\tau_S$: Lifetime of the fraction *s* in years
$f_S$: Weight given to fraction *s*

With this methodology and $CO_2$ emission data from fossil fuels and cement (1850-2000) and land use change (1950-2000), we calculate an elevated concentration in the year 2000 of +83 ppmv (about 62 from fossil fuels and 21 from land use change) compared to the observed + 90ppmv. The difference is due to the simple representation of the carbon cycle and leaving out the land-use change and forestry emissions prior to 1950.

CAIT only shows relative contributions to this increase in concentrations (in percent of global contribution to concentration increase) not absolute values (in ppmv), as relative figures are more reliable. Errors in the calculation method that influence the absolute values are applied in the same way to all countries (e.g., the constant *c*). By taking the relative values, these errors are cancelled out. Earlier comparisons of simple models with more sophisticated models have shown that, although the absolute values of temperature change may differ significantly, the relative values are relatively close (UNFCCC, 2002; den Elzen, 2002).

Future versions of CAIT may include a more sophisticated method to calculate contributions to concentration based, for example, on a full carbon cycle model, taking into account the conclusions of the ongoing scientific work on this subject.

### *iii. Radiative Forcing*

To compare the effect of the increased concentrations of the greenhouse gases for different gases, one needs to move one step further on the "chain of causality": from concentrations to radiative forcing. This relation is well described by the IPCC. In the simplest way, it can be approximated by a proportionality factor (1ppmv concentration causes $x$ $W/m^{-2}$ radiative forcing). Especially for $CO_2$, however, this relation is not linear (see above).

The radiative forcing indicator is not included in CAIT because currently country data for only one greenhouse gas ($CO_2$) is included, and therefore the advantage of being able to aggregate over greenhouse gases does not apply.

### *iv. Weighted Concentrations (future effects of historical emissions)*

This *weighted concentrations* indicator applies the concept of GWPs to concentrations (Höhne and Harnisch, 2002: 4). This indicator makes the concentrations and radiative forcing indicators 'forward looking.' For example, $CO_2$ decays much slower in the atmosphere than methane. Elevated $CO_2$ concentrations due to a particular source may cause *lower* radiative forcing today than elevated $CH_4$ concentration of that source. But because $CO_2$ decays slower, the cumulative future effect of the $CO_2$ may be *higher* than the cumulative effect of the $CH_4$.

This *weighted concentrations* indicator takes this consideration into account and gives the concentration of each gas (in e.g., ppmv) a certain weight, just as the GWP gives each emission (in e.g., tons) a weight. Long living gases (like $CO_2$) receive a higher weight than shorter living gases (like $CH_4$). The indicator is therefore 'backward-looking', 'backward-discounting', and 'forward-looking', and is comparable for all gases. As shown in Table 3, it is the only indicator that scores well in each category. This indicator also scores well in the categories shown in Table 2.

Currently, this indicator is not included in CAIT, for the data availability reason mentioned above. If used for $CO_2$ only, this indicator would result in the same relative contributions as the concentrations indicator. When historical estimates of non-$CO_2$ GHGs become available at the country level, this indicator can be added to CAIT.

### *v. Temperature Increase*

Moving further down the cause-effect chain, it is possible to develop an indicator for each country's relative contribution to global temperature increase. The rationale for this indicator is that it is not the accumulation of emissions that we are concerned about, but the changes to the climate resulting from temperature increase. It has gained considerable attention because this kind of indicator was proposed by the delegation of Brazil during the 1997 Kyoto Protocol negotiations.

As an indicator of responsibility, the Brazilian Proposal considers the effects of historical emissions on the *present* global average temperature increase (approximately 0.6 °C). This means that it attempts to account for the proportion of the current temperature increase attributable to the historical emissions of each region or country. Considering the evaluation criteria discussed above, one shortcoming of this approach is that it is not forward-looking (Elzen et al., 1999; Höhne and Harnisch, 2002). Due to the delay between emissions and increase in temperature, the indicator of contribution to *present* temperature increase weighs past emissions significantly more heavily than emissions from more recent years. Yet, recent emissions will undoubtedly have an effect on future warming.

Thus, to make the indicator of contribution to temperature increase forward-looking, an endpoint—such as 2100 or the date when temperature would peak globally—could be chosen. This would assess the effect of emissions over a given period (e.g., from 1900 to 2005) on the temperature in the year 2100 rather than the present.

As this indicator is further down the cause-effect chain, its calculation is more complex, the processes more uncertain, and additional non-linear effects and feedbacks are present. Either a simple relationship between radiative forcing and temperature change can be assumed (as in CAIT) or a sophisticated climate model may be used to represent these processes in greater detail.

Because of the complexities and unresolved issues associated with attributing relative responsibility for temperature increases, temperature increase in CAIT is calculated in the simplest linear form. The methodology is based on the revised Brazilian Proposal and the default conditions preliminarily suggested by the UNFCCC expert group.

The methodology starts with the concentrations, as calculated above. It assumes a linear relationship between concentrations and radiative forcing. For temperature increase, similar to concentrations, a constant response function for temperature increase composed of two exponential functions is used. The formula used is as follows:

$$\Delta T(t) = \lambda \int_{0}^{t} \alpha \cdot \Delta\rho(t') \left( \frac{l_1}{\tau_1} e^{\left(-\frac{t-t'}{\tau_1}\right)} + \frac{l_2}{\tau_2} e^{\left(-\frac{t-t'}{\tau_2}\right)} \right) dt'$$

*with,*

| S | $l_S$ | $\tau_S$ |
|---|---|---|
| 1 | 0.59557 | 8.4007 years |
| 2 | 0.40443 | 409.54 years |

$\Delta T(t)$: Increase in global-average surface temperature in °C

$\lambda$: Constant: 0,99 °C/Wm$^{-2}$

$\alpha$: Constant: 0.01584 Wm$^{-2}$/ppmv

$\Delta\rho(t)$: Increase in CO$_2$ concentration in ppmv as calculated above

$\tau_S$: Relaxation time of fraction *s* of the climate system in years

$l_S$: Weighting of the fraction *s*

With this methodology and CO$_2$ emission data from fossil fuels and cement (1850-2000) and land use change (1950-2000), we calculate a temperature increase in the year 2000 of 0.73°C (about .55 from fossil fuels and .18 from land use change) compared to the observed 0.6°C. The difference is due to the simple representation of the climate system, the omission of emissions of other greenhouse gases and aerosols (and $CO_2$ from land use change prior to 1950), other natural factors that influence the temperature, non-linearities, and feedbacks.

As with concentrations, CAIT shows only relative contributions to this increase in temperature (in percent of global contribution to temperature increase), not absolute values (in °C) as these are more reliable. Errors in the calculation method that influence the absolute values are applied in the same way to all countries (e.g., the constants $\lambda$ and $\alpha$). By taking the relative values, these errors are cancelled out. Earlier comparisons of simple models with more sophisticated models have shown that, although the absolute values of temperature change may differ significantly, the relative values are relatively close. (UNFCCC, 2002; den Elzen, 2002.)

Future versions of CAIT may include a more sophisticated method to calculate contributions to temperature increase based, for example, on a climate system model, taking into account the conclusions of the ongoing scientific work on this subject.

It is important to note that some of the difficulties described above are eliminated for the weighted concentrations indicator. The use of the weighted concentration indicator obviates the need for complex models to account for, *inter alia*, radiative effects of increases in solar radiation, changes in clouds cover, and non-GHGs (like aerosols). In addition, the weighted concentrations indicator takes into account the delay of the effects and does not need the evaluation at a point in time in the future.

### *vi. Impacts*

The end of the cause-effect chain is, of course, physical impacts from climate change, such as sea level rise, extreme weather events, ecosystem stresses, etc. As shown in Table 2, *close to impacts* was one of the categories against which the various responsibility indicators are evaluated. Thus, in this sense, this indicator scores the highest. However, this is not a practical indicator. First, it suffers from many of the same challenges as contributions to temperature increase. Second, there are additional hard-to-account-for feedbacks and non-linearities at this stage. Practically speaking, some impacts may take thousands of years to play out. Table 2 shows that *uncertainty* is the highest with this indicator. Furthermore, many impacts are hard to attribute to climate change per se, never mind the specific contributions of particular countries.

Finally, and perhaps most problematic, impacts from climate change are, and will increasingly be, highly diverse. It is not clear what specific impact this indicator would measure, or how it would aggregate multiple impacts. There is no single impacts indicator that could meaningfully account for the diverse (and unknown) impacts of climate change, especially since some impacts, like sea level rise, will be very significant for some countries (e.g., low lying coastal states) and insignificant for others (landlocked states). For these reasons, this indicator is not included in CAIT.

## 2.4. Emissions Intensities

Emission intensities are included in CAIT mainly due to their relevance in policy matters. First, intensity indicators have been proposed by some as indicators upon which to base a national performance target.[7] Second, intensity indicators in some instances may constitute an indicator of technological potential to reduce emissions. For example, a country with a higher intensity may have an opportunity to switch to lower carbon-emitting fuels (e.g., from coal to gas), or to increase the energy efficiency of technologies or processes. Finally, looking at a country's intensities over time—with the *Trends* feature of CAIT—can illuminate whether the economy has been de-carbonizing. Countries that, over time, are switching to lower carbon fuels, improving energy efficiencies, and/or restructuring their economies toward production of lower carbon goods and services will have declining intensities.

Three emissions intensity indicators are included in CAIT, each of which is treated in more detail below.

### *i. GHG Intensity of the Economy*

GHG intensity of the economy is a measure of greenhouse gas emissions per unit of economic output. GHG emissions are measured as $CO_2$ only, or $CO_2$ and additional greenhouse gases (depending upon the availability of non-$CO_2$ data in CAIT). Economic output is expressed as gross domestic product (GDP) (see Section 3.2.iii).

$CO_2$ intensity of the economy is a function of two variables. The first variable is *energy intensity*, or the amount of energy consumed per unit of GDP. This reflects both a country's level of energy efficiency and its overall economic structure, including the carbon content of goods imported and exported. An economy dominated by heavy industrial production, for instance, is more likely to have higher energy intensity than one where the service sector is dominant, even if the energy efficiencies within the two countries are identical. Likewise, a country that relies on trade to acquire (import) carbon-intensive goods will—when all other factors are equal—have a lower energy intensity than those countries that manufacture those same goods for export.

The second component of emissions intensity is *fuel mix* or, more specifically, the carbon content of the energy consumed in a country, which is also included in CAIT (see below, Section 2.4.ii). The product of energy intensity (E/GDP) and fuel mix ($CO_2$/E) is equal to $CO_2$ intensity ($CO_2$/GDP).

When *non-$CO_2$ gases* are included in this indicator, additional factors beyond energy intensity and fuel mix affect intensities and trends. For instance, $CH_4$ and $N_2O$ emissions from agricultural sources might be influenced significantly by commodity prices and shifts in international livestock and grain markets. Land-use change and forestry emissions might also be influenced by domestic and international forces unrelated to the factors discussed above.

Measurement Unit. Tonnes of carbon dioxide per million dollar ($tCO_2$/Mill. \$). Dollars may be measured in PPP (international dollars) or market exchange rates (\$US). GDP measures are in constant currency (i.e., adjusted for inflation), using the year 2000 (for \$US) or 2005 (for \$Intl) as the base year.

Year(s) of Coverage. 1980-2005.

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[7] See e.g., Bush Administration, 2002 and Argentina, 1999.

Source(s). This indicator is a composite of two data sources: (1) *GDP*: World Bank, 2008 (see Section 3.2.iii) and (2) *GHG Emissions* (see GHG Sources and Methods, at http://cait.wri.org).

### *ii. Carbon Intensity of Energy Use*

Carbon intensity of energy use measures the carbon content of a country's energy consumption (i.e., carbon emissions divided by energy use). Carbon emissions in this indicator cover economy-wide emissions from fossil fuels and cement manufacture. Energy use here refers to primary commercial energy consumption, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

In terms of carbon intensity, coal has the highest carbon content, followed by oil, and then natural gas. Nuclear, and renewable sources like hydro, geothermal and wind, have low or zero carbon intensities. Accordingly, nations that rely more on coal and oil will have the highest carbon intensities of energy use, irrespective of whether that energy is used efficiently or not. Carbon intensity of energy use may in some cases be an indicator of fuel switching options available to reduce emissions. Fuel mixes, however, are also highly correlated with countries' natural endowments of coal, oil, gas, and hydropower capacity (see Section 4.2.ii).

Measurement Unit. Tonnes of carbon dioxide per tonne of oil equivalent ($tCO_2$ / toe).

Year(s) of Coverage. 2005 (Note: 1960-2005 can be analyzed under CAIT's *Trends* features).

Source(s). This indicator is a composite of two data sources: (1) *Energy Use*: World Bank, 2008 (original source: IEA and UN, Energy Statistics Yearbook) and (2) *GHG Emissions* (see GHG Sources and Methods, at http://cait.wri.org).

### *iii. Carbon Intensity of Electricity Production*

Carbon intensity of electricity production measures carbon emissions per unit of electricity (kilowatt hour, kWh) generated. Electricity generation is measured at the terminals of all alternator sets in a station. In addition to coal, oil, gas, hydropower, and nuclear power generation, it covers generation by geothermal, solar, wind, and tide and wave energy, as well as that from combustible renewables and waste. Generation includes the output of electricity plants that are designed to produce electricity only as well as that of combined heat and power (CHP) plants. However, carbon emissions in this indicator cover only those from the electric power sector (i.e., only half – an estimated figure – of the emissions reported from CHP plants are included in the totals).

The carbon intensity of electricity production is one component of the carbon intensity of energy use (described above). As with carbon intensity of energy use, this indicator may suggest the availability of fuel switching options.[8] However, this indicator is narrower than the carbon intensity of energy use, as it covers only electricity production.

Measurement Unit. Grams of carbon dioxide per kilowatt-hour (g $CO_2$ / kwh).

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[8] This indicator also reflects the natural resource endowments countries have, with respect to both fossil fuels and renewable energy. For this reason, this indicator is also included under Natural Factors Indicators (as "Energy Use Mix"). See Section 4.2.

Year(s) of Coverage. 2005.

Sources. This indicator is a composite of two data sources: (1) World Bank, 2008 from *Electricity generation*: IEA, 2007b and (2) *Carbon emissions from electricity generation*: IEA, 2007a.

## 3. Socio-Economic Indicators

CAIT includes various socio-economic indicators relevant to climate protection. Within this context, the Climate Convention provides some useful guidance to determine a set of relevant indicators. The Convention's Preamble acknowledges countries' "social and economic conditions," and affirms the importance of achieving "sustained economic growth and the eradication of poverty" along with "sustainable social and economic development." Further in the Convention, article 3.1 refers to the respective "capabilities" of countries "to protect the climate system." In this section, we use these concepts—in particular the principle of capability—in attempting to identify socio-economic indicators that may be relevant for climate protection.

### 3.1. The Concept of Mitigative Capacity

Capability, generally, refers to the ability of individuals, institutions, governments, and other entities to perform functions, solve problems, and achieve objectives (UNDP, 1997). In the context of the Convention, "capability" might refer to a country's ability to "protect the climate system." Assessing a country's capability to mitigate climate change is obviously a complex and multifaceted undertaking.

To provide insight on the topic, the IPCC has developed the concept of *mitigative capacity*. From Yohe (2001), the IPCC adopts and discusses distinct "determinants" of mitigative capacity (in no particular order):

1. range of viable technological options for reducing emissions;
2. range of viable policy instruments that might affect the adoption of these options;
3. existence and structure of critical institutions to decide and implement the policies, and the derivative allocation of decision-making authority;
4. availability and distribution of financial resources required to underwrite their adoption, and the associated, broadly defined opportunity cost of devoting those resources to mitigation;
5. stock of human capital, including education and personal security;
6. stock of social capital, including the definition of property rights and the country's access to risk spreading processes (e.g., insurance and capital markets);
7. the ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers themselves.

Before implementing national policies to mitigate climate change, governments need a variety of capacities, including those to carry out inventories of their greenhouse gas emissions and assess various options for protecting the climate. Human capital (i.e., skills, determinant 5), financial resources (determinant 4), and information management (determinant 7) may be crucial at this stage.

Actually formulating and implementing national climate policies may require policy coordination at the national level, and in many cases, buy-in from key domestic constituencies, including industry, provincial governments, NGOs, and the public. This may require new laws or regulations covering diverse economic sectors. Further, governments may need to exercise regulatory control over private or public entities to ensure policies are enforced. The availability of technological and policy options (determinants 1 and 2), institutional structures and proper allocation of decision-making authority (determinant 3), financial resources (determinant 4), human capital (determinant 5), social capital (determinant 6), as well as information management (determinant 7), might be particularly important.

Thus, mitigative capacity can be a function of technology, institutions, empowerment, wealth, equity, skills, infrastructure, and information (Yohe, 2001). Discussion by IPCC (2001: 104) and Yohe (2001) emphasize that these determinants are interrelated. Accordingly, a country's mitigative capacity might be low if it is weak in *any one of the above determinants.*

Although related, there is a distinction between *capacity* and *opportunity* to mitigate climate change. Opportunity refers to a favorable combination of elements. For example, the availability of technological options (determinant 1) constitutes an opportunity to reduce emissions. However, other obstacles could still stand in the way, thereby preventing opportunities from being realized. Governments may face "social, cultural, political, and economic constraints" as well as barriers within the decision-making process itself (IPCC, 2001: 104). Other constraints could also be added to these, including high opportunity costs (determinant 4) of devoting resources to climate policy. The mitigative capacity to reduce emissions may thus be low, even when significant abatement opportunities exist.

## 3.2. Indicators

Mitigative capacity is complex and multifaceted. The fact that a weakness in a *single* determinant can result in an *overall* low mitigative capacity makes indicator development especially difficult. Nevertheless, the concept of mitigative capacity can still serve as a general framework to guide decisions on what socio-economic indicators are relevant to climate protection. Relevant indicators, which are discussed below, include health, education, income per capita, size of economy, energy use, and governance. In addition, the emissions intensity indicators included in CAIT and discussed in Section 2.4—namely, GHG intensity of the economy, carbon intensity of energy use, and carbon intensity of electricity production—may also be relevant to mitigative capacity, in that they may reflect opportunities (or the lack thereof) to reduce emissions. The hope of including all of these indicators in CAIT is to reflect some (possibly all) of the determinants of mitigative capacity previously discussed.

For each indicator, a brief description is given, including its relevance to mitigative capacity. Units of measure, data sources, year(s) of coverage, methodologies (if applicable), and notes are also shown below.

### *i. Life Expectancy at Birth*

Life expectancy measures the number of years a newborn infant would live if prevailing patterns of age-specific mortality rates at the time of birth were to stay the same throughout the child's life.

According to the World Health Organization, life expectancy provides a useful indicator of the overall health effects of environmental and other risk factors in a given population. The link between health and climate protection is one of opportunity cost. Countries with significant public health problems (and related societal consequences like those mentioned above) are likely to find it socially and politically difficult to allocate resources to climate protection. The opportunity costs (determinant 4) of devoting scarce resources to climate change mitigation may be high in such countries.[9]

Measurement Unit. Years.

Year(s) of Coverage. 2005.

Source(s). UNDP, 2007.

### *ii. Education: Literacy Rates and Enrollment Ratios*

Education levels are measured by adult literacy rates and school enrollment. WRI has calculated a simple education index that includes literacy and enrollment data, following the methodology used by UNDP (2003b) in calculating the Human Development Report's education index. Adult literacy is the percentage of people aged 15 and above who, with understanding, can read and write a short, simple statement on their everyday life. The gross enrollment ratio is the number of students enrolled in a level of education, regardless of age, as a percentage of the population of official school age for that level. The ratio used in CAIT is a combination of primary, secondary, and tertiary gross enrollment.

Countries with higher levels of education are likely to have higher mitigative capacity. Like income, this is supported by the determinants of mitigative capacity discussed above. Most specifically, education levels speak to a country's stock of human capital (determinant 5). Those countries with higher levels of educational attainment are likely to have more skilled staff to undertake important functions related to climate protection, including skills for implementing low carbon technologies, carrying out economic assessments and greenhouse gas accounting, information management systems, and an array of other activities.

Measurement Units. (1) *Literacy*: % of people ages 15 and above. (2) *Enrollment*: Combined Primary, Secondary, and Tertiary Gross Enrollment Ratio (%).

Year(s) of Coverage. 2005.

Source(s). UNDP, 2007.

Methodology. In calculating a simple education index, we have followed the methodology used by UNDP (2003b) in calculating the Human Development Report's education index. Accordingly, we have assigned a weight of two-thirds to the literacy rates, and a weight of one-third to the enrollment ratios to generate the aggregate education index. Again, following on UNDP, a 99% literacy rate is assumed as a maximum value and used for developed countries with no data. Regarding enrollment rates, some data are preliminary UNESCO Institute for Statistics estimates, subject to further revision. Some data refer to years other than 2005. The gross enrollment ratio can be greater than 100% as a result of grade repetition and entry at ages younger or older than the typical age at that grade level. For more details, see UNDP (2003b: 237-240).

Notes. The literacy data used measures only basic reading and writing ability. To provide a more accurate measure of mitigative capacity, a more nuanced measure of educational achievement is

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[9] However, in some cases these opportunity costs may be partially offset by the potential ancillary health benefits of climate protection (OECD 2000).

needed. Literacy "proficiency tests," for example, assess a range of reading and writing skills and are able to distinguish a spectrum of literacy levels, thus providing a finer measure of how well adults use information to function in society. Unfortunately, no such data currently exists that is globally comprehensive.[10] In the absence of a fine grained measure of educational achievement levels, we have used UNDP's measure as a reasonable proxy.

### *iii. Income Per Capita and Size of Economy (GDP)*

Gross domestic product (GDP) is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. There are two GDP indicator included in CAIT: income per capita (i.e., GDP per capita) and size of economy (i.e., total GDP). Either may be measured in purchasing power parity (PPP, international dollars) or market exchange rates ($US).

Most directly, *income per capita* is an indicator of financial resources, captured in determinant 4 above. Average incomes may also be likened to the concept of "ability to pay," meaning that richer countries are better equipped to pay for climate change mitigation in a manner that avoids sacrificing basic needs of citizens. However, this indicator also touches on other determinants mentioned above, although perhaps indirectly. For example, those countries with substantial financial resources per capita are better able to invest in other kinds of capacity development useful for climate protection.

*Size of economy* itself is a function of other variables, especially population. It is directly related to determinant 4, discussed above, in that those countries with larger economies are likely to have larger amounts of aggregate financial resources than smaller economies, all other things being equal. The larger an economy is, the larger may be public and private investments aimed to mitigate climate change as well as the amount (and effect) of public subsidies towards low carbon investments. In this context, the capacity to influence global emissions is greater in larger economies than in smaller ones, all other things being equal.

<u>Measurement Unit</u>. GDP, measured either in (1) purchasing power parity (PPP, international dollars) or (2) market exchange rates ($US).[11] Both measures are in constant currency (i.e., adjusted for inflation) using 2005 and 2000 as the base year, respectively. GDP-PPP is gross domestic product converted into international dollars using purchasing power parity rates. An international dollar has the same purchasing power in the domestic currency as a U.S. dollar has in the United States.

<u>Year(s) of Coverage</u>. 2005 (<u>Note</u>: 1960-2005 can be analyzed under CAIT's *Trends* features).

<u>Source(s)</u>. (1) World Bank, 2008 (original source, PPP: World Bank, International Comparison Programme database; estimates are based on regression performed by the World Bank) (original source, $US: World Bank national accounts data and OECD National Accounts data files). (2) <u>Supplementary Source</u>. PPP data for Afghanistan, Bahamas, Barbados, Cook Islands, Cuba, Iraq,

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[10] See International Adult Literacy Survey (IALS), a 22 country survey conducted between 1994 and 1998, <u>http://www.nifl.gov/nifl/facts/IALS.html</u>.

[11] Users can select either measurement unit under "Display," which is found under CAIT's "Customize" menu.

North Korea, Nauru, Niue, Palau, Qatar, Sao Tome & Principe, Serbia & Montenegro, Taiwan, Turkmenistan, and Zimbabwe are from the CIA *World Factbook* (various years).

### *iv. Energy Use*

Commercial energy use refers to apparent consumption, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. The World Bank (see source below) has revised the aggregation methods and procedures to include estimates for countries for which data are not available.

As a significant driver of greenhouse gas emissions, levels of energy use may suggest the ability of societies to mitigate emissions. Other factors held constant, those countries with high levels of energy use per person may be more capable of limiting or reducing greenhouse gas emissions than those countries with low levels of energy use. In part, this is due to the differing penetration rates of energy-intensive goods and services across countries. For example, in some developing countries, the penetration of refrigerators, air-conditioners, televisions, computers, automobiles, etc.—all of which require energy—is relatively low compared with industrialized countries. As societies develop, it is expected that energy use will increase. However, the degree to which this increases emissions will depend especially upon the carbon intensity of the energy use (see subsection v. below).

Measurement Unit. Tonnes of oil equivalent (total and per capita).

Year(s) of Coverage. 2005 (Note: 1960-2005 can be analyzed under CAIT's *Trends* features).

Source(s). World Bank, 2008 (original source: IEA and UN, Energy Statistics Yearbook).

### *v. Aggregated Governance Indicator*

This indicator attempts to capture the complex and multifaceted aspects of governance as a composite index based on six dimensions of governance: (1) political stability (e.g., perceptions of the likelihood of armed conflict); (2) government effectiveness (e.g., bureaucratic quality); (3) regulatory quality (e.g., regulatory burden, market-friendliness); (4) rule of law (e.g., black markets, enforceability of contracts); (5) voice and accountability (e.g., free and fair elections, political rights); and (6) corruption (e.g., prevalence among public officials). Each of these dimensions is weighted equally in this indicator. This governance indicator, devised by the World Bank, draws on 35 separate sources of subjective data on perceptions of governance constructed by 32 organizations.

Although some more than others, all dimensions of governance are relevant to mitigative capacity. The dimensions of governance captured in this indicator are especially linked to determinants 3 (institutions and decision-making authority), 6 (social capital), and 7 (information). Political instability or inability to exercise regulatory control over domestic entities, for example, might be barriers to the adoption and implementation of new technological options (determinant 1) and policies (determinant 2). Higher levels of "voice and accountability" might open up political space for NGOs and other interest groups to demand government actions on climate change.

Source(s). Kaufmann et al., 2008 (World Bank).

Notes. Many indicators attempt to gauge the effectiveness of governments and the extent of democratic institutions (see, e.g., UNDP, 2002: 36). Because of the complex nature of governance, a single indicator, whether objective (e.g., number of NGOs) or subjective (e.g., government stability) is unlikely to capture the wide range of relevant concepts. The World Bank has developed governance indicators in a wide variety of areas for most countries and combined them into composite indices. These indices cover six dimensions of governance mentioned above (Kaufmann et al., 2002, 2003).

The governance indicator used in CAIT is qualitatively different than the other indicators described in this section. Namely, governance is measured by a *subjective* indicator, whereas the others are objective indicators. The World Bank (and others, see UNDP, 2002: 37) governance indicators draw on 17 separate sources of subjective data on perceptions of governance constructed by 15 different organizations (Kaufmann et al., 2002).[12] The Bank points out that:

> "the margins of error associated with the composite estimates of governance for each country are typically quite large relative to the units in which governance is measured. This implies that cross-country comparisons of the quality of governance based on this type of data need to be made with considerable caution: many of the small measured differences in governance perceptions are too small to be statistically—or practically—significant, and only large differences are likely to be statistically meaningful."

## 3.3. Discussion

Many different socio-economic indicators could be chosen for inclusion in CAIT. For the reasons discussed above, we have chosen some that seem particularly relevant to the factors that shape mitigative capacity, as discussed in the IPCC Third Assessment Report and Yohe (2001). A further consideration was, of course, data availability; there is no ready-made indicator set that corresponds to all of the socio-economic factors relevant to climate protection. Overall, the suggestion is that, all other things held equal, those countries with higher levels of income, education, life expectancy, energy use, and governance will also be those with higher abilities to protect the climate system.

It is worth noting that several possible socio-economic indicators relevant to mitigative capacity are not included.

The Human Development Index (HDI) elaborated by the UNDP has not been included. However, its elementary components (GDP per capita, education index, and life expectancy) are included in CAIT and described above.

Although important, another notable indicator *not* represented here is mitigation cost. The main reason is the lack of reliable and comparable country level marginal abatement costs curves. In most economic models, countries tend to be aggregated together into regions. Even if the world were totally disaggregated at the country-level, marginal abatement costs would vary according to different economic models. Differences may stem from many factors, such as the model type (sectoral versus computable general equilibrium models), divergent assumptions relative to various elasticities, and

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[12] At the same time, however, since governance is a subjective concept, measuring it with subjective indicators has some advantages. Objective indicators, like voter turnout or number of NGOs, may not capture important aspects of governance.

divergent business-as usual scenarios. There is also no credible proxy indicator for country-level mitigation costs.

Also, conceptually, the availability of low cost reductions does not necessarily support the proposition that a country has the ability to take advantage of those reductions. "Low hanging fruit" often remains on the vine, and the lack of mitigative capacity might be precisely the reason why reduction opportunities are not exploited. Climate Convention principles seem to support this interpretation. Article 3.3 speaks directly to the topic of costs: "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost." This suggests that the *policy mechanisms* adopted should exploit inexpensive abatement opportunities everywhere; but this does not mean that the costs should be borne by that country where those opportunities happen to be concentrated.

Overall, mitigation cost is relevant to mitigative capacity, but the connection is indirect. Yohe (2001) explains that enhancing some determinants of mitigative capacity is likely to lower mitigation costs. Improvements in social capital (e.g., the definition and distribution of property rights and the accessibility of risk-spreading instruments like insurance), information availability, and equity of resource distribution, for instance, are "indirect" ways of reducing mitigation costs.

## 4. Natural Factors

A final category of indicators included in CAIT is termed "natural factors." Like the previous two categories, the rationale for inclusion of this category is loosely traced to the principles of the Climate Convention. Article 3.2 of the Climate Convention states that full consideration should be given to the "*specific needs and special circumstances* of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention."

### 4.1. The Concept of Natural Factors

"Specific needs and special circumstances" may refer to at least two situations faced by Parties. First, it may refer to circumstances that are truly unique or special to an *individual* Party. For example, Canada's situation as a large industrialized country bordering an even larger non-Party to the Kyoto Protocol can be said to be unique. Circumstances such as these are not particularly conducive to representation in an indicator framework such as this, namely because they tend to apply to only one or a few countries.

Second, there are some circumstances relevant to *many* Parties that have frequently been asserted in past negotiations. These circumstances tend to be derived from unchangeable facts of nature, geography, geology, or climate that Parties face. Like the example above, these are circumstances generally beyond the reach of public policy; circumstances that, if not taken into account, could result in "disproportionate or abnormal burdens" for certain Parties (Art. 3.2). We have termed these "natural factors" and included several of them in CAIT.

Specifically, Neumayer (2002) cites three natural factors that help explain differences in $CO_2$ emissions across countries: (1) climatic conditions, (2) availability of renewable and fossil fuel resources, and (3) transportation requirements of countries. Similarly, in seeking to understand cross-country differences in $CO_2$, Schipper et al. (2000) refer to the importance of "irreducible structural components." This refers to factors like population size, land area, industrial structure, natural resource endowments, and climate. These factors are "irreducible" in that they are difficult or impossible to change as a result of public policy. Yet, in many countries, significant quantities of greenhouse gas emissions can be traced to these factors.

Natural factors like the ones mentioned above can be thought of as having a moderating or aggravating influence on greenhouse gas emissions, discussed in Section 2. In other words, evaluating a country's emission levels (present or historical) might be done in light of certain natural factors faced by a country. For example, all other things equal, one might expect higher emission levels from a country with high heating and cooling needs, a large population and geographic size, etc. These kinds of natural factors, if not recognized and accounted for in certain policy domains, could result in "disproportionate or abnormal burdens." For reasons of equity or fairness, some Parties may wish that such factors be recognized in relevant policy decisions.

## 4.2. Indicators

This section describes the natural factor indicators included in CAIT. For each indicator, a brief description is given, including its relevance to natural factors. Units of measure, data sources, year(s) of coverage, and methodologies (if applicable) are also shown below. Table 4 below summarizes the national circumstances that are included in CAIT. Additional relevant indicators could be formulated. The selection here is limited due to data availability and other practical considerations.

**Table 4. Natural Factor Indicators**

| Natural Factor | Indicator(s) |
|---|---|
| Climate | a. Heating needs (heating degree days) |
| | b. Cooling needs (cooling degree days) |
| Natural Resources | a. Fossil fuel reserves (coal, oil, and gas); by tonnes of oil equivalent and tonnes of carbon dioxide equivalent (total and per capita) |
| | b. Energy use mix; by carbon intensity (carbon per unit of electricity production) |
| Geography | Total land area impacted by human activity (proxy for transport requirements) |
| Population | Total number of people |

### *i. Climatic Conditions: Heating and Cooling Needs*

Two indicators are used to express climatic conditions—heating and cooling degree days (HDD and CDD). The "degree-day" is a measure commonly used to evaluate demand for heating and cooling services. HDDs and CDDs are based on departures from an average temperature of 18 °C (65 °F), a base temperature considered to have neither heating nor cooling needs. For example, a weather station recording a mean daily temperature of 28° C would report 10 CDDs for that particular day. Hypothetically, if the daily average temperature were a constant 28° C all year round, that weather station would report 3650 CDDs over the course of one year (10 CDD x 365 days).

Heating and cooling degree day data is widely used in the United States and several other OECD countries. However, it is unavailable in most other countries of the world. WRI's methodology for calculating heating and cooling degree days is based on reported temperatures throughout the world, and a population weighting system similar to the one used in the United States. For a full description of data sources and WRI's methodology, see "Data Note: Heating and Cooling Degree Days." Available at: http://cait.wri.org.

All other factors held constant, those countries with higher heating and cooling needs (i.e., colder and warmer national climates, respectively), will emit larger quantities of greenhouse gas emissions.

It is important to recognize that, like all indicators, heating and cooling degree days are merely a proxy for climatic condition that might influence greenhouse gases. There are inherent limits to the usefulness of such indicators. First, it is not the case that a degree day calculation will capture each and every need for heating or cooling services, in part due to the possibility of extreme high and low temperatures (which can be obscured by averages). Other climatic factors, such as humidity and wind, may also influence the demand for heating and cooling services. Likewise, the carbon content of the energy used to deliver heating and cooling services will, of course, have a significant influence on the greenhouse gas implications of temperatures. Overall, degree days should be understood as a reasonable approximation—not an exact measure—of the heating and cooling needs (all other factors held equal) of a particular location.

Given that we are using national averages, the actual heating and cooling needs of an entire country would of course also be a function of *population size*.

Measurement Unit. Degree days. CAIT provides two HDD and CDD measures for each country: (1) the per capita / national average (labeled "degree days") and (2) the national total (labeled "weighted by population"). The latter is simply the degree day average for a particular country multiplied by its population.

Year(s) of Coverage. Historical averages vary from country to country.

Source(s) and Methodologies. See "Data Note: Heating and Cooling Degree Days." Available at: http://cait.wri.org.

### *ii. Fossil Fuel Reserves*

Fossil fuel reserves are measured as proved reserves; those quantities of coal, oil, and natural gas that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.

Fossil fuel reserves represent natural endowments of carbon-based energy resources. Domestic fossil reserves may help explain current and historical patterns of energy sector development and the resulting mix of energy sources in some countries (including those *without* substantial fossil reserves).

Measurement Units. (1) Million tonnes of oil equivalent (Mtoe) and (2) Million tonnes of carbon dioxide equivalent ($MtCO_2e$). Each measure can be expressed in total and per capita terms in CAIT. In addition, reserves can be viewed by individual fuel or a combination of fuels.

Year(s) of Coverage. 2006.

Source(s). BP, 2008, supplemented by CIA *World Factbook* (oil and gas) and WEC, 2007 (coal).

Notes. To allow comparability, reserves data has been converted into "million tonnes of oil equivalent" (Mtoe) using the conversion factors in the *Statistical Review of World Energy* (BP, 2008). Mtoe data has then been converted to carbon content by using the conversion values in the *Revised IPCC Guidelines for National Greenhouse Gas Inventories* (Tier 1). See Workbook Chapter 1. Available at: http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1wb1.pdf.

### *iii. Energy Use Mix: Carbon Intensity of Electricity Production*[13]

Carbon intensity of electricity production measures carbon emissions per unit of electricity (kilowatt hour, kWh) generated. Electricity generation is measured at the terminals of all alternator sets in a station. In addition to coal, oil, and gas, it covers generation from hydropower, nuclear, geothermal, solar, wind, and tide and wave energy, as well as from combustible renewables and waste. Generation includes the output of electricity plants that are designed to produce electricity only as well as that of combined heat and power plants. Carbon emissions in this indicator cover only those from the electric power sector (also see p. 18).

More than other indicators described in this section, carbon intensity of electricity production *can* be influenced by policy decisions (for this reason, it is included in the GHG Emissions Indicators category as well). However, this measure can also serve as a crude proxy for a natural factor. Namely, this indicator (like fossil fuels reserves) reflects to some degree a country's *energy resource endowment*. For example, countries with large coal resources—like Australia, the United States, India, China, and South Africa—have tended to exploit those resources, resulting in high carbon intensities. For other countries, hydropower potential has been exploited, resulting in lower carbon intensities. Likewise, countries that made decisions decades ago to invest in nuclear energy are likely to have lower carbon intensities.

A key reason why this indicator is chosen as a proxy for energy resource endowments is that energy resources used for electricity production are usually *domestic* in origin (i.e., not imported). The main energy resources used for electric power generation are coal (40 percent globally), gas (20 percent), hydro (16 percent), and nuclear (15 percent), (IEA, 2007b). As primary energy sources, these are traded in relatively small amounts. The one exception is gas which is typically used for power generation but is traded in moderate amounts. About 26 percent of global gas production is exported (including as liquefied natural gas (BP, 2008). In contrast, about 69 percent of global oil production is exported for consumption elsewhere (BP, 2008). Although some oil is used for power generation (about 7 percent globally), this often comes from domestic supplies of oil exporting countries (e.g., Saudi Arabia).

Finally, this indicator differs from proved reserves (discussed above) in several ways. First, it captures the carbon intensity of a country's *current* energy mix, rather than possible future emissions embodied in carbon that is still in the ground. Second, as noted, it represents the carbon content of the *total* mix of fuels in the power sector, rather than just fossil fuels. Third, this indicator can be influenced by public policy in significant ways. However, carbon intensity of electricity production tends to reflect a long history of economic forces and policy decisions that can be hard to change in the near term.

Measurement Unit. Grams of carbon dioxide per kilowatt-hour ($gCO_2$ / kwh).

Year(s) of Coverage. 2005.

Sources. This indicator is a composite of two data sources: (1) World Bank, 2008 from *Electricity generation*: IEA, 2007b and (2) *Carbon emissions from electricity generation*: IEA, 2007a.

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[13] This indicator is included in GHG Emissions Indicators (Section 2.4). As discussed in this section, the indicator is also included here, but for different reasons.

### *iv. Land Area Impacted by Human Activity*

This indicator measures populated (as indicated by lights at night) and agricultural land area within a country's borders; that is, that land area impacted by human activity.

The amount of land area within a country is an inherent and generally unchangeable feature of that country. Land area is relevant to greenhouse gas emissions in part because it reflects transportation needs, including by road and air, passenger, and freight. Schipper et al. (2000), for example, show that larger countries have by far the highest levels of domestic freight and also tend to have higher levels of domestic travel. Land area may also influence greenhouse gas emissions in other ways, such as through electric power transmission losses.

*Total* land area can be a misleading indicator, since large tracts of land in some countries may be uninhabited (or covered by bodies of water). For this reason, CAIT uses a measure of land area that has been impacted by human activities, including urban areas and agricultural areas.

Measurement Unit. Land area (sq km).

Year(s) of Coverage. 1994-1995.

Source(s). (1) *Land Area Impacted by Human Activities (% of land area)*: World Economic Forum – Environmental Sustainability Index (2001). Original source: NOAA/NGDC World Stable Lights Images - October 1994 to March 1995. Derived from DMSP OLS Nighttime Imagery during the dark half of each lunar cycle. 30 Arc Second Grid and USGS EDCDAAC Version 2.0 Global Land Cover Characteristics Data Base (USGS legend). (2) *Land area (sq km)*: World Bank, 2005 (original source: FAO, Production Yearbook and data files), supplemented by CIA, 2005.

Methodological Note. *Percent* of land area impacted and *total* land area (i.e., the two data sets above) were multiplied together to determine each countries total land area impacted by human activities. Total land area excludes inland water bodies.

Methodological Note on WRI Estimates. WRI made estimates of countries not covered by WEF-ESI's dataset of land area impacted by human activities. This was done by summing three land areas: (1) urban and built-up areas, (2) permanent croplands, and (3) temporary croplands. Most countries for which WRI made estimates have small land areas (e.g., like island states). This means that inaccuracies have a smaller impact on the cross-country distributions. The specific countries where WRI estimates were made can be seen in the relevant source data sheet of CAIT.

Supplementary Data Sources for WRI Estimates. (1) *Urban and Built-up Areas (sq km) & Croplands (sq km)*: http://earthtrends.wri.org (original source: Loveland, T.R. et al., 2000. Global Land Cover Characteristics Database (GLCCD) Version 2.0. Available at: http://edcdaac.usgs.gov/glcc/globdoc2_0.html). (2) *Permanent cropland (% of land area)*: World Bank, 2005 (original source: FAO, Production Yearbook and data files).

### *v. Population*

Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship—except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin.

While not truly a "natural" condition of a country, population size is a function of social and cultural factors with a long history. Accordingly, population is categorized as a natural factor in that it cannot easily be influenced by near-term policy changes.

Population size has a large influence on greenhouse gas emissions. Higher populations mean higher overall activity levels that drive greenhouse gas emissions, including more transportation, heating, cooling, and industrial production. Given the fundamental role of population size, all of the GHG Emissions indicators can be formulated on a per capita basis in CAIT. Population is also built into some of the other indicators, such as personal income levels (GDP per capita), which are offered both on a total and per capita basis. For this reason, population is excluded from the aggregated index feature, to avoid redundancies. Overall, whether population considerations are embedded in a particular indicator should be borne in mind when constructing aggregate indices.

Measurement Unit. Population, total.

Year(s) of Coverage. 2005 (Note: 1960-2005 can be analyzed under CAIT's *Trends* feature).

Source(s). (1) World Bank, 2008 (original source: World Bank staff estimates from various sources including the United Nations Statistics Division's Population and Vital Statistics Report, country statistical offices, and Demographic and Health Surveys from national sources and Macro International). (2) Supplementary Source. Population data for Afghanistan, Cook Islands, Iraq, Nauru, Niue, and Taiwan are from the CIA (various years).

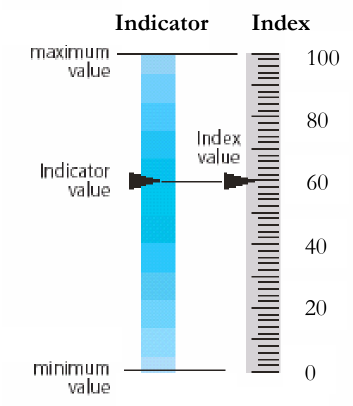
# 5. Indexing

## 5.1. General Indexing in CAIT

Many of the indicator tables and analysis features in CAIT use *indexing*. Tables depicting Health, Education, Carbon Intensity, and other indicators, for example, show index values (sometimes in tandem with absolute values).

Indexing allows us to represent the distribution of each indicator on a common scale, which can facilitate comparisons. In CAIT, indicators are indexed to a scale of 0 to 100, where 0 represents the minimum value in the data set and 100 represents the maximum value (see Figure 2).

**Figure 2**: Relationship between Indicator and Index Values.



**Source**: Adapted from UNDP (2002).

For example, Japan and Zambia respectively have the highest and lowest life expectancies. Japan, with a life expectancy of 82.3 years is accorded a value of 100. Swaziland, at 40.5 years, is given a value of 0. All other countries fall within that range. Figure 2 shows the relationship between an indicator value and an index value.

The indexing formula is as follows:

$$\text{Index value} \quad = \quad 100 \quad \text{x} \quad \frac{\text{actual value} - \text{minimum value}}{\text{maximum value} - \text{minimum value}}$$

So, Bangladesh, which has a life expectancy of 63.1 years, is assigned an index value of 54.1: 100 x ([63.1-40.5] divided by [82.3-40.5]).

## 5.2. Distinction between WRI and UNDP Indexing Methodologies

The indexing method used by WRI, described above, differs somewhat from the one used by UNDP for the Human Development Index (UNDP, 2002). The distinction between WRI and UNDP methodologies is explained here because of the prominence of the HDI as an aggregate index, and the difficulties users will encounter in attempting to replicate the HDI within CAIT.

In calculating the HDI, UNDP uses the concept of high and low "goalpost values" and distributes the data values within that range. The high and low goalpost values used by UNDP, however, do not necessarily correspond to the high and low values of the actual data (which WRI uses in constructing indices). For example, for life expectancy, UNDP used a "high" goalpost of 85 and a "low" goalpost of 25 years, whereas the actual high and low values of the life expectancy data set are 82.3 and 40.5. For GDP per capita, UNDP has used a high goalpost of $40,000 (which is less than Luxembourg's GDP per capita, the high value in that data set) and a low goalpost of $100 (which is less than the lowest value in the dataset, which is around $450). UNDP has also applied a log function in creating its GDP index, which has the effect of reducing the resulting disparities between countries.

The choice of indexing methodology will also influence the weightings in aggregate indexes. Although the UNDP combines each of its indexed data sets (education, health, and income) with equal weight to formulate the HDI, the particular indexing methods applied to each component of the index has the effect of changing their relative influence on the HDI. This is in the interest of producing a HDI that represents achievements along the different dimensions of human development, as seen by UNDP, which may not be measured perfectly by the source data. For example, UNDP states that "achieving a respectable level of human development does not require unlimited income," so accordingly they reduce the disparities between the richest nations by applying a log function and by using a $40,000 goalpost (UNDP, 2002: 253). This has a large effect on the GDP index and, accordingly, on the overall HDI.

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